Technological Perspectives for Rational Use of Water Resources in the Mediterranean Region

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Foreword

According to a 2006 UN report, if global water consumption continues, by 2025 more than 3 billion of the world's 7.9 billion people will be living in areas where water is scarce. The Mediterranean is one of the regions to be most affected by world climate changes, and faces problems involving water such as scarcity, pollution, conservation, sanitation and the management of resources.

Finding solutions to various water-related problems presents a complex challenge for our century. There is no doubt that for the Mediterranean region afflicted by water shortages, the integrated approach to manage limited water resources and to harness solutions outside the traditional water supply approach has to be an essential requirement for sustainable development. The scarcity of water and the unreliability of supply services and infrastructures are important constraints to the socio-economic development of the southern Mediterranean countries and also of some areas of the northern and eastern Mediterranean countries. Water scarcity is taking a terrible toll on people everywhere in the Mediterranean, especially in the regions on the south shores.

Management of water resources in the Mediterranean faces problems related to both physical and non-physical factors, especially political and economic processes This means that technical solutions for some problems often lead to failure because they do not consider the social, economic or political links and implications. On the other hand, the policy and decision makers may formulate policies or take decisions on water management that imply enormous investments without considering the long-term technical, system maintenance and socio-environmental effects and implications. In most cases, decisions related to water management ignore the opinion of the final consumers and do not call for their commitment or participation. There exists a general perception that water management models and schemes are still constructed without considering contributions from all stakeholders, who are vitally important to generate both the necessary efficiency of water planning and management, and the collective concern about these issues.

Traditional water management is based on modifying the hydrological cycle through the construction of small-scale or massive engineering projects. However, the dynamic process of managing water resources and demand is changing in the third millennium. This change is due to many factors: a shift away from relying only on finding new sources of supply to address perceived new demand; a growing awareness of the importance of preventing and mitigating water conflicts; a growing emphasis on incorporating ecological values into water policy; a re-emphasis on meeting basic human needs for water services and associated social issues; and a conscious breaking of the ties between economic growth and water use mitigated through economic instruments and allocation of scarce water for higher value activities, usually at the expense of certain forms of agriculture. Reliance on physical solutions continues to dominate traditional water planning approaches, but this approach is facing increasing opposition. At the same time, new methods are being developed to meet the demand of growing populations in the Mediterranean without requiring major new construction or new large-scale water transfers.

A clarification of the concept of water technology applied to the development of limited water resources and the future water requirements in the Mediterranean are important issues to be debated and clarified. Have water technology options been developed in a sustainable way throughout the Mediterranean (particularly in the developing countries of the region) during the last 40 years? Do we have today innovative and alternative "sustainable" perspectives of water technology development and sharing (not only transfer) in the developing countries of the Mediterranean? Water technology is an example of integration where engineering and science come together in water management, but does this integration "equally" take into account social, economic and environmental dimensions? These questions mark the need for a consensus on the future socio-economic and environmental perspectives that water technology must envisage in the Mediterranean, and a shared conceptual framework will also include the assessment of relevant Mediterranean-wide options and experiences.

Technology plays an important role in water management. Over the last decade of the 20th century, new strategies for the management of water resources have been promoted. These strategies are recommended in several chapters of Agenda 21 and they are also confirmed in the first paragraph of the UN Program on Integrated Water Resources Development and Management, which states that the development of appropriate water management requires the application of new sustainable technologies both in terms of analysis and engineering. Debate will address: a) engineering solutions for energy consumption, quality and the ecosystem (treatment and re-cycling), system performance and efficiency; b) engineering solutions for the development of analysis tools for modeling water quality-quantity, such as GIS, global positioning systems and remote sensing. Particular attention must be paid to the development of an equitable system of sharing, accessing and using technologies among different countries who have the same problems of insufficient water supplies.

In this framework of competing demand for water, the rational use of water resources can be a very elusive concept. An interesting conceptual paper to clarify this issue is presented in the Workshop. Focus in water management is gradually shifting to explore improvements in efficiency as a means to save resources, implementing options for managing demand and reallocating water among users to reduce gaps and meet future needs. Meaningful change towards a new approach and a new way of thinking has to begin with an open discussion of the ultimate ends of water policy. It is now time to place a high value on maintaining the integrity of the ecosystem when using water resources.

As an alternative to new infrastructures, efforts are now under way to rethink water planning and management, emphasizing the principles of integration between water policy and the three main dimensions of sustainable development: environmental, cultural and socio-economic. However, the new alternative approaches will also fail if they are not consolidated through the practice of participatory management, communication among interested stakeholders, water managers and citizens, the building of a common body of knowledge, and the increasing mutual awareness of the interested parties. Only in this way will the necessary attention finally be given to the promotion of socially and culturally sound water technology.

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PRESENTATION

The current material has been produced within the framework of:

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Water availability is a prerequisite for the sustainable development of the Mediterranean region. Major current and future problems with fresh water resources in this region arise from the pressure to meet the food, agricultural, human settlement and industrial needs of a fast-growing population. Water shortages and the unreliability of supply services and infrastructures are important constraints for the socio-economic development of the southern Mediterranean countries and also for some areas of the northern and eastern Mediterranean countries. There is no doubt that there is an increasing need for trans-disciplinary approaches and a comprehensive knowledgebase of new technologies to enable integrated and sustainable water planning and management, taking into account all the constraints and reflecting them in a sufficiently long-term physical and socio-economic scenario.

The second MELIA Project Workshop will involve debate and dialogue on the technological perspectives for rational use of water resources in the Mediterranean region. The aim is to asses and promote sector options and schemes for water saving and optimal water use (urban centres, agriculture and industry) and water conservation, considering that the most important yield of water saved will be provided by agriculture, and also to formulate a consensus on the future socio-economic and environmental perspectives that water technology must envisage in the Mediterranean.

Among the main topics that will be covered in the second MELIA Project Workshop are the strategies for basin management (water resource equilibrium and constraints to socio-economic development); assessment of the technical, economic, social and environmental aspects of saving water; sustainable technological solutions for water treatment, recycling and reuse; tools for monitoring and modelling water quality and quantity (telemetry, satellite image processing for management of water resources); efficiency and equity in water policies.

First part

Strategies for basin management: Water resources balance and constraints on socio-economic development

Rational water use in Egypt

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Abstract. In Egypt, the acceleration of economic and demographic development, with rapid urbanization, growing industrialization and agriculture, has stepped up the pressures on the country's water resources, triggering an increase in their demand accompanied by the deterioration of water quality. This situation is alarming as Egypt is an arid country that depends on a single source of water which is the Nile River. Besides the population growth, social factors (poverty, quality of life, crop pattern, unequal distribution of water and consumer's behavior), physical variables (water resources and land expansion), economic and political elements are the main driving forces of water scarcity. Demand-oriented measures that can be implemented in Egypt include: i) shifting to less water-demanding crops, ii) improving the efficiency of the existing public water supply system by reducing losses, detecting leakage and improving irrigation distribution and conveyance efficiency, iii) introducing tariffs for water conservation which might include various kinds of land or crop taxes, production charges, water pricing, or subsidies for water conservation, and iv) launching public awareness campaigns aimed at advocating a new water culture in a society based on the principle of conservation. A number of measures towards the rational use of water are already applied but still need extra efforts to be fully successful. Enhancing the institutional organizations, involving the private sector, stringent laws and cooperation with the Nile Countries are considered a must to increase the water use efficiency, control water demand and reduce the over irrigation and the misuse of water. Optimum use of water resources is implemented through the reuse of drainage water, recycling the domestic and industrial wastewater and desalination. Co-operation with the riparian countries of the Nile Basin, through the Nile Basin Initiative, is expected to implement Upper Nile Projects and in return to lead to additional inflow into Lake Nasser. This paper can be considered as an attempt towards highlighting the ways and means for a rational use of water so as to improve water use efficiency in Egypt. Emphasis will be laid on how to utilize the available quantity of water as well as how to get additional quota for Egypt through the Nile Basin Initiative projects.

Keywords. Egypt – Water resources – Demand-oriented measures – Rational use of water – Water use efficiency.

Utilisation rationnelle de l'eau en Egypte

Résumé. *En Egypte, l'accélération du développement économique et démographique, parallèlement à l'urbanisation rapide, l'industrialisation croissante et l'expansion de l'agriculture, a renforcé la pression exercée sur les ressources en eau du pays, provoquant ainsi une augmentation de la demande et par là même, une détérioration de la qualité de l'eau. La situation est alarmante étant donné que l'Egypte est un pays aride qui dépend d'une seule source d'eau, à savoir le Nil. A part l'accroissement de la population, les conditions sociales (pauvreté, qualité de vie, systèmes de culture, distribution inégale de l'eau et comportement du consommateur), les variables physiques (ressources en eau et expansion des terres), les forces économiques et politiques sont autant de facteurs déterminants de la pénurie d'eau. Il est donc utile d'envisager l'application de mesures orientées vers la demande, et plus précisément : i) opter pour des cultures moins exigeantes en eau, ii) accroître l'efficience du système public d'approvisionnement en eau, en réduisant les pertes, en décelant les fuites et en améliorant la distribution de l'irrigation et l'efficience de distribution de l'eau iii) appliquer un tarif pour la conservation de l'eau qui pourrait inclure différents types d'impôts sur les terres ou les cultures, les charges de production, la tarification de l'eau ou les subventions pour la conservation de l'eau et iv) lancer des campagnes de sensibilisation pour diffuser une nouvelle culture de l'eau dans une société basée sur le principe de la conservation. Bien que un certain nombre de mesures aient déjà été adoptées pour une utilisation rationnelle de l'eau, des efforts supplémentaires s'avèrent nécessaires afin d'assurer des résultats satisfaisants. Le renforcement des organisations institutionnelles, l'implication du secteur privé, une législation solide et rigoureuse ainsi que la coopération avec les pays du Nil sont un impératif pour pouvoir accroître l'efficience d'utilisation de l'eau, contrôler la demande et réduire la surirrigation et la malutilisation de l'eau. De toute évidence, une utilisation optimale des ressources en eau comporte la réutilisation de l'eau de drainage, le recyclage des eaux usées ménagères et industrielles et la désalinisation. La coopération*

avec les pays riverains du bassin du Nil, dans le cadre de l'Initiative du Bassin du Nil, devrait prôner la mise en oeuvre des Projets du Haut Nil et permettre d'accroître le niveau d'alimentation du lac Nasser. L'objectif de cette étude est donc de parcourir les moyens et les modalités nécessaires pour parvenir à une utilisation rationnelle et améliorer l'efficience d'utilisation de l'eau en Egypte. L'accent est mis sur la manière d'utiliser les quantités d'eau disponible et d'obtenir une quote-part supplémentaire en Egypte à travers les projets de l'Initiative du Bassin du Nil.

Mots-clés. *Egypte – Ressources en eau – Mesures orientées vers la demande – Utilisation rationnelle de l'eau – Efficience d'utilisation de l'eau*

I – Introduction

Water resources in Egypt are becoming scarce. Surface-water resources originating from the Nile are currently fully exploited, while groundwater sources are being brought into full production. Egypt is facing increasing water needs, demanded by rapidly growing population, increased urbanization, higher standards of living and by an agricultural policy which emphasizes expanding production in order to feed the growing population. The population is currently increasing by more than one million persons a year. With a population of approximately 74 millions in 2008, Egypt is expected to see an increase to some 100 millions by 2025. The most critical constraint facing Egypt is the growing shortage of water resources accompanied by the deterioration of water quality.

Water resources in Egypt are limited to the Nile River, rainfall and flash floods, deep groundwater in the deserts and Sinai, and potential desalination of sea and brackish water. Each resource has its usage limitation, whether these limitations are related to quantity, quality, space, time, or exploitation cost. Egypt receives about 98% of its fresh water resources from outside its national borders. This is considered to be the main challenge for water policy and decision makers in the country as the Nile River provides the country with more than 95% of its various water requirements.

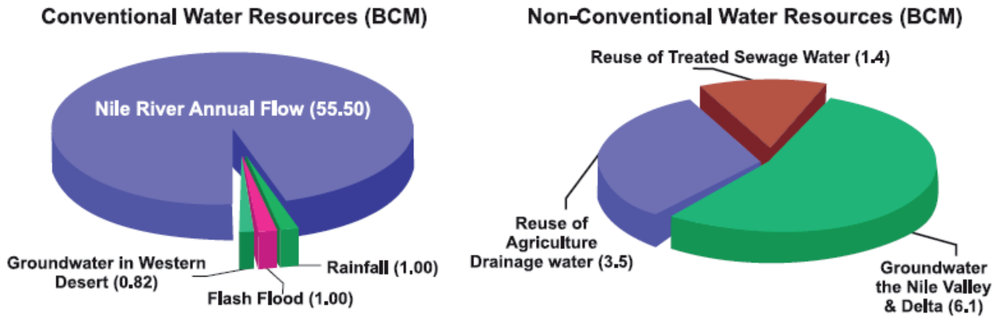

Figure 1. Water Resources of Egypt.

As illustrated in figure 1, the average annual quota of Egypt from the conventional water is limited in the Nile River which is determined as 55.5 BCM according to the 1959 agreement with Sudan. Another 0.82 BCM per year is utilized from groundwater in the Western Desert, in the Nubian sandstone aquifer, which extends below the vast area of the New Valley Governorates and the region east of Owaynat. Another 1.0 BCM per year is utilized from rainfall along the coastal area and flash floods occurring within short-period heavy storms in the Red Sea area and Southern Sinai that are directly used to meet part of the water requirements or used to recharge the shallow groundwater aquifers. Desalination of seawater in Egypt has been given low priority as a water resource because the cost of treatment is high compared with other sources (Amer *et al*., 2005). Desalination is actually practiced in the Red Sea coastal area to supply tourist villages and resorts with adequate domestic water supply where the economic value of the water is high enough to cover the treatment costs.

The non-conventional water resources include the renewable groundwater aquifer underlying the Nile valley and delta, the reuse of agricultural drainage water, and the reuse of treated sewage water. The amount of the groundwater in the Nile valley & delta is estimated at 6.1 BCM per year, the reuse of agriculture drainage water is about 3.5 BCM per year and the reuse of treated sewage water is about 1.4 BCM per year.

These limited quantities of water have to fulfill the Egyptian requirements in the fields of agriculture, which is the largest consumer of water (85%), industry and domestic uses. Increased population needs more water for domestic use as well as horizontal expansion to maintain the per capita of cultivated land. This reclaimed area either will increase the agriculture share of water or will reduce the quantity of water allocated per feddan (in case of fixing the agricultural share of water) which in return decrease the crops' yield. Also development of industry will consume more water which will affect the Egyptian water balance.

II – Water Scarcity in Egypt

Per capita fresh water availability in Egypt dropped from 1893 cubic meters in 1959 to 900-950 cubic meters in 2000 and tends to decline further to the values of 670 cubic meter by 2017 and 536 by 2025 (Abd-El-Hai, 2002). The main reason behind this rapid fall is the fixed water resources and the rising pressure from population growth. However, there are other more important factors in escalating the water issues in Egypt. They do not show direct linkages to the problem but have great contribution in establishing water stress conditions. These driving forces are categorized in four different subgroups as follows:

1. Social forces

The social forces can be viewed at four levels. Figure 2 reports the different layers of the social forces that contribute to escalating the water scarce conditions over time. Impacts of poverty, inequity, cropping patterns and consumer behavior contribute to emerging of water shortages which already exist whereas the population growth and improved quality of life will occur later.

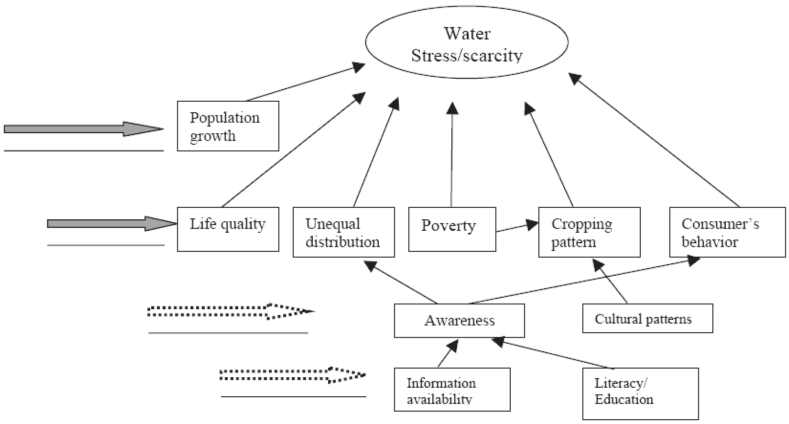

Figure 2. Different Levels of Social Forces Affecting Enhancement of Water Scarcity Conditions.

2. Quality of life

Accelerated economic growth in Egypt during the last decades is reflected in a better quality of life. The main indicators of living standards have improved remarkably over the last 30 years. Social and human development programs and health services have made advances in life expectancy, which has been increased from 55 years in 1976 to 67.1 years in 2001. Advancements in living standards together with population growth have already been reflected in expansion of water consumption levels for domestic use. Domestic water use grew from 3.1 BCM in 1990 (Abu-Zeid, 1991) to 5.23 BCM in 2000 (FAO Aquastat). Further augmentation of the life quality and the population growth will push up water demands.

A. Poverty

Poverty in rural communities of Egypt is still a problem although significant improvements in the standards of living have been made in the last three decades. Human Development Report (2003) estimated that 20.4% of the total rural population is poor and 6.1% is ultra poor(1). The distribution of the poor people in the country is quite uneven and shows significant differences among regions. For example, a number of provinces in the Delta has higher poverty rates than others that reach 35.4% where 10.9% of the population is ultra poor. In other provinces in Upper Egypt, the proportion of the ultra poor population is as high as 41.9%. Often low-income levels and poverty in rural areas limit the farmers' ability to invest in agriculture pushing them to plant the low-cost crops namely water thirsty crops (i.e. rice, sugarcane). This shift in the cropping pattern triggers the increase in water use.

B. Cropping pattern

Cropping pattern plays a vital role in determining the irrigation water demand. During the 1950s, 1960s, and 1970s, the agricultural sector was characterized by heavy government interventions in the production, trade and prices. The reform in the 1980s resulted in the liberalization of prices and government control of the cropping was abolished. Consequently, some changes in cropping patterns were made favoring production of high value-added crops. Among them were the rice and the sugarcane with the highest water requirements among the crops cultivated in Egypt. For example, the annual production of rice rose from 2.4 to 4.5 million tons (UN CCA, 2001) and fields of rice expanded almost by 50 percent (from 1 million feeding to 1.5 million) (MWRI, 2002).

The national survey (1998) shows that the main reason of crop choice is the profitability of crops. The choice of cultivated crops, based on a profit-driven cropping pattern, seems more relevant in this case if the poverty levels in rural Egypt are taken into account. The rice is a high value crop and is likely to be an important contributor to income raising. Thus, the cropping patterns that sometimes lead to water shortages serve the welfare interests of rural families.

C. Consumer's behavior

The water stress conditions are bound to such factors as conscious behavior of the consumer. This derives from the level of education, accessibility and availability of information and cultural patterns. For example, in new lands regardless of the presence of new irrigation systems, farmers still use flood irrigation (MWRI, 2002). They prefer the old methods they are used to and resist to the innovations. The short duration variety of rice finds difficulties to expand in spite of lower water requirement. One of the reasons mentioned is the rice taste which Egyptian farmers do not like. Another factor, which prevents the spreading of short duration rice, is the lack of information on the availability of such varieties. The behavior is also dictated by accessibility of inexpensive, almost "free" irrigation water.

In 1998, a national survey of Egyptian farmers was carried out, aiming at identifying the farmer's awareness, attitudes and practices concerning the water resource management. The study shows that about 61 percent of male and 29 percent of female farmers know that available water resources in the country are fixed. As mentioned in the introduction, the illusion of abundance of resources is widely spread in the country, so only 21 percent of farmers consider the scarcity problem, that can emerge in the future, seriously enough and 23.6% do not see the problem of scarcity at all. On the other hand, 57 percent of farmers hold the hopes that larger water quota is negotiable. The answers according to the education levels differ significantly showing higher awareness of the problem among higher-educated respondents. Low awareness can be explained with low, 53.1 percent literacy level in rural areas (UNDP, 2003) and poor accessibility to information. The literacy levels of females are lower, which is reflected in considerably lower awareness levels. Awareness about water conservation measures is low as well. Farmers are poorly informed about possibilities for how to decrease the water consumption. As survey indicates only 20 percent of male farmers and 4 percent of females had ideas about how to irrigate with less water; however, about half of the respondents are aware of advantages of night irrigation and almost all of farmers use land leveling (El-Zanaty 1998).

D. Unequal distribution

Unequal distribution of water is another factor that is involved in emerging water stress conditions. It is a result of water overuse at the head of the canal bringing less water toward its ends. Therefore, farmers at the tail of the canal and downstream suffer from water shortages and are forced to abandon cultivation of some part of their land in order to avoid yield losses, whereas at the head of the canal peasants enjoy the abundance of irrigation water. Interviews with farmers showed that some of them located far from the head of the canal were experiencing the losses of the yield due to under-irrigation caused by unequal distribution of water. Unequal distribution of water can be linked to the behavior of farmers who cannot see far going consequences of their actions. So is the abuse and damage of irrigation infrastructure in order to get wider access to water (Malashkhia, 2003). The low cooperation levels and low communication facilities make this problem even more complex.

Farmers cannot always be blamed for their ignorance or low consciousness since the over irrigation practices that lead to water shortages downstream are often induced by unreliability of the water provision in canals. Uncertainty in water availability pushes them to over-irrigate, as they are not sure in future water delivery (Holmen, 1991).

2. Physical variables

A. Water resources

More than 96 percent of all the Egyptian fresh water resources are supplied by the river Nile, which originates from outside the country boundaries and supplies ten countries among which Egypt. Egypt's share of Nile water is limited according to the 1959 international agreement between Sudan and Egypt at 55.5 BCM (Abu-Zeid, 1991). The rest of the water requirements is met by a renewable groundwater with 4.8 BCM/year and a drainage water reuse, which is estimated at 4.5 BCM. Treated municipal and industrial wastewater water returns to the closed water system 0.7 and 6.5 BCM, respectively (UN CCA, 2001). On the other hand, about 3 BCM, from the 55.5 BCM, is lost through surface evaporation from the irrigation system (MWRI, 2002).

Table 1. Present and projected water resources in BCM.

Source	2001	2017
The Nile	55.5	57.5 *
Renewable ground water	4.8	7.5
Agricultural drainage water	4.5	8.4
Treated domestic waste water	0.7	2.5
Treated industrial waste water	6.7	6.7
Desert aquifers	0.57	3.77
Rainfall and flush harvesting	-	1.5
Saving from management	-	1.5
Total	72.77	89.37

* Including the 2 BCM possible yields from Jonglei project. Jonglei project in Sudan intended to increase availability from Nile water reducing the evaporation from Sudan's Sudd swamps. Project has not been completed due to conflict in the region.

Source: (UN CCA,2001)

For the year 2017, water demand is expected to rise up to 87.9 BCM. The rapid growth of demand is planned to be partly supplied with additional water resources that can be obtained from non-renewable groundwater aquifers in the Sinai and the Eastern and Western deserts (UN CCA, 2001).

As mentioned in Table 1, the water balance for the year 2017 can meet the demand if the Irrigation Improvement Plan, Drainage Water Reuse, Treated Wastewater Reuse achieve the target figures. The objectives need some consideration regarding their implementation. This specifically refers to the prolonged conflict around Jonglei project in Sudan leaving little hopes for its termination or drainage water reuse that already amounted to 4.7 BCM in 1990 and to 8.5 in 2007.

B. Land expansion

Expected considerable incremental increase in demand occurs in agricultural and industry sectors (Abu- Zeid, 1991) due to further development of manufacturing sector and land reclamation projects. Annual 2.1 percent population growth rate obliges the agriculture sector to provide food for a larger number of people and this under conditions of continuously declining per capita crop area and per capita crop production (MWRI, 2002). The difficulties in relation to limited land resources are not restricted to the problem of food security but it is linked to the employment issue as well. The rural area is accommodating 57 percent of the population, 50 percent of which is involved in the agricultural sector (UNDP, 2003). The food and habitat requirements and increasing demand on job push the government to the horizontal land expansion plans. The last has been considered as a solution for the absorption of population growth and job generation. The Plans promise to add 3.4 million feddans of desert land to the cultivated land area (UN CCA, 2001). The land expansion projects intend to reclaim almost 44 percent of present cultivated land area by transferring the water to the desert lands. This means that, at the present water use practices, land expansion would place an enormous strain on water supply.

4. Economic forces

As supplies fail to catch up the growing demand, competition for water will increase to the benefit of domestic water users and at the expense of agriculture.

Table 2 illustrates the present water distribution among different economic sectors. Agriculture is the largest consumer of water resources worldwide and in Egypt as well. The annual freshwater withdrawals for agriculture in 2001 amounted to 83 percent (UN CCA, 2001). In spite of its high water consumption levels, its contribution to GDP accounts only for 16.5 percent compared to industrial and service sectors with 33.3 and 50.2 percent share in GDP respectively (Malashkhia, 2003). As some analysis pointed out, agriculture can be affected by increasing water scarcity due to growing demands from other sectors. It has to compete with high value users; this in the long run would lead to release of water from agriculture to the other sectors (Engelbert *et al.*, 1984). The consideration about water reallocation becomes relevant taking into account Egyptian government's support to the development of industrial sector (MWRI, 2002).

Table 2. Water allocation among water users.

Water Users	Worldwide (%)	Egypt (%)		
	1999	1990	2001	
Agriculture	65	84	83	78*
Industry	25	7.8	10	14*
Domestic use	10	5.2	6	8*
Total water use in BCM	-	59.2	67.47	68.67*

Source: Abu-Zeid, 1991, UN CCA, 2001 and *FAO Aquastat

5. Political forces (Irrigation water subsidies)

Water is a critical component of development in Egypt. However, limited water resources are not treated as a scarce commodity; on the contrary, it is heavily subsidized by the Egyptian government which unintentionally promotes wasteful practices and hinders the emergence of rational use of resources (Ahmad, 2002). Issue of subsidy involves many factors and its removal would have widespread effects on the whole society.

The domestic use of water shows the inefficiency of water distribution system in 1991 that reached 50 percent (Abu-Zeid, 1991). It is much the same even after 10 years. At present, the leakages in the system including illegal connections and other leakages are estimated at the same rate of 50 percent and in some cases they reach even 70 percent (Malashkhia, 2003). This situation in distribution schemes is partly generated by lack of funds for improving the operation and maintenance of the whole system which itself derives from the low cost recovery. The real cost of drinking water in Cairo is 0.65 LE per cubic meter and it is sold at 0.35 LE to the households. The commercial sector is subsidized as well. However, only half of the real water cost is recovered from the small workshops. On the other hand, large factories pay 0.50 LE per cubic meter of clean water. Collection efficiency is another issue that is characterized by the fact that 25 percent of all factories in Cairo do not pay the cost for water delivery (Malashkhia, 2003).

III – Demand-Oriented Measures for Water Conservation

Demand management tries to reduce and control water demands, as well as improve overall water use efficiency. Demand management allocates available water to competing user groups according to the needs. Water is often considered a free good in many countries where a supply oriented approach attempts to serve water in quantities, relying on the assumption that the user will make proper use of it. This has been the case in Egypt for several decades.

However, such a surplus-biased system wastes considerable amounts of water, since the precious resource is then taken for granted and no effort is made to conserve it. In contrast, a demand oriented approach assesses the real demand for water and tries to urge the users to conserve water and make better use of it (Bassiouni, 2003).

Demand-oriented measures that can be implemented in Egypt include the following:

1. Shifting to less water-demanding crops. For instance, introducing cropping patterns with low water requirements (i.e. abandoning rice and sugarcanes for other cropping patterns).

2. Improving the efficiency of the existing public water supply system by reducing losses, detecting leakage and improving irrigation distribution and conveyance efficiency. Inefficient water systems are a major source of water loss. In the developing world, in many cities, faulty pipes and illegal connections waste between 20 to 50 percent of public water supplies. In Egypt, the current losses in the distribution system are considered too high. Water conservation measures need to be implemented and practiced by all water users and unnecessary or wasteful uses need to be reduced or eliminated where possible. A sound, reasonable, and effective water conservation culture can make the difference between adequate supplies and shortages.

3. Introducing the implementation of financial measures for water conservation which might include various kinds of land or crop taxes, production charges, water pricing, or subsidies for water conservation. Moreover, water is usually priced much lower than the actual cost of securing, treating, and distributing it, leaving little incentive for households and industries to conserve water. Letting users pay for water or making it more expensive by paying the costs to treat and deliver water will awaken to the awareness about the scarcity of the resource. For, water scarcity is closely linked to water use; thus, the cost of water should be made higher. We must finally shift to viewing water as an economic commodity, as we already do with electricity. While there are possible alternative energy sources for the future, the only alternative to water is water.

4. Finally, introducing public awareness campaigns aimed towards advocating a new water culture in a society based on the principle of conservation. The significance of water conservation in irrigation and domestic uses can be promoted through such public awareness campaigns.

IV – Rational water use

1. Water saving techniques

A number of measures have been taken towards the rational use of water for different activities. Some of these measures have been applied to domestic water systems and industrial requirement. However, agriculture being the major consumer of water has the lion share of these measures. Following are the measures applied to agriculture among a complete package of water saving techniques (El Quosy, 2005):

A. Use of modern irrigation systems in newly reclaimed land

It is obligatory to use sprinkler and drip irrigation systems in the desert lands converted into agricultural production through reclamation. Gravity or flood irrigation in these areas is prohibited by law. This is obvious because of the high permeability of these soils and their high capacity of natural drainage.

B. The change from surface irrigation to drip irrigation in the orchards and vegetable farms in the old lands

Some 700,000 feddans in the old lands of the Nile Valley and Delta are occupied with different types of fruit trees, citrus and grape yards in addition to the area cultivated with summer and winter vegetables. This area is currently irrigated traditionally with surface irrigation. It is the plan of the country to change the irrigation system in these areas into drip irrigation. The cost of the irrigation system and the running cost of operation are expected to be borne jointly by the farmers and the state.

C. Land leveling

Field experiments proved that precise land leveling has a positive impact on the reduction of water supply since it reduces surface run-off to a minimum. Special attention is always paid to the major water consuming crops like sugar cane and rice.

D. Night irrigation

Farmers are encouraged to practice night irrigation since it reduces evaporation losses if irrigation is carried out during day time, in addition to the reduction of tail end losses taking place directly from irrigation to drainage canals if fresh water is not abstracted at night. It is worth mentioning that the Egyptian irrigation network is designed for 24 hours a day abstraction, i.e. there is no storage capacity in the system.

E. Modification of the cropping pattern

The cropping pattern in Egypt is governed by a number of factors which include: the country's need for food and natural fiber, the export requirement, the availability of land and water, the employment needs, the climatic conditions, status of soil salinity,…etc. It is always the desire of the officials to bring the agricultural water requirements to a minimum in order to make sufficient quantities available for other activities that might be of higher priority (such as drinking water supply) or of higher return per unit volume of water (such as industry or tourism). For this reason, the area of sugar cane is kept constant while sugar beet is increasing. The area cultivated with rice is limited to about one million feddans. The deviation from these two rules causes farmers to be heavily penalized by the law.

F. Introduction of short-age varieties

Another way of encouraging water savings in agriculture is to raise crops which stay a shorter period in the fields by reducing their growing age. A good example is represented by the short-age varieties of rice which stay in the field only 150 days compared with the traditional variety that need 180-210 days. The reduction in the number of days is immediately reflected on the number of irrigation gifts and consequently on the quantity of water supplied. Other examples are wheat, maize, cotton and legumes.

G. Irrigation improvement projects in the old lands

The alluvial soils of the Nile Valley and Delta reduce the possibility of changing the existing gravity irrigation into modern systems. The reason for this is:

- the very low permeability of the soils and the high possibility of soil salinization;
- the high initial cost of the imported material (sprinklers, drippers, filters, fertilizers,…etc) and the high cost of energy, maintenance and spare parts;
- the need for skilled labor which might not be available in rural areas while there is ample number of laborers acquainted with surface irrigation systems;

- the need to raise crops of relatively low return like wheat and maize. Other cash crops like vegetables and flowers are not easily marketed in the surrounding area.

For these reasons, the state has supported the improvement of surface irrigation in the old lands. A number of water and energy saving techniques are implemented through the Irrigation Improvement Projects (IIP). Some of these techniques are:

a. The change from the earth field ditches named Misqas into canals or pipelines. This change reduces seepage, aquatic weeds and evaporation from free water surface due to the reduction of the area of this surface;

b. The change from multi point abstraction of water from the mesqa into one point lift on the top end of a raised mesqa.

This is necessary for better steady and uniform mesqa flow plus the saving in energy needed to operate the lifting pumps. One of the major advantages of the above concept is the setting up of water users' associations on the mesqas which will be followed by the formation of water federations on the supply canals. This concept strengthens the idea of users' participation in the management of the system at its low level which relieves the government agencies from such obligations giving them the opportunity to have better management of other higher level activities.

c. The change from upstream control into downstream control.

The distribution system in Egypt, as mentioned earlier, is based upon upstream control. The Irrigation Improvement Project has introduced downstream control at the level of the supply canals as one of the measures that initiate demand management.

The traditional head regulators operated manually or mechanically on the basis of upstream control are replaced by regulators equipped with automatic gates capable of providing the required flow when demand is in progress, reduced flow when demand decreases and complete shut off when demand is stopped. In the mean time this type of system allows for a storage build-up during periods of no abstraction to permit heavy abstraction afterwards.

2. Optimum use of resources

A. Reuse of drainage water and treated wastewater

Egypt is one of the pioneer countries in the reuse of water. This process started as early as the 1920's and the water multiplier now stands at 150-200%. All drainage water of the Upper Egypt returns back to the River Nile raising its salinity from about 200 ppm at Aswan to less than 300 ppm near Cairo. Four more billion cubic meters of drainage water generated in the southern part of the Delta are mixed with fresh water and reused for different purposes. It is the plan of the country to reuse another three billion cubic meter per year for the irrigation of Al Salam Canal Project (620,000 feddans or 250,000 hectares) and for the feeding of Nubaria Canal (one of the largest irrigation canals in the Western Delta which serve an area of more than seven hundred thousand feddans of newly reclaimed lands.), the canal will be fed with one billion cubic meter of drainage water from Omoum Drain (El Quosy, 2005).

At present, treated sewage and industrial effluent can supply about seven million cubic meters per day or about two billion cubic meters per year. Plans to use this water for the cultivation of special crops (timber trees, industrial crops such as cotton, flax, flowers,…etc.) are under preparation.

B. Desalination of brackish and sea water

Desalination has long been confined to situations where no other alternatives were available to produce drinking water (some coastal towns, islands, remote industrial sites), or where energy was abundantly available (power stations, gas and oil production fields). Today, desalination is becoming a serious option for the production of drinking- and industrial water as an alternative to traditional surface water treatment and long distance conveyance. The desalination capacity in Egypt has grown to some 150,000 m^3/day. Most of the plants treat seawater, but a growing number of installations use brackish water. The capacity of individual plants is generally small and ranges between 500 and 10,000 m^3/day (MWRI, 2005).

There is unlimited potential for further development of seawater desalination in Egypt along the long shoreline. Sectors of application are the tourist sector and the industries along the coast. Considering the vast reserves of brackish groundwater in Egypt, there is also great potential for brackish water desalination which can be applied at much lower cost. Desalination of inland brackish groundwater requires special attention for the discharge of the brine (the highly saline by-product of desalination). Treatment of domestic waste water and of drainage water is a potential new field of application for which vast quantities of water are available in Egypt.

C. Importance of international co-operation

The international aspect is a crucial factor in Egyptian water policy. Because Egypt's water resources are all produced outside the country (upstream of Lake Nasser), the planned expansion of supply has to be undertaken in collaboration with upstream governments. This places Egypt in a very difficult planning situation, since it simply does not possess control over the speed of the implementation of the water conservation projects along the White Nile. It is estimated that the inflow to Lake Nasser could be increased by as much as 18 billion m^3 per year to be shared by Egypt and Sudan by implementing the four phases of the upper Nile projects (Jonglei I, Jonglei II, Machar Marshes and Bahr El-Ghazal). And, as it looks now, Egypt will increasingly come to rely on the implementation of these projects (Hivdt, 2000).

D. Nile Basin Initiative (NBI) projects

The NBI intervention seeks to build confidence and capacity across the basin through a shared vision program (SVP), and to initiate concrete investment and action on the ground through a subsidiary action program (SAP). The NBI plans to implement projects, in partnership with member states that will contribute to strengthening the cooperation mechanism and to long-term sustainable development, economic growth and regional integration (Sileet *et al.*, 2007) .

The SVP contributes to the creation of an enabling environment for investments and action on the ground and will promote the shared vision through a set of effective basin-wide activities. An initial set of basin-wide SVP projects has been endorsed by Nile-COM. They include: environmental action, power trade, efficient water use for agriculture, water resources planning and management, coordination, applied training, and socio-economic development and benefit sharing. Following are the SVP projects contributing to water efficiency, integrated water resources management (IWRM), confidence building and awareness and their objectives and expected impacts:

Nile Trans-boundary Environmental Action Project (NTEAP) with its five components (Institutional strengthening, community level land, forest & water conservation, environmental education and public awareness, wetlands and biodiversity conservation, and basin-wide water quality monitoring) aims to provide a strategic framework for environmentally sustainable development and to support basin wide environmental action. The water quality monitoring component contributes to the enhancement of water quality in Nile Basin Countries.

Water Resources Planning and Management (WRPM) project has four components: water policy good practice guides and support, project planning & management good practice guides, Nile Basin decision support system, and regional coordination & facilitation. These components contribute to achieving the project's goals in enhancing analytical capacity for basin wide perspective to support the development, management and protection of Nile Basin water resources in an equitable, optimal and sustainable manner.

Efficient Water Use for Agricultural Production (EWUAP) project with its four components (water harvesting, community managed irrigation, public and private managed irrigation and project coordination &facilitation) aims to establish a forum to assist stakeholders to address issues related to efficient use of water for agricultural production in the Nile Basin, and to provide an opportunity to develop a sound conceptual and practical basis for Nile Riparian countries to increase the availability and efficient use of water for agricultural production.

Some of the SVPs have an indirect impact and contribution in the IWRM in the Nile Basin through strengthening the capacity for practitioners and post graduates in subjects of water resources planning and management in public and private sectors (Applied Training project), developing confidence in regional cooperation at both Basin and local levels (Confidence Building and Stakeholder Involvement project) and enhancing the process of integration and cooperation to further socio economic development in the Nile Basin (Socio economic Development and Benefit Sharing).

SAPs plan and implement action on the ground at the lowest appropriate level. They comprise actual development projects at sub-basin level, in order to address the challenges of regional co-operation and development opportunities with trans-boundary implications. Two groups of countries have been formed to investigate the development of investment projects on the Nile Basin. These are the Eastern Nile Group (ENSAP), which includes Egypt, Sudan and Ethiopia; and the Nile Equatorial Lakes Group (NELSAP) comprising Uganda, Tanzania, Kenya, Rwanda, Burundi and the Democratic Republic of Congo and Egypt.

E. ENSAP relevant projects can be described as follows

Integrated Watershed Management: Obvious regional benefits of this project will be erosion control leading to decreased siltation and sedimentation in downstream river/reservoir reaches, which will increase reservoir life, improve hydropower production and irrigation efficiency, leading to an overall increase in land productivity, which will yield higher agricultural outputs, and thus enhance food security and alleviate poverty.

Baro-Akobo-Sobat Multipurpose: The project may offer opportunities for win-win multipurpose development. Important water conservation gains may be possible through improved water management, storage and flood routine.

F. Eastern Nile Planning Model

An Eastern Nile Planning Model (ENPM) has been proposed as a common analytical basis for identifying, and assessing options, quantifying benefits and impacts, evaluating tradeoffs, and analyzing and managing information to support complex decision making processes on the Eastern Nile.

Flood preparedness and Early Warning: Climate and river flows in the Eastern Nile of water (EN) are highly variable. The region is thus prone to extremes of droughts and floods. While there is some flood warning activity in individual countries, there is no integrated or cooperative flood warning system for the Eastern Nile basin.

Irrigation and Drainage: Among other factors, unpredictable seasonal and spatial distribution rainfall in some regions is a factor contributing to low agricultural productivity. The development of irrigation and intensification of existing agricultures offer the potential to increase food security, enhance agricultural productivity and improve livelihoods. The regional benefits of this project are expected to be maximized through the integrated development of different components, as well as building different sub-projects under the integrated development of the Eastern Nile Project.

Eastern Nile Joint Multipurpose Program: Integrated and joint basin management offers the greatest opportunity to unlock economic growth, promote regional integration, and realize peace and stability. Investments in new storage capacity and improvising watershed management have the potential to improve irrigation and agricultural productivity in all countries by reducing sedimentation in reservoirs, mitigating drought impact and flood damage, and supplying substantial hydropower electricity to meet rapidly expanding demand.

G. NELSAP project

The Regional Agricultural Program will promote opportunities for cooperation in the Nile Basin through private investment, public- private partnerships and enhanced trade, in the field of high value crops and products. It will also identify steps to increase food security through increased investment, income generation and pro-poor growth.

3. Development of national water resources plan for Egypt 2017

The Egyptian governmental institution represented by MWRI has developed what is called a National Water Resources Plan (NWRP) to support the country's development until the year 2017. Specifically, NWRP has three major pillars:

- Increasing water use efficiency;
- Water quality protection;
- Pollution control and water supply augmentation.

NWRP is based on a strategy that has been called 'Facing the Challenge' (FtC). FtC includes measures to develop additional resources, make better use of existing resources, and measures in the field of water quality and environmental protection.

Improving the performance of the water resources system. More water will be available for the various uses and the water quality will improve significantly. The agricultural area will increase by 35% as a result of horizontal expansion and of the two mega projects in Toshka and Sinai. Space for living will be created in the desert for more than 20% of the population as a result of these projects. The implementation of the strategy will support the socio-economic development of the country and provide safe drinking water to its population. The access of the population to safe sanitation facilities will double from the present 30% to 60%. Summarizing and as stated in the objectives, the strategy will safeguard the water supply up to the year 2017.

The FtC strategy follows an integrated approach to cope with the increasing pressure on the water resources system in Egypt and contains a wide range of measures and policy changes up to the year 2017. The implementation of this strategy is a real challenge. Further development of the system after 2017 may require some drastic policy decisions at the national level, e.g. accepting some limitations in growth of the agricultural sector and increasing the developments and corresponding employment in the industrial and services sectors. An increase in the Nile water supply will ease the situation somewhat and should be pursued. A limited increase is not unrealistic, either as a result of water conservation projects in Sudan, changes in reservoir operation of Lake Nasser or (in the very long run) as a result of climate change.

The integrated approach of FtC assumes that all measures are really implemented. Failure to implement some measures may have severe consequences for the overall strategy. This is in particular the case for the expected improvement of the water quality. An insufficient improvement of the water quality will mean that the increase in the reuse of water will be much less than expected with the consequence that there will be less water available for agriculture, leading to less water available per feddan and a further lowering of cropping intensities.

4. Legislation

New implementation concepts need laws and regulations updates. Generally, water laws in Egypt are as old as the country itself. They were never static, they always have dynamic nature. However, at this stage of history, when demand is pressing supply heavily, a need for strict laws is probably more than any previous time. A new water law is being developed at the present time. This law puts more emphasis on four important points:

- Increased penalties for water miss-users or those who cause waste in different fields;
- Strengthening of "Polluter Pay" principal;
- Encouragement of participation both at the low level through water users associations in old and new lands as well as at the higher level of supply canal through the setting up of water federations;
- Introduction of water extension services represented by the Irrigation Advisory Services "IAS" which provide farmers with the advice they need for a better and rational use of irrigation water. Other users, such as for domestic supply, are made aware by publicity through different media (newspapers, radio, television,…).

5. Institutional reform

Egypt as one of the oldest country in the world practicing river-fed agriculture depends on a strong central organization working on conveyance and distribution of water. All these agencies should change from the old regime of complete government control to the new concept of users' participation.

In the meantime, the vital approach and concept of integrated water resources management should also be part of this reform. This means that separate entities such as irrigation, drainage, structures, survey, mechanical and electrical divisions are no longer acceptable and even separation between water, soil, crop, and climate is not the correct way of management. It is the opinion of the officials in Egypt now to create an irrigation district which includes all the above disciplines and practice real integrated water management.

6. Participatory irrigation management (PIM)

One of the fundamentals of increasing water use efficiency is the involvement of all stakeholders as much as possible in the various management activities and levels. As water is essential to all forms of life and prosperity, competition for water among users is already escalating as growing needs outstrip the limited resources. The objective should be to transform the competition between stakeholders into a form of cooperation that achieves the highest overall revenue with the least sectoral harm. Private stakeholders associations can provide a counterweight to the government departments own technical agencies to enhance water use efficiency. Most of the developed countries adopted PIM policies some time ago, as a matter of fiscal necessity. Farmers in developed countries enjoy high levels of education, and strong support services through both the private market and the public sector.

7. National water quality monitoring program

Water quality deterioration is one of the most contributed factors in water losses in Egypt. Egypt releases 12.5 BCM per year of drainage water to the Mediterranean Sea because of its unsuitable quality (MWRI, 2005). The National Water Quality Monitoring Program has been launched based on the integrated approach for water resources management. It was developed by the National Water Research Center to serve as the solid scientific foundation for Egypt's policy development and decision making. The main objectives of this program are covering Egypt with water quality network to assess decisions of water use, to enhance the human resources capacity building and to unify the standards.

8. Role of the private sector and privatization

There is always a mix between privatization and the role of the private sector in irrigation. Although irrigation in Egypt is practiced though a strict central governmental authorities, the private sector is heavily involved in the provision of services such as construction (through private as well as public sector contractors), engineering consultants, selling irrigation equipment, management of large-scale modern irrigation systems, drilling of groundwater wells,…..etc. Privatization of the irrigation system in Egypt has already started by the establishment of water users associations and water federations.

The following step would be the establishment of management boards capable of conveying and distributing water from one end of the system to the fields. This type of service provider will be in place in the very near future as soon as government agencies give green light by contracting complete commands to water boards. It is not necessary that water boards be responsible for large or small areas. The exercise may start with very small areas and grow up with time and experience.

V – Conclusion

This paper has cast light on the rational water use in Egypt. It represents an attempt to collect the scattered and fragmented knowledge about the subject in order to highlight the major characteristics of the planning process. Egyptian water resource planning is given the task of satisfying the ever-increasing water demands which are dictated by a rapidly growing population, increased urbanization, higher standards of living, and an agricultural policy which emphasizes expanded production in order to feed the growing population. There is, and probably always will be, enough water to satisfy municipal and industrial water use.

From the analysis of water resource planning in Egypt, the planning emphasis can be characterized by the following eight points: (1) a shift from water abundance to water deficit; (2) the importance of international co-operation; (3) supply bias; (4) environmental concern; (5) lack of data; (6) established priority to non-agricultural uses of water; (7) delayed implementation; and (8) the establishment of an administrative framework for water resource planning.

Thirst for water will become one of the most pressing resource issues of the 21st Century. Egypt water consumption is rising and continues to grow rapidly. The scope and extent of water conservation is decisively shaped by the shift to a demand-oriented water management strategy in other words a demand-managed water culture. Such a policy is imperative for Egypt and for other arid countries facing similar water constraints.

The agricultural sector is considered as critical for tackling poverty in developing countries. Egypt is not an exception as its large population is engaged in agricultural activities. In the future, irrigation water, which is the absolutely crucial part of Egypt's agriculture, has to satisfy demands of even larger population and increasing living standards. Till now, the water shortages have been tackled by increasing extractions of resources and developing new supply options for the irrigation system. However, most of the supply options are already exhausted and cannot maintain significant enlargements. Some improvements can be achieved through efficiency increase. The demand side management entails some potential for water saving which might be possible through cost recovery as one of the financial instruments for water conservation.

The main objections raised by efficiency and cost recovery measures are negative social effects and environmental implications. Without building favorable preconditions for cost recovery, the introduction of user charge at this stage might face inevitable problems. Preconditions imply community involvement in canal management, well-defined rights, responsibilities for quota violations in case of drainage water reuse and rice cultivation. Whatever conservation measure will be applied, the main problem for the environment will remain the same. Soil salinization due to drainage water reuse or reduced water applications on fields will be a threat. Balanced approach in pricing and adequate knowledge of the soil salinity itself can ease the task. This would mean intensive awareness campaigns enriching farmer's information about salinity management, spreading the information about new water-saving and salinity resistant crops. Water scarcity is not an easy issue to deal with but still there are hopes that its negative effects can be minimized. To this end, an inclusive picture of the problems with all the factors involved has to be realized. In this study, an attempt has been made to view just some aspects of the whole picture. However, for a further understanding of the issue, other factors need to be added, which might be the subject for future study.

Egypt water resource planning is facing a number of problems - such as the lack of funds and non-rational governance - which predominate in less-developed economies. Establishing a planning system, in general, is expensive; therefore, it is developed only if needed. Egypt in fact might have had too much water at one time, a surplus which has severely hindered the necessity to implement a planning system. Emphasis on water resource planning depends on the scarcity of the resource. The greater the scarcity, the more planning is needed to counteract it. According to that argument, Egypt is expected to strengthen its water resource planning capability in the near future, following a greater scarcity of its water supply (Hvidt, 2000).

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(1) The poverty line used in HDR 2003 for rural area is 3963 LE (Egyptian Pound). Poor is a person whose expenditure capacity is lower than the specified poverty line. Those who are below food poverty line (3752.6 LE) are considered as ultra poor.

The possible effects of irrigation schemes and irrigation methods on water budget and economy in Atatürk dam of south-eastern Anatolia region of Turkey

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Abstract. The South-eastern Anatolia Project (GAP) has been implemented in the southeast part of Turkey, covering 9 provinces and the two most important rivers of Turkey. The main purpose of this gorgeous project is to uplift the income level and living standards of people in the region, to remove the inter-regional development disparities and to contribute to the national goals of economic development and social stability. The cost of the project is 32 billion USD consisting of 13 sub-projects in the river basins of Euphrates and Tigris. The project has evolved over time and has become multi sectoral, integrated and human based on the sustainable regional development. Upon the fully completion of the project, 1.8 Million hectares of land will be able to be irrigated in Euphrates and Tigris Basins through surface and underground water resources. From 1995 until now, 273.000 ha. of land have already been irrigated within the GAP Project. Roughly 739,000 ha. of this land will be irrigated from Atatürk Dam, the largest dam of GAP Project. At present, nearly ¼ of this area is under irrigation. Some technological developments have been experienced in the Project area, ranging from upstream controlled schemes having trapezoidal section, lined or unlined, to upstream controlled schemes having high pressurized piped system; and from conventional methods to drip irrigation method. The effects of those kinds of developments over water budget of irrigation schemes from Atatürk Dam have been studied. The data gathering from both 472,000 ha. of pumping irrigation and 267.000 ha. of gravity irrigation area is used in this study. Monthly plant water consumptions are determined through referenced plant water consumption gathered by GIS in association with plant growth index acquired from regional research studies. Irrigation module and annual total irrigation requirement are determined under different schemes and methods by means of monthly estimated plant water consumption rates. The contribution to the cost of energy generated by Atatürk Dam and to the cost of energy under pumping irrigation is determined.

Keywords. Water Budget – Atatürk Dam – GAP Region – Irrigation – Efficiency.

Les effets possibles des périmètres et des méthodes d'irrigation sur le bilan hydrique et l'économie d'eau du barrage d'Atatürk dans l'Anatolie du sud-est en Turquie

Résumé. *Le Projet de l'Anatolie du Sud-Est (GAP) a été mis en place dans la région sud-orientale de la Turquie, qui inclut 9 provinces et deux des principaux fleuves de la Turquie, dans le but d'élever le niveau du revenu et le standard de vie des habitants, de réduire les disparités dans le développement et contribuer à la réalisation des objectifs nationaux de développement économique et stabilité sociale. Le projet, dont le coût s'élève à 32 milliards de dollars, comprend 13 sous-projets des bassins hydrographiques de l'Euphrate et du Tigre. Après une certaine évolution dans le temps, le projet et actuellement multisectoriel, intégré et axé sur l'objectif d'un développement durable. Au terme du projet, 1,8 millions d'hectares de terres pourront être irrigués dans les bassin de l'Euphrate et du Tigre, en exploitant des ressources en eau superficielles et souterraines. A partir de 1995, 273.000 ha de terres ont déjà été irrigués dans le cadre du projet GAP. Approximativement, 739.000 ha de ces terres seront irrigués en exploitant le barrage d'Atatürk, qui est le plus grand du projet GAP. A l'heure actuelle, presque ¼ de cette région est irrigué. Dans la zone du projet, des innovations techniques intéressantes ont été testées, depuis les périmètres contrôlés en amont avec des canaux de section trapézoïdale, revêtus ou non, aux périmètres contrôlés en amont, avec un système de canalisation à haute pression, depuis les méthodes conventionnelles à l'irrigation au goutte-à-goutte. En plus, on a évalué les effets de ces développements sur le bilan hydrique des périmètres d'irrigation du barrage d'Atatürk. Les données obtenues sur 472,000 ha soumis à l'irrigation par pompage et 267.000 ha soumis à l'irrigation gravitaire ont été utilisées dans cette étude. La consommation mensuelle d'eau de la culture est déterminée sur la base de la consommation d'eau des plantes de référence, estimée par le SIG et associée* *à l'indice de croissance de la plante repéré dans des études régionales. Le module d'irrigation et le besoins d'irrigation annuels totaux sont déterminés compte tenu des différents périmètres et méthodes, sur la base des taux mensuels de consommation d'eau de la plante estimés. On considère également la contribution au coût de l'énergie générée par le barrage d'Atatürk et le coût de l'énergie dans le cas de l'irrigation par pompage.*

Mots-clés. *Bilan hydrique – Barrage d'Atatürk – Région du GAP –Irrigation – Efficience.*

I – Introduction

1. South-eastern Anatolia Project (GAP) and Atatürk Dam Irrigations

The South-eastern Anatolia Project, aiming at increasing the income and raising the standard of living of the population of this region by utilizing its natural resources, eliminating interregional disparities and contributing to the objective of restoring an economic development at national level and social stability and becoming a trademark of Turkey, is a multi - sector, integrated attempt for development, based on soil and water resources with the human being at its focal point (Akçakoca, 1997).

Previously, GAP had been planned as a bundle of 13 projects, with the objective of irrigation and hydroelectric power generation on the Rivers Euphrates and Tigris. The building of 22 dams and 19 hydroelectric power plants were envisaged within its scope. Today, beyond dams, hydraulic power plants and irrigation facilities on the Euphrates and the Tigris, the South-eastern Anatolia Project represents a comprehensive regional development effort based on a multi - sector, integrated and sustainable development approach targeting the full - fledged development not only of the region, but also of entire Turkey and its neighbouring areas, including investments and services in urban and rural infrastructure, agricultural infrastructure, transportation, industry, education, health, housing, tourism and various other sectors.

The surface area of the region, covering the provinces of Adiyaman, Batman, Diyarbakir, Gaziantep, Kilis, Mardin, Siirt, Sanliurfa and Sirnak, constitutes approximately 10% of the total surface area of Turkey (75,193 km²). According to the 2007 census, the population of the GAP Region provinces was 7.6 millions, constituting approximately 10.2% of the country's total population. The urban population of the region is 66%; the rural population 34%.

Upon the completion of the GAP, the irrigation of 1.8 million hectares of land, generation of 27 billion kWh hydraulic energy annually, 209% income increase per capita and employment opportunities for approximately 3.8 million people are targeted. Stated in figures, upon the completion of GAP, 2.1 billion dollars of agricultural benefit and a benefit of 2.2 billion dollars in terms of energy will be achieved, thus having a contribution of 4.3 billion dollars to the national economy.

Of the installed capacity of the 7476 MW hydroelectric power plant within the scope of GAP, 5513 MW have been materialized and 18.3 billion kWh energy have been generated in 2007. As of the end of the year 2007, the irrigation of 273,000 ha of land is in operation, and additional irrigation facilities for 100.000 ha of land are under construction.

The Atatürk Dam, which is the biggest and the key construction of the project, is the third dam built on the River Euphrates. With an active capacity of 19 billion m³ within a total capacity of 49 billion m³ and an installed capacity of 2,400 MW, it is Turkey's largest dam ranking 6th in the world, considering the capacity of rock-filled dams. An area of 739,323 ha will be irrigated from the waters of the Atatürk Dam. 472,000 ha of this land will be irrigated by electric - pump irrigation (Table 1).By the end of 2007, 190,000 ha of land are irrigated by Lake Atatürk Dam, of which 161,000 ha are irrigated by way of surface irrigation and the remaining 29,000 ha by pump irrigation. Presently surface irrigation facilities for 10,862 ha of land and pump irrigation facilities for 1,846 ha of land are under construction (Figure 1).

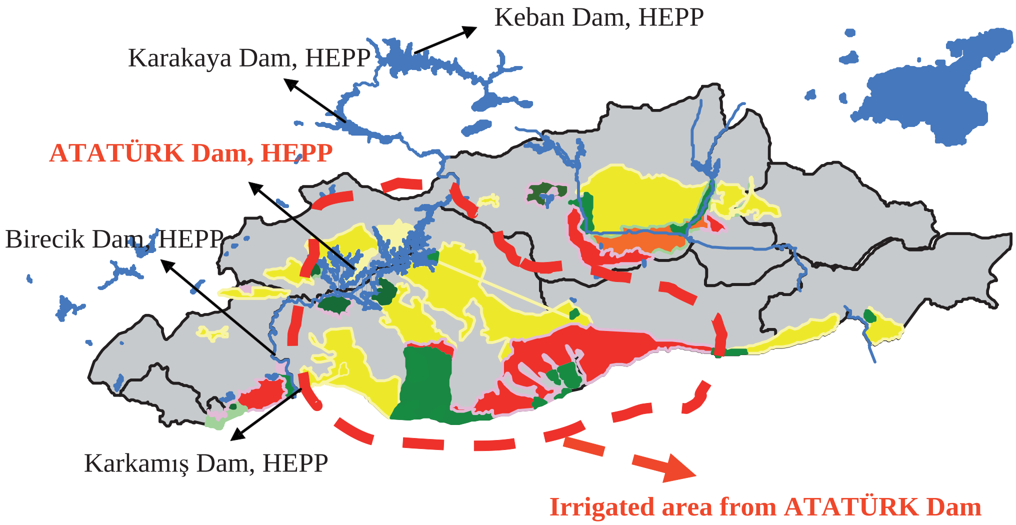

Figure 1. GAP Irrigation Projects.

Table 1. Atatürk Dam's Irrigation Projects.

Irrigation Projects	Units		Gross Area	Operation Area	Under Construction Area	Stage of Planning and Tender Area
Urfa Tunnel Irrigations (385,190 Ha)	Mardin Ceylanpınar+Yukarı Harran	Gravity	108,384	10,597	2,888	94,899
		Pumping	118,264	0	0	118,264
	Ş.Urfa Harran		147,887	139,913	7,974	0
	Akçakale Groundwater Irrig.		10,255	10,255	10,255 (Renewal)	
	Paşabağı		400	400	0	0
	Siverek Hilvan Pumping		156,373	0	0	156,373
	Bozova Pumping		48,414	8,669	0	39,745
	Bozova Merkez Pumping		1,080	1,080	0	0
	Yaylak Pumping		18,322	18,322	0	0
	Suruç Pumping		94,814	0	0	94,814
	Atatürk Pumping		26,793	0	0	26,793
	Samsat Pumping		8,337	960	1,846	5,531
	Total		739,323	190,196	12,708	530,888

In this study, the impact of water savings achieved by converting the planned surface irrigation system at the Atatürk Dam into pressure irrigation systems, on the national income and income of the farmers will be discussed.

II – Materials and Methods

The GAP region consists of 7.5 million ha of land in total, 3.2 million ha of which is arable land. On 1.8 million ha of this agricultural area, irrigated agriculture will be carried out. In the GAP Region, the size of an average agricultural holding is about 1.1 ha.

The climate of the GAP Region is separated into two parts (northern and southern GAP), considering temperature and precipitation regime (Anonymous, 1990). In the northern GAP Region, with an annual precipitation of over 600 mm and temperature of less than 2.5 ºC in February, pump irrigation from the Atatürk and Samsat dams is carried out. In the southern GAP Region, with an annual precipitation of less than 400 mm and temperature of over 5 ºC in February, the related irrigation systems are the Suruç and Urfa tunnel irrigations within the Mardin-Ceylanpınar, Upper Harran, Şanlıurfa-Harran, Paşabağı and Akçakale YAS projects. For regions with a temperature of over 5 ºC in February and precipitation level between 400-600 mm, Yaylak, Bozova, Bozova Merkez and Siverek - Hilvan irrigation projects have been designed. Regarding soil classification, the main part of the irrigable soil in the GAP Region, consists of class 1 and 2 land. Yaylak, Bozova and Bozova Merkez irrigations consist of class 2 and 3 land; Siverek - Hilvan, Samsat and Atatürk irrigations are considered within class 2 and 3 land. As references for the crop pattern within the project area, studies by (Koç, 2001), who evaluated the crop pattern for the GAP Region taking into account the country's needs and market conditions, and studies by (Demir *et al.* 2001a), based on the report by Yıldırım 2002, who determined the ecological requirements of plants in his study called 'Irrigation Conditions, Climate, Plants and Homogeneous Areas' (Table 2) have been taken into account.

Table 2. The Crop Pattern by Atatürk Dam's Irrigations with (%).

Crop	GAP Average	Ş.Urfa-Harran, Akçakale YAS and Paşabağı	Mardin-Ceylanpınar	Siverek-Hilvan Pumping	Bozova Merkez, Bozova and Yaylak Pumping	Suruç	Samsat and Atatürk Pumping
Wheat	23.20	22.40	22.58	23.20	23.20	28.00	23.50
Cotton	45.60	46.40	47.30	47.00	47.00	49.70	47.60
Melon & Watermelon	5.30	5.30	4.88	5.00	0.00	0.00	0.00
Bean	1.20	1.20	1.18	1.20	1.20	4.00	1.20
Vegetables	6.40	6.40	6.45	5.30	0.00	0.00	0.00
Sunflower	0.80	0.80	0.78	0.80	0.80	0.80	0.80
Alfalfa	2.90	2.90	2.68	2.90	2.90	2.90	2.00
Fruit	8.30	8.30	8.23	8.30	8.30	8.30	8.30
Maize	4.50	4.50	4.15	4.50	14.80	4.50	14.80
Lentil &Chickpea	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Onion	0.80	0.80	0.80	0.80	0.80	0.80	0.80
I. Crop Total	**100**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Soybean II. Crop	2.40	1.00	2.20	2.40	0.00	0.00	0.00
II. Crop Maize	5.60	8.82	6.31	5.60	9.00	8.50	8.00
II Crop Maize Slag	3.70	3.00	3.35	3.70	3.70	3.70	3.70
Vegetable II.Crop	2.80	2.00	2.80	2.80	2.80	2.80	2.80
II. Crop Vetches	2.32	2.00	2.16	2.32	1.32	1.82	2.32
II. Crop Total	**16.82**	**16.82**	**16.82**	**16.82**	**16.82**	**16.82**	**16.82**
General Total	**116.82**	**116.82**	**116.82**	**116.82**	**116.82**	**116.82**	**116.82**

Source: Demir et al., 2001.

The evaporation and precipitation values have been taken from Demir and others, who have utilized figures of the last 30 years, obtained by 112 meteorological stations, consisting of 27 large climate and 85 precipitation stations and the GAP Region and its surroundings and have been calculated with the help of geographical information system by the FAO Penman method for each irrigation (Table 3 and 4).

Table 3. Monthly evapotranspiration values defined by the GIS.

Project Names	Month ETo Value (mm/mount)												Annual
	1	2	3	4	5	6	7	8	9	10	11	12	
Atatürk	31	42	69	97	144	181	193	173	126	81	42	28	1212
Bozova ve Bozova Merkez	33	44	75	112	164	205	179	170	135	92	47	29	1291
Samsat Pumping	29	39	67	96	141	176	191	170	124	78	40	27	1185
Akçakale Yas	31	45	78	121	183	230	231	211	153	95	45	28	1451
Ş.Urfa-Harran ve Paşabağıı	31	43	75	115	173	220	215	198	146	92	43	27	1383
Mardin-Ceylanpınar	39	49	81	116	175	224	244	218	160	99	50	35	1497
Siverek-Hilvan	40	49	82	115	167	216	234	210	157	99	49	34	1457
Suruç	33	47	81	120	175	210	199	184	139	88	44	29	1356
Yaylak	31	43	72	103	151	184	180	164	125	81	42	28	1212
GAP Region Average	34	46	80	118	175	222	238	213	156	97	47	31	1463

Source: Demir et al., 2001b

Table 4. Monthly Total Precipitation values defined by the GIS.

Project names	Monthly rainfall values (mm/month)												Annual
	1	2	3	4	5	6	7	8	9	10	11	12	
Akçakale Yas	51	46	47	35	24	2	1	0	0	16	34	46	308
Atatürk	96	86	86	63	36	7	1	0	2	30	60	105	577
Bozova ve Bozova Merkez	43	52	56	41	35	3	0	0	0	14	41	66	355
Samsat Pumping	105	100	88	58	38	6	1	0	1	26	75	108	611
Ş.Urfa-Harran ve Paşabağıı	54	50	58	32	32	4	1	0	0	17	42	57	353
Mardin-Ceylanpınar	45	54	55	45	30	3	0	0	0	12	42	56	346
Siverek-Hilvan	48	61	59	50	38	6	0	0	0	19	46	60	393
Suruç	67	54	21	53	32	7	1	0	2	23	54	29	347
Yaylak	44	79	132	26	29	0	0	0	0	18	38	124	492
GAP Region Average	62	70	70	54	38	6	0	0	1	22	56	68	452

Source: Demir et al., 2001b

Considering the plant growth coefficients, values of Ilbeyi, who calculated plant growth coefficients (kc) (8) by utilizing studies on plant water consumption in the Region and throughout Turkey, and figures obtained by Allen (5), have been taken into consideration (Table 5).The entire transmission canals and canalette networks of Akçakale YAS, Paşabağı and Bozova Merkez irrigations are equipped with low and high pressure pipes. The conveyance canals of the other irrigations consist of concrete lined canals and distribution networks equipped with low and high pressure pipes. Eighty percent of the Harran Plain irrigation consists of canalette system and 20% of low pipe networks. For networks with a pipe diameter of up to 400 mm, high density polyethylene (HDPE) pipes have been used; for networks of a greater diameter, glass reinforced plastic pipes (GRP) have been used. The technical peculiarities and net areas of irrigation are detailed in table 6. In order to convert gross areas into net areas, the coefficient 0.93, which resulted from the Şanlıurfa - Harran Plain Irrigation, has been utilized. The last column of the table reports the mean pressure, enabling sprinkling irrigation for each irrigation and energy consumption for 1 m³. As a sample for gradual pumping for irrigation, the Siverek - Hilvan Pump Irrigation Scheme is shown in Figure 2. In order to provide additional pressure to be required apart from the State Hydraulic Works (DSI), necessarily energy amounts for elevating water to 35m, including head losses, have been taken into consideration.

Table 5. Calculated Plant Growth Coefficient for the GAP Region by FAO Penman methodology.

Crop	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Cereal	0.67	0.63	1.20	1.35	0.97	0.18					0.35	0.58
Cotton				0.22	0.78	1.25	1.09	1.24	0.88	0.25		
Sugar beet			0.16	0.35	0.85	1.03	1.12	0.95	0.20			
Potato				0.22	0.38	0.69	0.96	0.20	0.35			
Melon & Watermelon				0.13	0.38	0.82	0.91	0.77	0.47			
Bean				0.14	0.50	1.05	1.15	0.33				
Vegetable				0.13	0.92	1.48	1.72	1.87	1.87	1.26	0.66	
Sunflower				0.19	0.45	0.85	1.15	0.77	0.68			
Alfalfa			0.96	1.19	1.47	1.76	1.76	2.22	2.20	1.72		
Fruit			0.30	0.70	0.92	1.05	1.05	1.05	0.95	0.40		
Pomegranate			0.30	0.70	0.92	1.05	1.05	1.05	0.95	0.40		
Olive				0.50	0.55	0.60	0.65	0.65	0.65	0.60	0.25	
Pepper				0.13	0.92	1.48	1.72	1.87	1.87			
II. Crop Soy bean							0.50	0.90	1.15	0.32		
II. Crop Sesame						0.12	0.40	0.95	1.10	0.19		
II. Crop Maize							0.68	1.90	2.26	0.45		
II. Crop Peanut						0.14	0.45	0.90	1.15	0.40		
II. Crop Vegetable									0.70	0.85	1.05	0.50

Source: İlbeyi, 2001 and Allen et al., 1998.

Table 6. The technical aspects of Irrigations.

Irrigation Name	Net Area	Irrigation methods	Main canal	System	Total Efficiency of conveyance and distribution	Demand for Pumping energy (kWh/m^3)	Additional energy for Pressurized irrigation (kWh/m^3)
Akçakale	9,537	Gravity	CCC	PLP	0.92	0.000	0.137
Atatürk Pumping	24,917	Gravity	CCC	PLP	0.92	0.225	0.137
Bozova Pumping	45,025	Pressurized	CCC	PHP	0.92	0.247	0.000
Bozova Merkez Pumping	1,004	Pressurized	PHP	PHP	0.99	0.230	0.000
Mardin-Ceylanpınar (Gravity+Pumping)	210,782	Gravity	CCC	PLP	0.92	0.183	0.137
Paşabağı	400	Gravity	PLP	PLP	0.96	0.000	0.137
Samsat Pumping	7,753	Gravity	CCC	PLP	0.93	0.230	0.137
Siverek-Hilvan Pumping	145,427	Gravity	CCC	PLP	0.92	0.222	0.137
Suruç Pumping	88,177	%60 Gravity, %40 Pressurized	CCC	%60 PLP, %40 PHP	0.92	0.235	0.070
Ş.Urfa-Harran	137,535	Gravity	CCC	%80 CCC, %20 PLP	0.89	0.000	0.137
Yaylak Pumping	17,039	Pressurized	CCC	PHP	0.92	0.195	0.000

CCC: Canal with Cement Concrete lining, PLP: Pipe with Low Pressurized (California), PHP: Pipe with High Pressurized

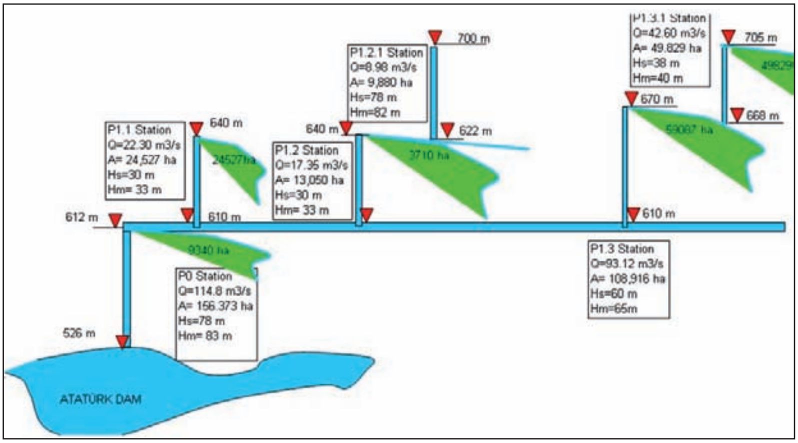

Figure 2. Siverek-Hilvan Pumping Irrigation Scheme.

Irrigation modules and annual water requirements have been calculated by the General Directorate of the State Hydraulic Works (DSI), with two alternatives, under pressure and surface irrigation conditions taking into regard water transmission, distribution and application outputs. Apart from the State Hydraulic Works, wetting rates at drip irrigations have been taken into account. In table 7, criteria used by the State Hydraulic Works and in this study have been displayed in detail.

Table 7. Criteria used by DSİ and this study.

Crop	DSI Criteria				Criteria for this study			
	Method of Irrigation	Irrigation efficiency	Wetting Ratio	Total Irrigation efficiency	Method of Irrigation	Irrigation efficiency	Wetting Ratio	Total Irrigation efficiency
Cereal	Border	0.61	1.00	0.61	Sprn.	0.70	1.00	0.70
Cotton	Furrow	0.61	1.00	0.61	Drip	0.85	0.75	1.13
Melon & Watermelon	Furrow	0.61	1.00	0.61	Drip	0.85	0.50	1.70
Bean	Furrow	0.61	1.00	0.61	Sprn.	0.70	1.00	0.70
Vegetables	Furrow	0.61	1.00	0.61	Drip	0.90	0.75	1.20
Sunflower	Furrow	0.61	1.00	0.61	Sprn.	0.70	1.00	0.70
Alfalfa	Sprin.	0.70	1.00	0.70	Sprn.	0.70	1.00	0.70
Fruit	Furrow	0.61	0.50	1.22	Drip	0.85	0.35	2.43
Maize	Furrow	0.61	1.00	0.61	Drip	0.85	0.75	1.13
Lentil &Chickpea	Border	0.61	1.00	0.61	Sprn.	0.70	1.00	0.70
Onion	Furrow	0.61	1.00	0.61	Sprn.	0.70	1.00	0.70
II. Crop Soy bean	Furrow	0.61	1.00	0.61	Sprn.	0.70	1.00	0.70
II. Crop Maize	Furrow	0.61	1.00	0.61	Drip	0.85	0.75	1.13
II Crop Maize Slag	Furrow	0.61	1.00	0.61	Drip	0.85	0.75	1.13
II. Crop Vegetable	Furrow	0.61	1.00	0.61	Drip	0.85	0.75	1.13
II. Crop Vetches	Border	0.61	1.00	0.61	Sprn.	0.70	1.00	0.70

On the River Euphrates, there are 5 dams and hydroelectric power plants. Keban and Karakaya dams are located upstream of the Atatürk Dam, Birecik and Karkamış Dams downstream (figure 3).

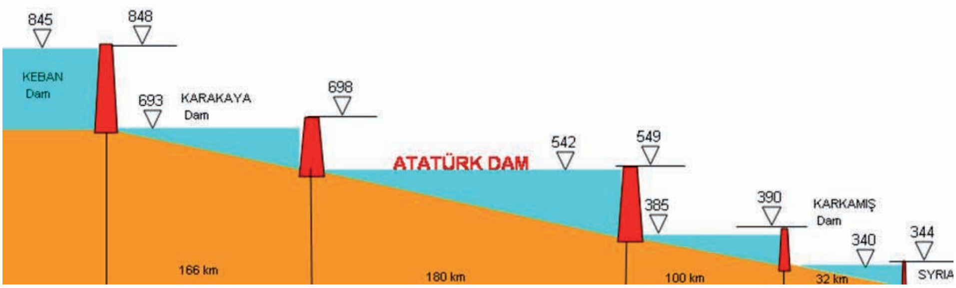

Figure 3. Dams on Euphrates River.
Source: DSI's brochure

Water savings, gained by the Atatürk Dam, will generate energy through the Atütürk and Karkamış hydroelectric power plants (HEPP). The energy generating capacity of Atatürk HEPP, with an energy generating capacity of 8.9 billion kWh annually on average, will display a decrease after irrigation. The River Euphrates Dam runoff volume is about 26.7 billion m³ (Tables 10 and 11). The energy value of water per unit is roughly calculated at about 0.332 kWh/ m³ on average considering the Atatürk Dam HEPP. The annual energy generating capacity of Birecik is about 2.52 billion kWh, that of the Karkamış Dam 0.65 billion kWh, with a runoff amount and energy value per water unit of 30.4 and 30.8 billion m³ and 0.116 and 0.021 kWh/ m³ respectively. The overall hydraulic energy value of water savings due to irrigation technologies of Atatürk Dam Irrigation facilities per water unit is 0.469 kWh/ m³.

Findings

For each irrigation, figures for farming and resource irrigation modules and annual overall irrigation water requirements have been calculated for surface and pressurized irrigation systems. As a sample, figures of the Siverek - Hilvan Pump Irrigation have been given in table 8a and b.

Table 8a. Irrigation module and irrigation water requirement in surface irrigation.

Months	Farming demand (mm/ay)	Farming Module l/s/ha	References Module l/s/ha	Monthly Irrigation water Requirement m³/ay
January	0.0	0.000	0.000	0
February	0.2	0.001	0.001	317,763
March	19.0	0.073	0.079	30,954,203
April	50.8	0.195	0.212	79,986,430
May	170.2	0.655	0.712	277,222,300
June	315.1	1.212	1.317	496,549,888
July	327.4	1.259	1.369	533,199,379
August	340.2	1.309	1.422	554,011,674
September	208.6	0.802	0.872	328,704,267
October	30.3	0.117	0.127	49,360,446
November	0.8	0.003	0.003	1,241,015
December	0.0	0.000	0.000	0
Annual Total	**1,462.7**			**2,351,547,364**
Irrigation water requirement per unit area (m³/ha)				**16,170**

Table 8b. Irrigation module and irrigation water requirement in pressurized irrigation.

Months	Farming demand (mm/ay)	Farming Module l/s/ha	References Module l/s/ha	Monthly Irrigation water Requirement m³/ay
January	0.0	0.000	0.000	0
February	0.2	0.001	0.001	276,908
March	16.7	0.064	0.070	27,266,697
April	43.6	0.168	0.182	68,766,701
May	112.1	0.431	0.469	182,497,817
June	180.6	0.695	0.755	284,667,591
July	185.1	0.712	0.774	301,415,436
August	192.6	0.741	0.805	313,677,147
September	119.6	0.460	0.500	188,417,528
October	19.0	0.073	0.080	31,016,274
November	0.4	0.002	0.002	630,849
December	0.0	0.000	0.000	0
Annual Total	**870.0**			**1,398,632,947**
Irrigation water requirement per unit area (m³/ha)				9,617

The given tables show that, in case of surface irrigation conditions, the irrigation network capacity, expected to be 1.422 l/s/ha to meet water requirement in August, retrograded to 0.805 l/s/ha with a 43% capacity decrease when preferring pressurized irrigation system. Similarly, the annual water requirement for Siverek - Hilvan Pumping Irrigation, covering an area of 145,427 ha, is of about 2.35 billion m³ in case of surface irrigation, but regressed to 1.40 billion m³ with pressurized irrigation.

Calculations for each irrigation have been summarized in table 9.

As the table displays, water requirement for irrigations through the Atatürk Dam by utilizing surface irrigation system will be 10.1 billion m³/year; but it drops to 6.5 billion m³/year when using convenient pressurized irrigation systems. With water savings of 4.4 5 billion m³, energy of 2.07 billion kWh/year will be generated. This saving nearly accounts for the annual capacity of the Birecik Dam. When taking into consideration that 1 kWh has the value of 0.045 £/kWh (€ = 1.95 YTL) at the electricity generation point, additional electricity of 92.2 billion £/year will contribute to the economy of the country.

In spite of the fact that water savings will be achieved when converting from surface irrigation to pressurized irrigation, energy will be spent for pressurized irrigation. Since less water will be used with pressurized irrigation, less energy will be used for pumping irrigations, which elevate the water up to 60 - 70 m. By using surface irrigation, on the other side, water has to be elevated up to 35m with greater energy consumption. Table 10 reports the energy consumption values. When utilizing pressurized irrigation systems at the Atatürk Dam, additional energy of 65.5 billion kWh/year will be used; this figure of 3% is insignificant when compared with the energy value of the saved water. Furthermore, through piped irrigation networks, due to the topography no additional pressure will be needed in 30 - 35% of cases. This again shows that there will not be the need for additional energy requirement, considering the overall irrigation networks taken into consideration.

Table 9. Farming demand, irrigation module, annual irrigation water requirements and water saving according to the Surface and Pressurized irrigation systems.

Irrigation Name	Surface Irrigation (DSİ)				Pressurized Irrigation (This study)				Total Water Saving (million m^3/year)
	Farming demand (mm/month)	Irrig. Module (l/s/ha)	Annual irrig. water req. (million m^3/year)	Unit area Irrig. Water Req. (m^3/ha/year)	Farming demand (mm/mounth)	Irrig. Module (l/s/ha)	Annual irrig. water req. (million m^3/year)	Unit area Irrig. Water Req. (m^3/ha/yearl)	
Akçakale	1564	1.522	164.9	17287	961	0.852	97.6	10236	67.3
Atatürk Pumping	1102	1.095	303.4	12177	652	0.616	179.5	7204	123.9
Bozova * Pumping	1208	1.209	600.6	13340	733	0.710	364.7	8099	235.9
Bozova * Merkez Pumping	1208	1.124	13.4	12397	733	0.660	8.1	7527	5.3
Mardin-C. pınar (Gravity+ Pumping)	1553	1.520	3619.5	17172	918	0.855	2138.6	10146	1480.9
Paşabağı	1468	1.368	6.2	15547	868	0.766	3.7	9187	2.5
Samsat Pumping	1079	1.064	91.5	11797	638	0.599	54.1	6.976	37.4
Siverek Hilvan Pumping	1463	1.422	2351.5	16170	870	0.805	1398.6	9167	952.9
Suruç Pumping	1299	1.208	1266.2	14360	810	0.726	789.3	8951	476.9
Ş.Urfa Harran	1468	1.476	2306.4	16770	868	0.826	1362.9	9909	943.5
Yaylak* Pumping	1125	1.070	211.8	12432	681	0.640	128.1	7518	83.7
Total			10935.4				6525.2		4410.2
Saved water energy equivalent (billion kWh)									2,07

**Presently, irrigation is carried out by sprinkler irrigation system. Irrigation at irrigation units displays that 30 – 35% excess water is being used, because of lack of know-how of the Farmers.*

Table 10. The energy consumption of irrigation network based on the surface and pressurized irrigation methods.

Irrigation Name	Total Energy Consumption (million kWh/year		Difference (million kWh/year)
	Surface Irrigation	Pressurized Irrigation	
Akçakale	0.0	13.4	-13.4
Atatürk Pumping	68.3	65.0	3.3
Bozova Pumping	148.3	90.1	58.3
Bozova Merkez Pumping	3.1	1.9	1.2
Mardin-Ceylanpınar Gravity+Pumping)	662.4	684.4	-22.0
Paşabağı	0.0	0.5	-0.5
Samsat Pumping	21.0	19.9	1.2
Siverek-Hilvan Pumping	522.0	502.1	19.9
Suruç Pumping	297.6	240.7	56.8
Ş.Urfa-Harran	0.0	186.7	-186.7
Yaylak Pumping	41.3	25.0	16.3
Total	1,764.0	1,829.5	-65.5

Along with the contribution of pressurized irrigation to the country's economy, Table 11 displays its contributions to the Farming economy. In the GAP Region, the overall size of an agricultural holding is about 1.1 ha. When using surface irrigation, the Farmers consume additional energy, but by using pressurized irrigation, they save energy due to water savings. Holdings with additional energy consumption are Mardin - Ceylanpınar, using surface and pump irrigation and Şanlıurfa - Harran, Akçakale and Paşabağı, using only surface irrigation. Farmers, using pump irrigation, pay less for energy when converting to pressurized irrigation, compared to surface irrigation.

Table 11. Consumed energy together with its financial value at the average agricultural enterprises.

Irrigation Name	Surface Irrigation		Pressurized Irrigation		Distance (£/year)
	Consumption in energy kWh/year	Money value £/year	Consumption in energy kWh/year	Money value £/year	
Akçakale	0	0	1,543	108	-108
Atatürk Pumping	3,014	211	2,869	201	10
Bozova Pumping	3,624	254	2,200	154	100
Bozova Merkez Pumping	3,136	220	1,904	133	86
Mardin-Ceylanpınar (Gravity+Pumping)	3,457	242	3,571	250	-8
Paşabağı	0	0	1,384	97	-97
Samsat Pumping	2,985	209	2,816	197	12
Siverek-Hilvan Pumping	3,949	276	3,620	253	23
Suruç Pumping	3,712	260	3,003	210	50
Ş.Urfa-Harran	0	0	1,493	105	-105
Yaylak Pumping	2,667	187	1,613	113	74

III – Results and Proposals

1. By using pressurized irrigation systems, 40% of water saving is achieved compared to surface irrigation. The capacity of water savings amounting to 4.4 billion m³/year with regard to the River Euphrates energy system has a value of 2.07 billion kWh and 192.2 billion €.
2. The network capacity will decrease at a rate of 39 - 44%. This will result in significant savings in irrigation investments.lass
3. The overall energy requirement of the Atatürk Dam irrigations by way of surface irrigation is about 1.8 billion kWh/year, but will insignificantly increase (65 million kWh/year) when turning to pressurized irrigation. This increase constitutes 3% of the additional energy generation and is thus insignificant.
4. Farmers, using surface irrigation, are paying additional amounts for water, but by using pump irrigation costs for water will decrease.
5. Since drinking water resources are diminishing, requirements of other sectors are increasing and energy prices are escalating; piped networks and pressurized irrigation systems, which provide savings in water, shall be preferred. In this respect, in Turkey, newly constructed irrigation networks fall within an economical framework, designed as low and high-pressure piped networks. In order to ensure the widespread use of pressurized irrigation systems, funds from national resources, from the European Union and the World Bank have been utilized to enable Farmers to convert to these systems by using 50% of these funds as aids or credits with no interests.
6. In order to ensure the widespread use of pressurized irrigation systems, the benefit of these systems shall be explained and demonstrated to the Farmers.
7. By the beginning of the year 2008, it has been observed that credits without interests, allocated by the Ziraat Bankası (Agricultural Bank for Agriculture), have been utilized for pump and well irrigation throughout the province of Şanlıurfa. Despite the fact that surface irrigation comprises 80% of the irrigation system in Şanlıurfa - Harran Plain Irrigation, 17% of the credit without interest for irrigation has been utilized. Thus, coercive measures shall be taken besides measures to encourage pressurized irrigation systems for surface irrigation.

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Sustainable management of reservoirs and preservation of water quality

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Abstract. Sustainable development of water structures have been in hot debate for more than a decade. Further sustainable development of water basins or integrated management of water basins are the following ideas. However, after 150 years of dam construction, the number of undeveloped water basins is not too high. Today, we need better tools to manage the basins which have already been developed. In this aspect management of reservoir siltation is a backbone for sustainability of dams and water resources of the respective basin. Therefore, in the present paper the mechanics of reservoir siltation, several alternatives for desiltation process and new research on the topic are discussed. Consequently, a new approach to Sustainable Development of Basin Water Storage Capacity is described.

Keywords. Sediment transport – Reservoir sedimentation – Delta formation.

Gestion durable des réservoirs et préservation de la qualité de l'eau

Résumé. *Pendant plus de dix ans, le développement durable des ouvrages hydriques a fait l'objet d'un débat considérable qui a mis en évidence la nécessité de promouvoir un développement plus durable et/ou une gestion intégrée des basins versants. Toutefois, 150 ans après la construction du barrage, le nombre de basins versants sous-développés est peu important. Il est donc nécessaire de mettre au point des outils plus performants pour gérer les basins déjà développés. A cet sujet, la gestion de l'envasement du réservoir est fondamentale pour la durabilité des barrages et des ressources en eau dans le bassin. Par conséquent, dans le présent travail on passée en revue la mécanique de l'envasement du réservoir, les diverses alternatives pour le processus de désenvasement et les nouvelles orientations de la recherche dans ce domaine, pour présenter, enfin, une nouvelle approche de Développement Durable de la Capacité de Stockage de l'Eau de Bassin.*

Mots-clés. *Transport des sédiments – Sédimentation du réservoir – Formation du delta.*

I – Introduction

Civilization is known to have started with the invention of the wheel but the first wall built by men has an undeniable importance, too. Walls have various purposes mainly as separation and conservation. When a high structure which may be simply called as a wall is built right across a river, it prevents the flow of water and forms a reservoir at the upstream. In civilization, these types of structures, i.e. dams, which are designed as more complex walls, are built in order to provide the use of water for life, such as irrigation, domestic uses, hydropower purposes and also for water control during floods etc. In today's world, when a problem takes place in the operation in time, it is inadmissible to abandon a huge structure without any effort. In technological perspective, while considering the rational use of water, keeping the basin water storage at its original level has great significance. However, siltation prevents the rational usage of basin water storage. The adverse effect of trapping sediment in reservoirs does not only influence the upstream face of the dams but also affect the downstream face of the dams. For a basin near the coast, the continuity of flow of solid particles together with water up until the coastline is very important, because these particles form a delta by being deposited right at the region where the river meets the sea. This influences the conservation of ecology in the downstream negatively. The prevention of the continuity of flow of solid particles will help avoiding the downstream delta formation and destructive effects on the downstream face. Since, the water spilled from the spillway is not loaded with solid particles, they have the ability to gain more velocity being unsaturated. Thus, the scour rate will increase at the downstream and the fertility of the downstream plains decreases. Because of these reasons, the most important criterion after the structural stability is sediment transport blockage of reservoirs.

There are 40 000 dams in the world and their number grows steadily. The world records in sediment production measured in arid climate conditions are as high as 6000-8000 m3/km2/year. Every year 0.5-1.0% of the world's reservoir capacity is lost due to sedimentation (White, 2000). Therefore, sediment data should be included in the design procedure of a reservoir in conjunction with the hydrological data. These data are used in the analysis of operational optimization including the economic life of the reservoir. In Turkey, the economic life of a dam is taken as 50 years, whereas it can change for other countries to 75 or 100 years. In this design approach, only environmental and social issues are included in the initial stage of the project but any change over the operation and maintenance period is not included (Palmieri *et al.*, 2003). This period, which actually depends on sedimentation, should be taken into consideration at the design stage in order to achieve the sustainable development of basin water storage. The sediment accumulation starts firstly along the upstream of reservoir and if no intervention is done at this stage, the sediment transport of the river will be stopped and the reservoir will start to fill up. However, modeling techniques and some precautions and interventions during operation can solve these major problems. As a matter of fact there are three approaches for sustainable development of basin water storage capacity such as preventing sediment inflow, sustainable management of the reservoir and search for new storage alternatives. These techniques should be also considered at the design stage. Today, the World Bank is promoting life cycle management approach. In this approach, sedimentation, decommissioning of the dam, different reservoir sedimentation management alternatives, social and environmental safeguards, economic optimizations for all of the management techniques can be included in pre-feasibility study.

1. Reservoir Siltation in the World and in the Mediterranean Region

According to ICOLD, if the height of a dam is higher than 15 m from the foundation or the volume of the reservoir is equal to or more than 3 hm3, the dam is classified as a large dam. Today, there are 45 000 large dams around the world and the largest share with 22 000 of them belong to China. In the Mediterranean Area, Spain is the champion with 1196 dams. Turkey comes second with 625 dams and France ranks third with 566. The life-time of a reservoir depends on several natural factors, among which climatic parameters and geographic – geological factors are the most important. As a matter of fact, these factors determine the sediment production. The world records in sediment production measured in arid climate conditions are as high as 6000 – 8000 m3/km2/year. Table 1 shows the storage, power and sedimentation of the corresponding dams in given areas. Coming specifically to the Mediterranean Region, Ludwig (2008) gives the number of dams in the riparian countries during the second half of the 20th century (Figure 1).

In Figure 2, sediment yield of the Mediterranean Basin can be seen. The Mediterranean drainage basin incorporates more than 160 rivers with a catchment greater than 200 km^2, of which only a few are larger than 50 x 103 km^2. This observation emphasizes the role of the smaller rivers (Poulus, 2005; Poulus and Collins, 2002). Poulus and Collins (2002) examined 69 rivers out of 169 of the Mediterranean drainage basin and concluded that the construction of hundreds of dams around the Mediterranean Sea, especially over the last 50 years, has led to a dramatic reduction in the sediment supply to approximately 50% of the potential (natural) sediment supply. Such a reduction is considered to be the primary factor responsible for the loss of coastal (mainly deltaic) land, with annual rates of erosion ranging from tens (Ebro, Po) to hundreds of meters (Nile).

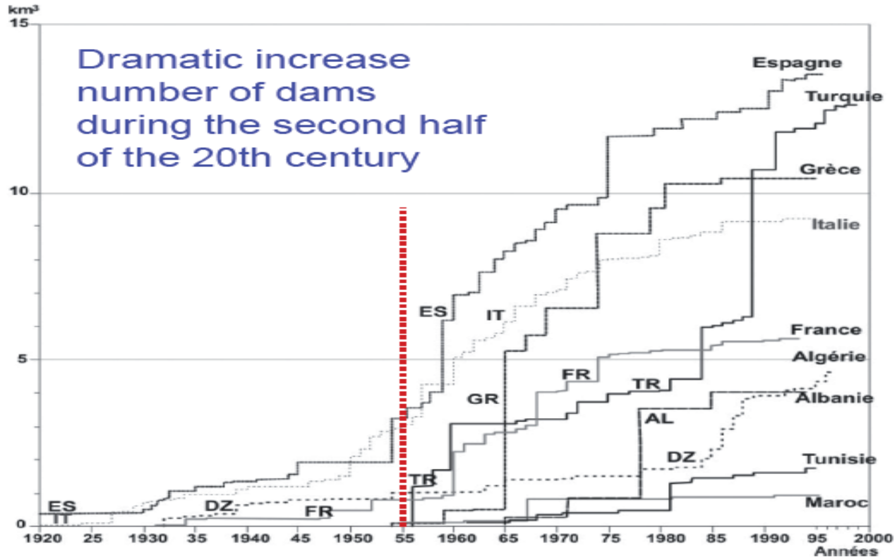

Figure 1. Increase of water storage capacity of the riparian countries of the Mediterranean Sea (After Ludwig, 2008).

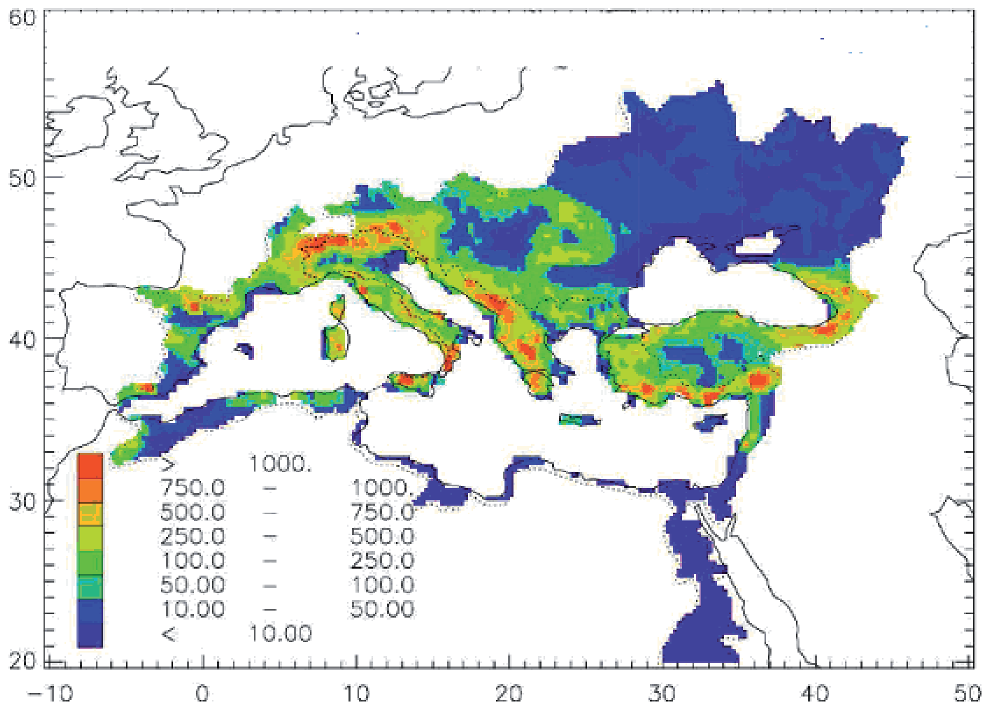

Figure 2. Sediment Yield of the Mediterranean Drainage Basin.

Table 1. Worldwide Storage, Power and Sedimentation.

Region	Number of large dams	Storage (km^3)	Total Power (GW)	Hydropower Production in 1995 (TWh/yr)	Annual loss due to sedimentation (% of residual st orage)
Worldwide	45 571	6325	675	2643	0.5 – 1
Europe	5497	1083	170	552	0.17 – 0.2
North America	7205	1845	140	658	0.2
South and Central America	1498	1039	120	575	0.1
North Africa	280	188	4.5	14	0.08 – 1.5
Sub Saharian Africa	966	575	16	48	0.23
Middle East	895	224	14.5	57	1.5
Asia (excluding China)	7230	861	145	534	0.3 – 1.0
China	22 000	510	65	205	2.3

Source: RESCON Manual Volume I, 2003, After White, 2000

2. Siltation of Turkey's dams

The diversity in the topography brings diversity in the climate of Turkey like many other Mediterranean Countries. As a result, large variations in precipitation take place. The average annual precipitation depth in Turkey is around 643 mm, which is lower than 800 mm, the average precipitation depth of the world (Usul, 2005). Inner Anatolia and East Anatolia receive heavy snow in winter. The annual flows of many of the large basins have a trend of fluctuation. Nearly every 30 years, a drought period takes place. However, the periods between these drought seasons have shortened after 1960. The last drought was in 1994 and lasted five years (Komuscu *et al.,* 2005). Average annual surface water in Turkey is 193 billion m^3 and groundwater is 41 billion m^3. The total amount of exploitable surface water is 110 billion m^3 and groundwater safe yield is 12 billion m^3. The quantity of water per capita is around 1700 m^3/year for a population of 67.8 millions. Today, Turkey utilizes only 39.3 billion m^3 of its capacity. However, it is expected that in 2030, the amount of available water per capita will be less than 1000 m^3 per year. As a result, dam construction in Turkey will continue although there are 555 large ones already built up. The first dam built in Turkey during the Republic Era is Cubuk I Dam, completed in 1936, built for the domestic water requirement of the city of Ankara. After the second World War, an increase in construction of dams and hydroelectric power plants could be observed in Turkey. The state constructed more than 1000 dams and most of the rivers were taken under control. Most of these dams have reservoir volume smaller than 100 hm^3, and their technical accessories are simpler than in the large dams. Consequently, they are even endangered by siltation. The specific sediment-yield of the watersheds in mountainous areas of Turkey where the most dams are and will be constructed is considerably high.

3. Literature Review for Turkey

Fakioglu (2005) studied Seyhan Dam which is located in Seyhan Basin, near the Mediterranean Sea. In this study, the author has evaluated the sediment yield by comparing the hydrographical maps produced in different periods and considered the causes of sedimentation and countermeasures accordingly. It is found out that the active volume of the reservoir was 1238 hm^3 in 1966 and has decreased to 831 hm^3 until 2005. Also, the accumulated sediment volume was 407 hm^3 in 2005.

Another case study on the effect of flow change and sediment transport on the river bed scour downstream is made by Işık *et al.*, 2005. Sediment rating curves in Lower Sakarya River are determined and compared by using measured suspended load before and after the construction of Gökçekaya Dam in the Middle Sakarya Basin. It was observed that the sediment transport decreased at a rate of 40-65% after the construction of Gökçekaya Dam and consequently, the comparison of cross section measurements in 1965 and 2003 pointed out an enlargement in the width and a scour up to 7 m in the depth of the river.

A case study on Kızılırmak Basin (located nearby the Black Sea, also the third largest basin of Turkey) shows that 12 important dams on Kizilirmak River (İmranlı, Yamula, Bayramhacılı, Hirfanlı Kesikkopru, Kapulukaya, Bura, Obruk, Dutludere, Boyabat, Altınkaya and Derbent Dams), which were built with the aim of energy, flood control and irrigation, have been trapping the alluvium; therefore, the solid material reaching the coastline has decreased by 98%. This has resulted in a decrease or even a stop in the increase rate of the delta; the coastal stream and waves cause erosion of delta. A numeric illustration for the second consequence is studied by many authors. Guler *et al.* (2002) points out that the yearly setback is around 30 m and Kokpinar *et al.* (2000) gives the total number between 1990 – 2000 as 1 km back.

Although there are significant environmental effects, siltation starts to appear under the coastline of the Black Sea after 50 years of dam construction; the design life approach is being used in the design stage of new dams. There are limited studies about reservoir siltation, focusing on the design life of the dam (Yalcinkaya, 1991; Yilmaz, 2005; Yilmaz *et al.*, 2005). Sonmez and Dincsoy (2002) prepared a report for the determination of annual sediment yield and possible precautions for Ivriz Dam, which is located in the Central Anatolia, by using Geographical Information System (GIS).

4. Siltation mechanism

Nevertheless, in order to understand the complex mechanism and to find a universal solution, both experimental and numerical studies by hydraulic engineers are needed. The main problem in modeling desiltation is the determination of the particles' motion behavior. Fan and Morris (1992) divide the principal sedimentation into three categories: the deltaic deposition of primarily coarse materials; deposition of fine sediments from homogenous material; and transportation and deposition of fine sediment from stratified flow.

Coarser particles deposit mostly at the entrance of the reservoir forming a delta as shown in Figure 3. Deposited coarser sediment materials at the upstream reach of a reservoir will cause the water level to rise during flood time; spillway capacity will be overloaded. Delta formation is modeled by using available semi-empirical sediment transport equations for the river flow (Pulcuoglu, 2008). This kind of models can be useful for saving time while calculating and comparing several approaches of sediment load carried by a river and its accumulation profile. The profile of accumulation is also very useful for the location of intake structures in reservoirs since any sediment particles cause great harm to the intake structures, pipes, turbines, gates of hydropower equipment or irrigation systems, etc.

The state of flow after delta is a quasi-homogeneous flow. Since water within the reservoir has a lower density than the incoming flow which carries sediment, the flow becomes gradually stratified and plunges into the bottom. The plunge point may migrate forward. Lee and Yu (1997) reported a limiting value of densimetric Froude number for plunge. Then, density current or gravity currents occur. Due to their turbulence, they are generally called turbidity currents. Turbidity currents are accepted to be the governing process in reservoir sedimentation (De Cesare *et al.*, 2001). They move sediment further towards the dam body. If there is an outlet on the dam body facing turbidity currents, sediment can continue its voyage (outlet B in Figure 3). Otherwise, sediment is gradually deposited on the bed... this condition reduces their capacity over time; consequently, replacement of storage becomes necessary. On the other hand, finer sediment is carried by quasi-homogeneous flow to nearer parts of the body of a dam (Yu *et al.*, 2004). A muddy lake eventually forms and deposits sediments which decrease the storage capacity of the reservoir and also reduces sediment supply into downstream river. In stably stratified reservoir, selective withdrawal is accomplished by placing slit or slot outlets at different levels. An outlet at the upper layer (outlet C in Figure 3) for intake to the turbines or water supply takes clear water. At this process, initiation of muddy lake is an undesired situation. In some situations, dam is abandoned due to sedimentation even if it is not completely silted. Sediment accumulation in the dead volume of a dam after a certain time may interfere with the operation of bottom outlets (outlet A in Figure 3). On the other hand, sediment accumulation in the active volume will reduce the useful storage of reservoir and the water stored in reservoir will not be sufficient for intended purposes.

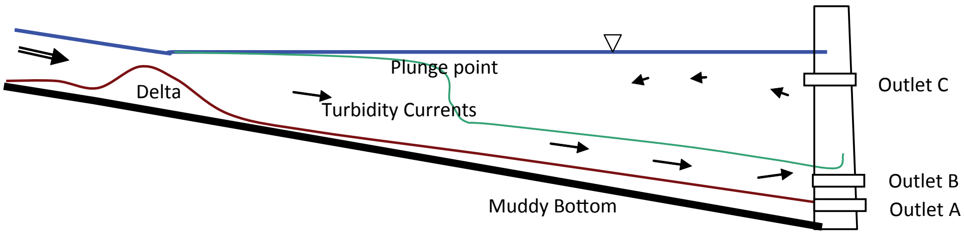

Figure 3. Typical reservoir cross section.

Majority of selective withdrawal experiments are made with brine and fresh water because sand particles may create unsteadiness in the flow. There are also many studies on the initiation of motion of sediment starting from the beginning of the last century. The most commonly used chart is plotted by Shields (1936). This chart could not have been replaced because it is entirely empirical, but many developments are made and many points are added to the plot by many researchers, e.g. Vanoni (1964), White (2000), Mantz (1977) and others.

As mentioned before, initiation of motion of sediment particles has been studied by many researchers among which Shields plotted a band in a dimensionless chart. On this plot, the band is assumed to be region where the motion starts; therefore, above this band, the motion is assumed to be started already, whereas the below region means that the particles do not move. But the most important property of this diagram is the assumption of logarithmic law of velocity distribution because all of the experiments are accomplished under open channel flow conditions. Gobelez (2008) made several experiments on the initiation of motion using sand particles in a model reservoir. This study gives an idea about the conditions of flow at the threshold of motion of particles. A further experimental study on the quantity of transported material is needed for the desiltation procedure. These studies can serve in the purpose of design of bottom outlets of dams. The properties of the outlet directly influence the flow conditions (Cobanoglu, 2008). Furthermore, the flow pattern within the reservoir and concentration of sediment is to be measured by advanced measurement techniques such as Particle Image Velocimeter (PIV) in the laboratory conditions. Additionally, the amount of sediment which is carried out will be measured. This kind of studies can result to get realistic entrainment rate of sediment. Then, the amount of total transported sediment as a function of flow properties and outlet dimensions can be obtained.

Figure 4 reports a sample measurement to visualize the streamlines of the flow in a model reservoir which has a one outlet (Gobelez, 2008; Yilmaz and Tigrek, 2007).

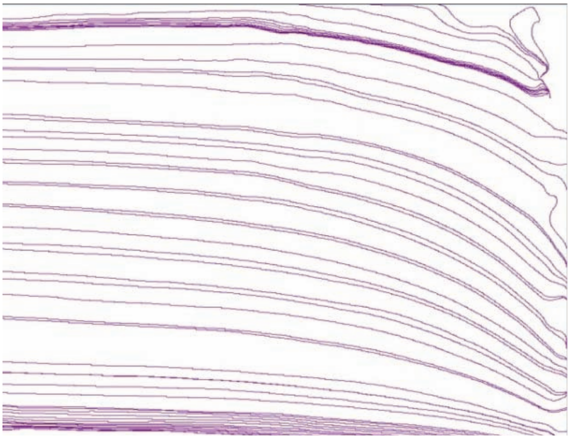

Figure 4. A sample measurement visualizing streamlines in a reservoir when bottom outlet is open.

5. Sustainable Development of Basin Water Storage Capacity

Water has a vital importance for human being for the purposes of basic needs such as drinking and providing hygiene. In addition, water provides agricultural and industrial development, hydropower generation, navigation and ecosystem conservation; therefore, water also provides development. However, the amount of fresh water is limited and also qualified resources are not sufficient for the increasing human population. Thus, the existing water resources should be managed properly to fulfill the needs of human beings and to reach the developed country level as well. In other words, the water resources should be used in a sustainable manner; that “use and discard” philosophy should no longer be followed.

The concept of Sustainable Development is defined as “development that meets the needs of the present without compromising the ability of the future generations to meet their own needs” by the World Commission on Environment and Development in 1987 (Tortajada, 2001). In addition, for the water-based development projects the concept of sustainable development includes determination and planning of the demands for the water through the project region, rational water use, participation of the stakeholders, equitable development for human development, achievement of the environmental and social protection by a sensible economic growth, comprehensive observation and assessment, effective supervision and provision of the necessary conditions for the protection of water related structures (Tortajada, 2001). Sustainable development in water is actually accomplished by using the basin water storage capacity in a sustainable manner. This object is called “Sustainable Development of Basin Water Storage Capacity”. In order to attain “Sustainable Development of Basin Water Storage Capacity”, three courses should be followed such as Preventing Sediment Inflow, Sustainable Management of the Reservoir and Search Lost Storage Replacement or Decommissioning of Dam.

Preventing Sediment Inflow can be applied by Watershed Management, Upstream Check Structures (Debris Dams) and Reservoir Bypass.

- Watershed Management. Watershed management is a method which is used to reduce the reservoir siltation coming from the upstream basin of the reservoir by using some techniques such as forestation, prevention of erosion by vegetation and tillage management, sediment trap and change in land usage. As a matter of fact, watershed management aims to conserve soil and consequently conserve water. In order to achieve this aim, techniques should be combined efficiently. However, especially in semi-arid regions it is impossible to manage the watershed effectively.

– Upstream Check Structures (Debris Dams). Debris dams are relatively smaller dams than the main dam provided by spillway structures. Their function is to stop the main sediment coming from tributaries to the reservoir of a dam which will be used to supply either power or water. It can extend the life of the dam but the debris dam itself will require reservoir sediment management program.

From the economic viability point of view, short lifetime and relatively high cost of debris dams are a problem. Sediment concentration of tributary conversely affects the lifetime of debris dam. This means that if sediment concentration in the tributary is large, lifetime of the dam is short. In addition, debris dams are not active in design flood reduction. The cost of a debris dam is another problem, since a debris dam implies the construction of a dam, of auxiliary structures and the foundation treatment. Increasing the main dam capacity weighed against debris dam capacity is more economical and useful than building a new additional dam.

However, if accumulated sediment in the debris dam is used for construction purposes, like roadway constructions etc., debris dams' usage will be cost effective by making arrangements at institutional level.

– Reservoir Bypass. Reservoir bypassing is to let the sediment-laden flow pass from a channel, meanwhile keeping the sediment-free water.

Actually, reservoir bypass system is very hard to apply. First of all, it should be designed correctly and operation should be planned carefully since it is a very expensive system. As a matter of fact in order get a feasible Bypass System, some special conditions should be provided at the same time. For example, topography conditions and size distribution of sediment load are very important factors that should be bewared.

Furthermore, bypassing sediment-laden water from channel is not acceptable for arid areas where water is really needed.

Sustainable Management of the Reservoir can be achieved by Evacuation of Sediments from Reservoir and Management of Reservoir.

– Evacuation of Sediments from Reservoir

– Flushing: Flushing is a sediment removal technique by which the deposited sediment is scoured from the reservoir by increasing flow velocity and then transported through low level outlets. Flushing can be operated in two ways such as by lowering water level or without lowering water level, called "flushing under pressure" and "free-flow flushing" respectively. Flushing under pressure is to release water through the bottom outlets by keeping reservoir water level high. On the other hand, free-flow flushing releases water by emptying the reservoir and also routes inflowing water from upstream by providing riverine conditions (Morris & Fan, 1998). For semi-arid regions, "flushing under pressure" applicability is suitable because of water scarce.

Another categorizing of flushing is done again by Fan & Morris and summarized in Table 2.

Table 2. Types of flushing.

	Sediment discharge (2)	Operating rule (3)	Outlet type (4)	Mode of action (5)	Advantages and disadvantages (6)
Sediment routing during floods	Discharge < inflow: Sedimentation rate significantly reduced if hydraulic detention time is greatly reduced during sediment discharge events	Outlets opened as early as possible, or reservoir level remains seasonally low, to minimize storage during sediment-laden flood periods	Low-level outlet required to achieve significant reduction in reservoir pool level	Impede deposition of slowly setting silt and clay particles by minimizing detention period	Useful at many types of sites. Can utilize excess water during floods for sediment control; cannot stop sedimentation
Drawdown flushing	Discharge > inflow: Under favorable circumstances sediment accumulation can be arrested	Outlets opened as early as possible to create rapid flow through reservoir during rising limb of flood	Bottom outlets capable of discharging sediment-laden flood flow with minimum backwater	Turbulent flow maintains sediment in suspension, and can remobilize some previously deposited sediments by erosion	Under proper conditions, capable of arresting sedimentation.
Emptying & Flushing	Discharge > inflow: Under favorable conditions, sediment accumulation can be arrested and lost capacity can be regained by erosion	Reservoir empty during flood season to permit scour of sediment deposits by floods	Bottom outlets required to permit reservoir to be drained; outlet capacity may be less than the flood flow	Turbulent flow maintains sediment in suspension, and some sediment deposits removed by retrogressive erosion	The only strategy which can recover lost capacity, but it requires emptying the reservoir on a regular basis
Venting Density Current	Discharge < inflow: Under special circumstances, accumulation of fine sediments can be significantly reduced	Open bottom vents when density current reaches dam site; water level draw-down not required	Low elevation bottom outlets of moderate capacity to minimize backwater of muddy flow	A portion of the density current containing silt and clay is vented	Does not require drawdown of reservoir pool level

Sluicing: Sediment sluicing is an operational design. In most cases the reservoir is drawn down in flood season and then sediment carrying inflow directly passes through the reservoir. The sediment has no chance to settle down. After flood season the clear water will be stored and reservoir will be raised for the next season usage. In the worldwide usage, generally sluicing and flushing are used together.

Density Current Venting: Density current venting means to route the sediment-laden flow through the stored water in the reservoir. In order to have successful density current venting, the incoming sediment-laden flow would have enough velocity and fine particles to form turbid flow. If these favorable conditions are got, current should be able to reach dam. At this time the bottom outlet will be opened and the current will be vented through. In this method, it is not necessary to decrease the reservoir water level contrary to flushing or sluicing.

Mechanical Removal

Dredging: Dredging is the mechanical removal of accumulated sediment in the reservoir from a reservoir bed by pumping (traditional hydraulic dredging) or by mechanical equipment without emptying the reservoir and then dumping the dredged sediment at a suitable area. Dredging method is suitable for medium- and small-sized reservoirs, which do not have enough water for flushing.

Trucking: Trucking is the excavation of the accumulated sediment from a reservoir like dredging but it requires the drawdown of the reservoir. Then the excavated sediment is transported to a suitable disposal area by using traditional earth moving equipment. Cost of drawdown, transportation cost and suitable area cost make the method very expensive. This is why trucking is not widely used.

HSRS: Hydrosuction Removal System (HSRS) is similar to traditional hydraulic dredging and it is simply a siphon and airlift system, which uses the potential energy stored by the hydraulic head at the dam, removes the sediments through a floating or submerged pipeline to an outlet. This system is named Hydrosuction Removal System (HSRS) and Sediment Evacuation Pipeline System (SEPS) in the USA, Geolidro System in Italy. This method has some advantages with respect to traditional dredging. For example, since potential energy stored by hydraulic head is used there is no need for any equipment to produce energy. Therefore, the operating costs are substantially lower than those of traditional dredging. In addition, finding suitable disposal site is not needed in HSRS, because sediment goes to the downstream end of the reservoir, which is also environment friendly. The reason to use this technique is the lack of water for flushing. The released water and sediment can be used for irrigation.

6. Management of Reservoir

Operational Rules. The reservoir operating rule can effect how the sediment deposition occurs. For example, during flood season if reservoir water level is high, the sediment is mostly deposited in the upper reaches of the reservoir. On the contrary, during flood season if the reservoir is drawn down, the sediments tend to deposit in the dead storage zone of the reservoir.

Tactical Dredging: Tactical dredging is the same as traditional dredging; the difference is to remove accumulated sediment in the reservoir locally. For example, in hydropower dams it is important to keep the vicinity of the outlets clear. If the outlets of the reservoir get blocked, the hydropower production will stop. In addition, the mechanical equipment like turbines used to produce energy will be damaged because of sediments. Therefore, by tactical dredging the useful life of the reservoir will decrease, also operation and maintenance costs will increase unexpectedly. It is understood that localized dredging can be an effective tool to prolong the reservoir life.

7. Search Lost Storage Replacement or Decommissioning of Dam

Raising Dam Height. Raising dam height is to increase the reservoir capacity in order to compensate the storage loss due to sedimentation. Especially in arid regions raising should be seen as a cost-effective method. Nevermore, in the long term period it is not a solution for sediment problem. In addition this method requires very careful engineering.

Building New Dam. In order to replace the storage lost of an existing dam, a new dam can be built downstream or upstream of the existing reservoir or on another river. Generally, in Turkey it is used this to replace the lost storage capacity but it is a temporary solution.

Decommissioning (Retirement of Dam). Decommissioning is removing all the structures of a dam project so as to end the operational life of a dam. Decommissioning of a dam is not a reservoir sediment technique; on the contrary it is an economic option if the dam useful life is finished. In other words, if operation costs of the reservoir are higher than the benefits gained from the reservoir, decommissioning is an economic option for further actions.

Aras (2008) and Cetinkaya (2006) studied the economic aspects of the sustainable development of basin water storage capacity. In this study, the methods that provide extension of reservoir life are discussed from the hydraulic, economic and applicability point of view. In addition, an already existing, free of charge, program RESCON, which examines and compares some sediment evacuation methods and decommissioning, economically and also hydraulically, is used. Moreover, some sensitivity analyses are presented and construed for Turkey Dams to understand the program suitability under Turkish conditions. RESCON is a spreadsheet-based program written in Visual Basic programming language and works with macros. There are two pages to input the required data. There are eight types of data the user should input for the program RESCON in these two pages. These are as follows: Reservoir Geometry, Water Characteristics, Sediment Characteristics and Removal Parameters, Economic Parameters, Flushing Benefits Parameters, Capital Investment, and Environmental Parameters.

II – Discussion and Conclusion

The need of hydraulic structures for energy, flood control, and irrigation purposes will always take place as long as civilization continues. The design and construction of hydraulic structures control not only the rivers, but also the solid particles naturally carried by streams. Especially, large dams are the subject of many studies in this area. This is because their large bodies cause huge problems. When sediment particles are trapped by the construction of a body on the river bed, the transport process stays incomplete which is observed as the decrease or stop in formation of deltas. Also the trapped particles reduce the active volume of the reservoirs. Most of the time, the nature may not be calculated sensitively with math and science. Therefore, all design and optimization procedures of hydraulic structures may not serve in the most efficient way in the economic life of them. In order to provide a sustainable future for both nature and man-made structures, many researchers study today both the determination of the problems and their solutions. For determination of problem, different GIS and manual observation techniques on the river morphology and evaluation methods for these observation data are being studied. For the solution of the problem, the trapping effect of the large hydraulic structure and solutions for the removal of trapped particles to continue the transport process are being studied.

The perverse effect of trapping sediment in reservoirs is observed both on the downstream ecology of the river, and on the active volume of the reservoir. The consequences of sediment problems can not be observed in short time interval such as hours or days. The large dams are designed to be filled up in nearly 50 years. Consequently, it takes months and years for a coastline to backset because of the loss of material to be supplied by the river. In order to cope with this problem, careful observation and determination of effective parameters is very important. There are studies based on GIS and other manual observation methods to determine the changes in the river morphology. Likewise, many solution methods are also studied as discussed above. Dams are large bodies affecting the nature seriously; therefore in designing such a structure, many aspects should be considered because they cannot be treated easily when a problem takes place when it is in operation. When the first dam is built on a river, the problem of accumulation of sediment particles has begun. There are several ways to avoid the problem but the procedure starts with the well understanding of the complete process. Many computer programs together with model experiments have been and are still being studied for this purpose. But in addition to the massive laboratory works done, the experiences in the world should also be taken into account while developing and comparing methods. Also whatever the protection and the solution method is, the economic optimization is the most important criterion in engineering applications.

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Second part

Assessment of the technical, economic, social and environmental aspects for saving water

Access to drinking water at an affordable price in developing countries

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Abstract. Affordability of water for human consumption is an official target or a legal requirement in many countries. While everyone agrees that drinking water prices should be reasonable, there is no agreed method to set up a limit of reasonableness or of economic accessibility for water. In transition and developing countries, the affordability index is generally higher depending whether the country seeks to reduce subsidies for water. Improving access to affordable water requires attention to the affordability index.

Keywords. Affordability index – Water prices – Economic accessibility – Developing countries.

Accès à l'eau potable à un prix abordable dans les pays en développement

Résumé. *L'abordabilité de l'eau pour la consommation humaine représente un objectif officiel ou une exigence légale dans de nombreux pays. Si tout le monde s'accorde à reconnaître que le prix de l'eau potable devrait être raisonnable, il n'existe aucune méthode établie pour fixer un seuil de raisonnabilité ou d'accessibilité économique de l'eau. En général, dans les pays en transition ou en développement, l'indice d'abordabilité varie considérablement suivant que le pays essaie ou non de réduire les subventions pour l'eau. Afin d'améliorer l'accès à l'eau à un prix abordable, il est nécessaire d'accorder une attention spéciale à l'indice d'abordabilité.*

Mots-clés. *Indice d'abordabilité – Prix de l'eau – Accessibilité économique – Pays en développement.*

I – Introduction

Affordability of water for human consumption is an official target or a legal requirement in many countries. It was referred to in the Millennium Declaration but is NOT mentioned in most references to the content of the Millennium Development Goals. The right to drinking water is not the right to buy bottles of mineral water but the right to consume drinking water even when users do not have the means to pay its usual price.

While everyone agrees that drinking water prices should be reasonable, there is no agreed method to set up a limit of reasonableness or of economic accessibility for water. Economic affordability of drinking water provided by supply networks and associated sanitation may be described by an index comparing the water and sanitation bill of a household to its disposable income (affordability index).

In industrialized countries, households with an income equal to the median disposable income generally spend around 1.1% of their income for their water and sanitation bill. Poor households spend on average approximately 2.6% of their income. Higher indices are observed in some regions and for very poor people. In order to help vulnerable people, public authorities often take measures aiming to reduce water bills to less than 3%. The similarity of indices in use in various countries and of approaches could provide an objective basis for quantifying the concept of water affordability. By and large it would seem that State practice supports the choice of an affordability index of 3 to 4% of disposable income of poor households in industrialized countries.

In transition countries and developing countries, the affordability index is generally higher depending whether the country seeks to reduce subsidies for water. Median households often have to spend 2.5% of their income for water, i.e. over twice what is practiced in industrialized countries. Consequently the affordability index of poor households is about three times larger (7.5%) because of the low income of very poor households. State practice shows that such high values of the index are generally tolerated. A number of developing States have adopted policies to promote an affordability index for poor households of 3 to 5% and implement measures to reduce the burden of water expenses for poor people.

Improving access to affordable water requires paying attention to the affordability index and taking measures to reduce it such as differentiated pricing, targeted aid programmes, cross-subsidy systems, etc. Many developing countries have implemented such measures. Those countries which do little on affordability are likely to impose a high burden of water expenses on the most deprived people.

II – Affordability of water is a right for all

Everyone will agree that in the framework of economic and social rights, drinking water should be available to all at an affordable price, either as a political objective or as a legal obligation (see below). However, the meaning of an affordable price is generally undefined both at international or national levels.

This paper seeks to quantify the concept of affordability of drinking water supplied by public networks with special emphasis on water in transition or developing countries; it is based on relevant statistics and legal texts from developed or developing countries. By water price, we mean the price actually paid by a household for water supply and sanitation services taking into account any subsidy and rebates for water use.

1. The right to affordable water at international level

In General Comment Nr 15 "The right to water" (E/C.12/2002/11) issued by the Committee on Economic, Social and Cultural Rights, it is stated that:

- "The human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and <u>affordable</u> water for personal and domestic uses";
- "The obligation to fulfil requires States parties to adopt the necessary measures directed towards the full realization of the right to water. The obligation includes, inter alia, ...ensuring that water is <u>affordable</u> for everyone".

One sentence of the Comment helps to understand what is meant by "affordable":

- "Equity demands that poorer households should not be disproportionately burdened with water expenses as compared to richer households".

As poorer households are always burdened by higher water expenses than richer households (Fig. 1 and 2), the key word is "disproportionately". As usual, no indication is given to determine when the disproportion is excessive and national courts have probably not provided appropriate jurisprudence to assess disproportion when dealing with water prices.

Affordability for water emerged as a general principle at international level in 1992 in the Dublin Statement on Water and Sustainable Development: "it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation <u>at an affordable price</u>." In March 2000, the Ministerial Declaration of The Hague on Water Security in the 21st Century (Second World Water Forum) included the common goal that "every person has access to enough safe water <u>at an affordable cost</u> to lead a healthy and productive life". In September 2000, the General

Assembly of the United Nations adopted the United Nations Millennium Declaration in which it referred to improving access to water for people who "are unable to reach safe drinking water" but also for people "who are unable to afford safe drinking water". The emphasis on affordability should be stressed because nearly no one refers today to this issue and nearly all commentators ignore people who "are unable to afford safe drinking water".

Affordability is included in only a few international treaties. In Latin America, the Additional Protocol to the American Convention on Human Rights in the Area of Economic, Social and Cultural Rights, i. e. the so-called "Protocol of San Salvador" (1988) states that:

"Everyone shall have the right to live in a healthy environment and to have access to basic public services."

In Latin America, many national laws require explicitly the provision of basic services to the poor.

In Europe, the Protocol on Water and Health (London, 1999) deals with State obligations concerning water supply and sanitation; it includes in particular the provision:

- "Equitable access to water, adequate in terms both of quantity and
- of quality, should be provided for all members of the population,
- especially those who suffer a disadvantage or social exclusion".

Equitable access means here access at an affordable price and even free access in some cases.

At European Union level, the Protocol Nr 9 to the Treaty of Lisbon (2007) on services of general interest has formally introduced the concept of affordability in EU law:

> The shared values of the Union in respect of services of general economic interest include in particular:... a high level of ... affordability, equal treatment and the promotion of universal access and of user rights".

This Protocol means that drinking water should be available to all everywhere in the EU at an affordable price. EU directives already exist for affordable postal and telecommunication services and directives for affordable electricity and gas are under discussion.

2. The right to affordable water in national law

In a large number of countries, national law states that drinking water should be available to all, even the most deprived people, and that the price of water must be equitable, fair, acceptable, accessible, affordable or reasonable. Examples of such laws have been found in over 20 countries. For instance, the 2006 French Water law states that water for essential uses shall be available at economic conditions acceptable to all ("dans des conditions économiquement acceptables par tous") and that it is right of the individual. However, the content of this right is still unclear.

In Indonesia, a regulation adopted in 2006 prescribes that domestic expenses for the fulfilment of the standard of basic needs for drinking water should not exceed 4% of the income of the user or household (deemed to earn the provincial minimum wage). In this case the objective is clear and measures could be taken to meet the objective.

The right to affordable water can be implemented by managing water services in an efficient way, by providing sizable subsidies to the water sector, by adopting a social tariff for water or by providing targeted aid for water. Social tariffs and targeted aid for water are not yet implemented on a large scale in developing countries.

III – Affordability needs a definition and a yardstick

As there is no generally accepted definition of the meaning of affordability or a limit of unaffordability, there is a need to propose an approach to evaluate what an unaffordable price for water could be.

Water might be considered as being unaffordable if it is more expensive than “elsewhere”, for instance if it costs more than what is charged to 90% of the users. If water prices were uniform, this approach would be of little help. Water might be considered to be unaffordable if it includes unconnected payments such as a bribe or side payment. But this is not applicable when such payments are absent.

A more appropriate approach might consist in comparing water expenses with family budget assuming that water expenses are paid explicitly by the household (not through taxes). The ratio of the water bill of a household to its disposable income describes the size of the part of the household budget used for water; it is called the “affordability index” of the household. If the index is high, water is said to be too expensive, too costly or even unaffordable. When it is low, people do not raise the issue of affordability because water expenses are a trivial part of the family budget. This definition of affordability is in line with a statement in General Comment N°4 on the Right to Adequate Housing (HRI/GEN/1/Rev.7(2004)): “Steps should be taken by States parties to ensure that the percentage of housing-related costs is, in general, commensurate with income levels”). The same logic can be used for water. The European Commission in both its Green and White books on services of general interest expressed itself in favour of a definition of affordability based on the cost of services and the disposable income of the user.

Having defined an index of affordability, the issue is to determine under which conditions water can be said to be unaffordable, i.e. when the right to water at an affordable price would be violated. We will limit our analysis to drinking water supplied by public networks under the control of public authorities and exclude water provided on the free market (water sold from tanks, in bottles or at a stand post).

To assess affordability, we take into account all expenses for water paid by a household when buying water and include sanitation expenses and taxes paid with water and we add other water and sanitation expenses if identified and paid separately (through local taxes). Water prices vary with consumption (when metered), technical and geographical conditions, quality of service, environmental standards, inclusion of rainwater expenses or not. To allow comparisons, consumption is generally standardized at 120 m3 per year per household connected to a supply network. The water bill is generally below water costs because of subsidies and can actually be a very small part of the full costs of water.

Water expenses are compared to disposable income of the household. It can be a “median” household if the disposable income is the “median” income. It can also be a “poor” household if the disposable income is much smaller. The income of the poor family can be 50% or 40% of the median income, the upper limit of the first decile of income, the average income of the first decile, etc. An easy reference for the income of “poor” households is 40% of the median income.

Water prices and disposable income vary from one municipality to another. Regional or national averages can be established to derive aggregate affordability indices but hide considerable differences. Water expenses vary little with income because water is an essential good necessary for life. They represent a higher proportion of total consumption expenses of poor people than of average people (Fig.1 and 2). Wealthy people have an index 10 times below the index of poor people. Because of this difference only poor people will complain of the high price of water but such complain is not always made because water expenses are a small part of housing expenses (that include rent, heating, electricity, water and telephone).

When water prices increase, people who have little means could in principle reduce their water consumption but this is difficult to achieve because water consumption is related to basic needs (health, cleanliness, toilets, food, beverage, etc), is weakly dependant on income level and, in some case, the water bill is weakly dependant on consumption. Alternatively poor people could use unsafe water with the risk of becoming sick and spreading epidemics (typhoid, cholera, etc.). Another solution would be to forego other essential expenses such as food or health expenses to pay for an increase in water price.

Public authorities could alleviate the effects of the increase in water price by improving efficiency, providing higher water subsidies for all or by setting up social tariffs or aid targeted on the poor. The last solution is less costly for public finance but more complex to implement. It requires specifying who will be aided and who will finance the aid.

We shall base our analysis on observations of policies and measures taken by public authorities and not on theoretical or ideological concepts. Indications that water prices are unaffordable are given by the amount of water thefts, the amount of unpaid bills, the unwillingness of many users to pay their bills. Such indications of unaffordability are not usable at international level because they closely depend on institutional and historical factors.

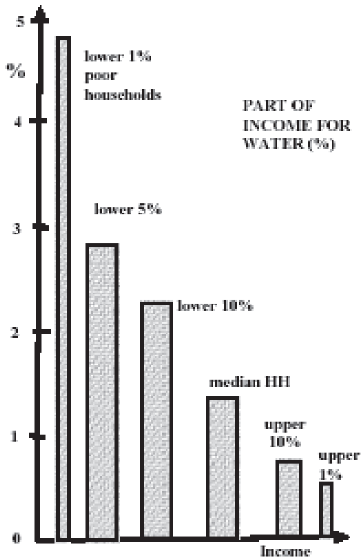

Figure 1. Water expenses as a function of income (France).

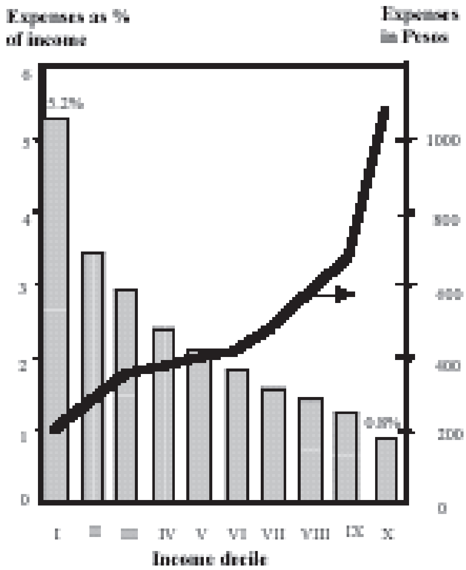

Figure 2. Water expenses in Mexico (1996).

IV – Range of water affordability indices in various countries

Because of the large number of parameters that influence the price of drinking water and sanitation and the level of household's income, affordability indices vary within a wide range (from 0 to 20%). It can be nil if water is freely available (public fountain or stand post) or very high if the user has to pay a water vendor. Consistent series of reliable affordability indices are not easily available. Caution should be exercised when comparing water affordability indices because prices vary rapidly and data are not always comparable.

In Western Europe, the affordability index for median households in various industrialized countries is around 1.1% (Fig .3). The range of indices (from 0.7 to 1.7%) is relatively limited as if countries had decided what they should charge to their citizens for their water consumption and what they should bear through subsidies. These values represent the usually observed levels of indices, not a target.

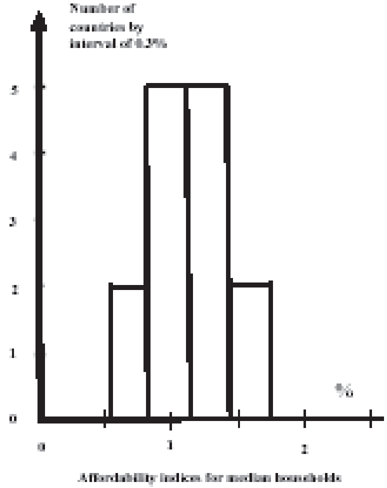

Figure 3. Distribution of affordability indices in 14 European countries.

For households with 40% of median income and identical water consumption (120 m3/yr for households[1]), the affordability index is 2.75% (1.1% /0.4) when there is no social measure (social tariffs, targeted aid for water, aid for water debts, etc.). The affordability index can be higher than the average 2.75% if people are very poor (e.g. unemployed people living on state aid) or in municipalities where water is particularly expensive. Indices above 5% are found in Western Europe and can exceed 10% in developing countries. Fortunately social assistance when available alleviates unaffordability problems such as a reduction in food consumption, less medical and dental treatment, non payment of other utilities, less attendance of schools, longer working hours.

In countries with intermediate or low income, the affordability index is generally higher than in Western Europe because the decrease in the price of water is lower than the decrease in disposable income. This is particularly true when income inequality is large and poverty is deep. Because of data constraints, affordability indices have been compared for only three groups of countries : transition countries, Latin America and Africa.

For transition countries (EECCA), the affordability index of median households is generally in the range 1.5 to 3% (average 2.6%, Fig. 4), i.e. over twice the comparable index in Western European countries (1.1%). Closer examination of the data shows that there are probably two groups of EECCA countries : those with high water subsidies and low water price (affordability index for median households near 1%) and those with reduced subsidies and higher water prices (affordability index of median households near 3.5%). While the first group of countries has no affordability problem at this stage, the second group of EECCA countries could have such problems because people in the lower decile of income or below 40% of median income would have an affordability index between 5 and 10%. For instance, in Ukraine 6.4% of users have to pay over 6% of their income for water (Fig. 5). In Russia, people in the lower decile spend more than 6% for water. These figures are large but people have little alternative.

An affordability limit of 4%, as proposed by OECD for poor households in EECCA countries, may not reflect State practice in all these States; it may be difficult to achieve, as it could mean providing aid for water to more than 20% of the population. An affordability limit of 3% as proposed by UNDP would be even more difficult to implement and could be unrealistic where water prices are already high.

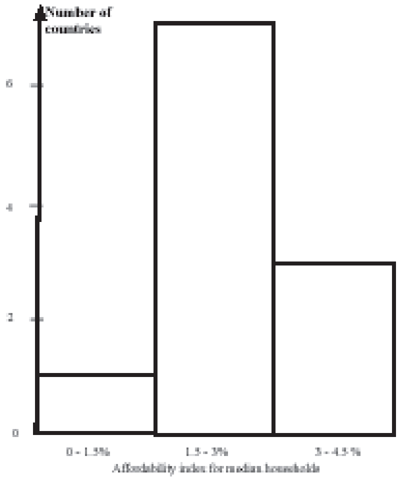

Figure 4. Distribution of affordability indices in 11 transition countries .

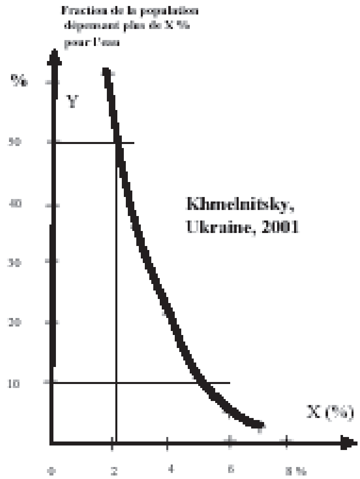

Figure 5. Water unaffordability curve in Ukraine (OCSE, 2001).

In Latin America, most countries have affordability indices above 4% for median households (Fig.6), which are much higher than the previous estimates (around 2.5%). Because of social tariffs, the affordability index for poor households does not exceed 10% and would generally be around 6% for the first decile of income. This would show that governments in that region consider that an affordability index for poor household of 6% is acceptable.

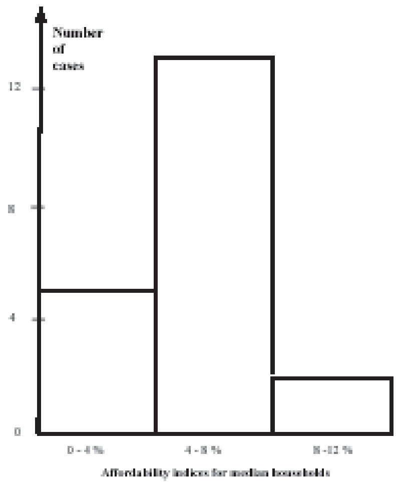

Figure 6. Distribution of affordability indices in Latin America (ADERASA).

In Africa, the affordability index for median households is around 2.8% and for poor households connected to public water supply it could easily reach 7.5%. Much higher values of the index have been observed in slums with water supplied by water vendors.

The analysis of affordability indices for poor households in the world leads to the conclusion that many governments have accepted (Box 1) that water expenses of poor households exceed 7% of the disposable income of poor households, i.e. much more than the target or benchmark of 5% used by the Asian Development Bank.

The limit of unaffordability, i.e. the level of the affordability index, above which developing or transition countries would take special measures in favour of poor users, is likely to be around 7%. Some developing countries have decided to make sure that water for poor households is not too expensive. For instance, in Morocco, the target of 3% for water supply and sanitation is considered appropriate.

In some countries (Table 1), national water law or strategy prescribes a target of a maximum of 3% for water expenses alone and a maximum of 6% for water and sanitation expenses together. These are policy targets that would have to be implemented by various measures and which are likely to lead to higher affordability indices for the very poor. In Chile a person having to pay more than the affordability limit is entitled to receive an aid. In Columbia, poor people pay less for water than rich people.

V– Targeted aid and social tariffs

In a large number of developing countries with metered supply, water tariffs are progressive with a first block of water consumption at reduced price for all. Such measures are designed to help poor users and will achieve the expected results depending on the level of water consumption, the structure of households and the financing mechanism of the tariff reduction. Progressive tariffs may have a social function provided that they benefit mostly to poor users. This requires a small first block and possibly the denial of the lower tariff to people which are not poor (value of housing, use of electricity, etc). In some cases, most of the subsidy for water will actually be used by wealthy users. Cross subsidies between enterprises and households help reduce water expenses of households.

Box 1

Examples of high affordability indices
(figures above 5%)

Fraction of disposable income used for water

a) *Industrialized countries:*
   France: 1% of the population spends more than 4.8%;
   United Kingdom: 2% of the population spends more than 8%.
b) *Transition countries in Europe:*
   Hungary: the lower quintile spends more than 5.3%;
   Poland: households with less than 50% of median income spend over 10.8%;
   Rumania: the lower quintile spends more than 5.7% and households with less than 50% of median income spend over 8.1%;
   Latvia: the lower quintile spends more than 5.1% and households with less than 50% of median income spend over 6.3%;
   Russia: the lower decile spends more than 6%;
   Ukraine: 6.4% of the population spends more than 6%;
   Armenia: 12.3% of the population spends more than 5%.
c) *Latin America:*
   Chile: the two lower quintiles in Valparaiso spend on average over 5%;
   Uruguay: the lower quintile spends more than 10.4%;
   Surinam, Bolivia and Colombia: the lower quintile spends more than 8%;
   Ecuador: the lower quintile spends more than 9%;
   El Salvador, Argentina and Jamaica: the lower quintile spends more than 11%.
d) *Africa:*
   Burkina Faso: the lower quintile spends more than 29% for water.

Targeted aid and social tariffs have been introduced in over 25 non-OECD countries and in over 10 OECD countries to make water more affordable (Box 2). They provide discount (or equivalent aid) ranging between 20 and 100% on the price of water to people that can prove to be poor. By and large, it would seem that many targeted measures in force aim at bringing down the affordability index to less than 5% (Box 3).

Setting up targeted aid systems is not easy if there is no system in place to identify poor users and is not very useful if there is a high proportion of poor households. Rather than using an economic approach, countries have subsidized equipment specially designed for people with high affordability indices such as water stand posts, public latrines (VIP) (Box 4) or clever water stand posts (with electronic cards).

Some countries refuse to envisage special measures for water because they do not wish to provide aid for various essential needs and prefer dealing with the poverty issue as a whole. Other countries do not separate water bills from housing bills and provide aid for all housing related expenses. There are also countries that do not provide social aid to poor people and leave this issue to local communities to manage outside any official set up.

Table 1. Unaffordability limits for water Maximum part for water expenses in disposable income (Official targets or targets used for implementation of aid systems).

Country	Water	Sanit.	Part	Reference disposable income
Lithuania	X	X	2%	individual household
Northern Ireland	X	X	3%	individual household
Argentina	X	-	3%	individual household
Venezuela	X	X	3%	minimum salary
United States	X	-	2,5%	median household
	X	X	4%	median household
Indonesia	X	-	4%	minimum provincial salary
Chile	X	X	5%	individual household
	X	X	3%	individual household
Mongolia	X	-	4%	individual household
	X	X	6%	individual household
For reference				
UNDP	X	X	3%	individual household
OECD	X	X	4%	individual household
BAD	X	X	5%	individual household

VI – Affordability indices in practice

In the absence of social measures to alleviate the burden of water expenses, the affordability index of poor households is in many cases above 7%. Social measures when taken generally introduce a discount on water expenses of at least 25% that brings down the index to approximately 5%. In industrialized countries, few people have a high affordability index (over 8%). In England, little is done to alleviate this situation while poor households in France are entitled by law to receive a targeted aid (as a right and not as a charity if they have water debts). In Chile, the State provides a water subsidy to poor users (see Box 2). This social measure was introduced when water prices were increased. In Columbia, the water tariff depends on the type and location of the user's dwelling.

VII – Selecting limits of unaffordability

The usual behaviour of States in relation to the affordability index gives an indication of what is generally considered as an appropriate price for water. The unaffordability limit that triggers action by public authorities at local level in favour of water for poor households has to be decided by responsible authorities bearing in mind available financial means for such action. Public authorities have to consider the average affordability index of very poor people (lower decile) and decide whether this is acceptable or need to be reduced.

Box 2

Table 2. Countries With A Social Tariff Or A Social Discount For Water Of Poor Users (list to be completed).

Europe	America	Other areas
Belgium	Argentina	Australia
Bulgaria	Bolivia	China
France	Brazil	Gabon
Italy	Chile	Indonesia
Greece	Colombia	Morocco
Hungary	Costa Rica	Mongolia
Netherlands	Mexico	Pakistan
Poland	Nicaragua	South Africa
Portugal	Panama	
Spain	Paraguay	
UK	Peru	
	USA	
	Venezuela	

NB : This list does not refer to lifeline tariffs nor to increasing block tariffs.

Box 3

Chile implements the right to water at an affordable price

In Chile, users belonging to the lower income quintile are entitled to a discount on their water bill if they are poor, i.e. if they have to spend more than approximately 5% of their income on water and sanitation. It is provided to 624 000 households in urban areas and to 87 000 households in rural areas identified by public authorities (16.6% of the total population). The discount amounts to a reduction of 25 to 85% of the bill (maximum 15 m^3); it is borne by the State budget (32.5 billion pesos or 5.9% of water sales in 2006, 9 US$ per household per year). The system was strengthened in 2004 to offer free water to 225 000 very poor households. Chile has recently approved a plan to implement an unaffordability limit of 3% for water and sanitation.

For such an assessment, they could take account of:

a) the maximum price paid for water in 90% of the municipalities;
b) the median affordability index which is not exceeded in 90% of the municipalities ;
c) the affordability index of poor households at the upper limit of the first quintile of income ;
d) the implicit unaffordability limit relating to special aid systems for water debts;
e) the unaffordability limits used in neighbouring or similar countries (3 to 6%);
f) the unaffordability benchmarks proposed by international organisations (3 to 5%).

They could also decide that the affordability index of poor households should not be higher than three times the index for median households or that poor households should not spend on water more than one tenth they spend on food. They could decide that the aid for access to water should be in line with aid for access to electricity when it exists.

Box 4

Public stand posts may provide water at an affordable price

Water stand posts have been built in cities during the Antiquity. They have been an important symbol in the implementation of the right to safe water at an affordable price in industrialized countries. They initially provided free water to all as a symbol of solidarity; when they were introduced, the operator had to support the expenses of the stand post in exchange for the right to lay pipes under the street and to sell water to customers requiring a connection.

Today in countries with extensive water networks, new fountains are still created as a social symbol and also for providing water at an affordable price especially for homeless people. Water stand posts are being installed in transition countries and in developing countries such as Uganda (one stand post for 300 people).

Users in some countries have to pay a small fee to the custodian of the equipment. Some municipalities would prefer to close them down because they are "costly", create a price inequality or attract "wrong" people. They consider that a valuable good should not be provided without payment and object to what they describe as unfair competition for the water distributor. International financial institutions are said to suggest the closing down of stand posts in some developing countries where water prices have been increasing. On the reverse, stand posts are seen as the only available system to provide water when networks are not sufficiently developed. Stand posts with magnetic card are being developed in Morocco and South Africa to provide a free water allowance to poor households and to avoid water wastage.

It is up to responsible authorities to make the choice of an unaffordability limit for water. Some countries will take no measure to make water more affordable while other countries will provide help for other essential goods and services. On the basis of collected evidence, it may be guessed that countries which act to bring down the affordability index for water are likely to bring the index for poor people to 3% in industrialized countries or to 5% in developing countries. The real issue is not to adopt such a figure as an objective but to develop the corresponding social measures in favour of poor people. Many developing countries are not using targeted systems for water because they lack a developed social security system. The tariff approach is not always usable because metering is unreliable or inexistent.

VIII – Conclusions

In a number of countries, public authorities seek to maintain the water affordability index of poor households below 3 to 7% of their disposable income. Lower values of this range are used in developed countries. In developing countries higher values are often found. Affordability indices exceeding 10% are observed for a small minority of poor people. While affordability benchmarks of 3 to 5% are promoted by international organisations, such limits will not be achieved unless targeted social measures are implemented and funded. In some cases such benchmarks are not realistic at all because in order to implement them there would be a need to provide aid for water to a large fraction of the population.

Measures to make water more affordable for the most deprived people have been taken in many countries but not in all countries. There are well-designed social tariffs or targeted aids in a number of countries. However many developing countries have taken no action on affordability issues except by providing subsidies for water services that help affluent people to pay water they could have paid themselves. While such subsidies are can be useful, they should be directed to people those without access to water or sanitation rather than to those with access to water.

To support access to water and sanitation for all and to be able to increase, if need be, the price of water and sanitation without creating social problems, public authorities should consider the following actions :

a) to introduce explicitly in the internal law the principle that drinking water should be affordable to all;

b) to adopt a definition of the water affordability index and assess it in various regions for various groups of population;

c) to promote discussions on the choice of appropriate measures for water tariffs or targeted aid in line with the users wishes and on the financing of these measures in order for water to be affordable to all bearing in mind other necessary household expenses;

d) to examine if bodies in charge of water tariffs are legally entitled to introduce differentiated tariffs, social tariffs or other systems of targeted aid to facilitate access to water for poor households;

e) to develop the various elements of a social policy for water aimed at implementing the principle of affordable water for all and report on the implementation of this policy.

Acknowledgments

This paper is based on the book “De l’eau potable à un prix abordable” published by the Water Academy in 2008 (see www.water-academy.org). This book provides statistical evidence on affordability indices, a description of various mechanisms used to improve water affordability in over 40 States, a detailed case study on water affordability in France where it is shown that this country is operating a system which decreases water expenses of poor households from 4 - 5% down to 2.4 - 3% of their disposable income. A detailed analysis of water affordability in international law and in national legislations is also presented.

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[1] We use household figures because most users are households with at least 2 persons. The standard consumption of 120 m^3 generally relates to a household of 3 persons or more. Water consumption and expenses of individuals (households of one) are higher.

An operational direct model to accurately determine crop evapotranspiration of crops cultivated in the Mediterranean region

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Abstract. Two methods can be considered as able to determine *E* for well irrigated crops. The first method is indirect (the "crop coefficient approach"). It is based on the knowledge of a crop coefficient, K_c, and an estimation of the reference evapotranspiration of grass E_0 . The second method directly calculates the *E* of a crop, without a step through a reference surface. It similarly applies a Penman-Monteith type formula. However, in this method the canopy resistance, r_c, is specific for each species, it is not constant but variable as a function of climatic characteristics of the atmosphere below the top of the boundary layer above the crop. This study proposes to explore and to test a more operational version of the direct model. In this version, the canopy resistance r_c will be considered as constant but specific for each crop. The performances of this method are evaluated with respect to the above cited direct and indirect methods, by means of experimental validation carried out on 3 crops having contrasted height. The best performance was given by the original version of the direct model, both at daily and hourly scales. The operational version of the direct model gave acceptable results only for grass. The indirect model gave the worst results both at daily and hourly scales. The practical use of this new version is discussed in the conclusions.

Keywords. Canopy resistance – Height crop – Penman-Monteith formulation – Vapour pressure deficit – Aerodynamic resistance.

Un modèle opérationnel direct pour déterminer correctement l'évapotranspiration des cultures en Région méditerranéenne

Résumé. *Il existe deux méthodes pour déterminer correctement l'E des cultures irriguées. La première méthode est indirecte (l' « approche coefficient cultural »). Elle repose sur la connaissance d'un coefficient cultural,* K_c*, et sur l'évaluation de l'évapotranspiration de référence du gazon* E_0*. La seconde méthode calcule directement l'E d'une culture, sans considérer la surface de référence. Ella applique la formule du type Penman-Monteith. Cependant, dans cette méthode, la résistance du feuillage,* r_c*, est spécifique pour chaque espèce ; elle n'est pas constante mais varie en fonction des caractéristiques climatiques de l'atmosphère sous la partie supérieure de la couche limite au-dessus de la culture. Le but de la présente étude est d'explorer et de tester une version plus opérationnelle du modèle direct. Dans cette version, la résistance du feuillage,* r_c*, est considérée comme constante, mais spécifique pour chaque culture. La performance de cette méthode est évaluée par rapport aux méthodes directe et indirecte qu'on vient de citer, à travers la validation expérimentale sur trois cultures ayant une différente hauteur. La meilleure performance est obtenue par la version originale du modèle directe à l'échelle journalière et horaire. La version opérationnelle du modèle direct a donné des résultats acceptables seulement pour le gazon. Le modèle indirect a donné les résultats les plus mauvais à l'échelle journalière et horaire. Enfin, l'application pratique de cette nouvelle version est illustrée dans les conclusions.*

Mots-clés. *Résistance du feuillage – Hauteur de la culture – Formule de Penman-Monteith – Déficit de pression de vapeur – Résistance aérodynamique.*

I – Introduction

The evapotranspiration (*E*) of an irrigated crop can be calculated directly by using the Penman-Monteith formula with a specific value of the crop resistance and the meteorological variables measured above the canopy. In practice, the use of this formulation needs, for each species, specific modelling of the canopy resistance (r_c) in relation to the environmental variables (Katerji and Perrier, 1983; Katerji and Rana, 2008). The direct calculation of *E,* compared to micrometeorological methods and weighing lysimeter, is considered the best way to estimate correctly the actual *E* (see the review by Katerji and Rana, 2008). Nevertheless, this way to calculate *E* has been considered too complex to be used in practice, since it needs the modelling of the canopy resistance r_c specific for each cropped surface. At the moment, this constraint, together with the need of determining the climatic variables above the given crop, leads to consider this direct method as not much operational.

From the application point of view, the calculation of the crop *E* is usually made by the formulation by Allen *et al.* (1998). It is an indirect calculation; in fact *E* is determined by the following relationship:

$$E = K_c E_0 \tag{1}$$

In this formulation, E_0 is the reference evapotranspiration and K_c is the crop coefficient.

Following a critical revision, the more recent FAO no. 56 paper (Allen *et al.*, 1998) redefined the concept of E_0 and adopted the Penman-Monteith equation adapted to a grass crop. Anyway, the authors simplified the procedure to calculate the resistance r_c for the grass. In fact, this was considered constant in all climatic conditions and takes a fixed value in the Penman-Monteith formula. The accuracy of the *E* values determined by the Eq. (1) depends on two factors. Firstly, on the accuracy of the determination of E_0 as carried out by the users in different geographical sites; then, on the accuracy of the K_c values. These values were given by Allen *et al.* (1998) for three stages of crop growth cycle (initial, middle and end) for the main cultivated crops.

The hypothesis of a constant resistance r_c in the determination of E_0 for the grass could be a possible source of error. However, some studies showed that this hypothesis gave acceptable estimation of E_0 in different regions of the world (Allen *et al.*, 1994a, 1994b). Other studies, mainly carried out in semi-arid and arid regions, showed opposite results, i.e. that the previously mentioned hypothesis underestimated, except for a few exceptions the values of E_0 as measured by lysimeters (see the results obtained by Steduto *et al.* 1996 in Morocco). The under-estimation ranged between 2 and 18% (Rana *et al.*, 1994; Steduto *et al.*, 1996; Ventura *et al.*, 1999; Lecina *et al.*, 2003; Pereira, 2005). Moreover, in humid regions, de Medeiros *et al.*, (2006) observed that the hypothesis of a constant r_c leads to a 13.4% over-estimation of the E_0 measured by lysimeter. Anyway, since the experimental error of the direct measurement of E_0 by the lysimeter is about 15% (Katerji and Rana, 2008), the performance of this method seems to be reasonable. Therefore, the approach proposed by Allen *et al.* (1998) merits the attention of researchers.

The second source of possible error concerns the values of K_c. Actually, these values showed more or less important differences with respect to the experimentally determined values of the E/E_0 relationship. Many papers can be found on this subject in the scientific literature. If we consider only the more recent literature (Testi *et al.*, 2004; Parkes *et al.*, 2005; Rana *et al.*, 2005; Lovelli *et al.*, 2005; Amayreh and Al-Abed, 2005; Kar and Verma, 2005; Vu *et al.*, 2005; de Medeiros *et al.* 2006), it is possible to find differences of ±40% between the K_c values reported by Allen *et al.* (1998) and the values experimentally obtained, especially during the middle growth cycle. These big differences are mainly due to the complexity of the coefficient K_c, which actually integrates several functions (Testi *et al.*, 2004): aerodynamic factors linked to the height of the crop, biological factors linked to the growth and senescence of the leaves, physical factors linked to the evaporation from the soil, physiological factors linked to the response of the stomata to the air vapour pressure deficit and agronomical factors linked to the crop management (distance between rows, using mulch, irrigation system, etc.). For this reason, Allen *et al.*, (1998) recommended that the evaluation of K_c values in local climatic conditions by observed data using lysimeters is necessary. Nevertheless, the simple local determination of K_c is not enough if general values of

K_c are required. Therefore, it is necessary to search for the relationships between K_c and more or less complex parameters, such as the surface area of the leaves, the humidity of the soil surface and the 3D energy balance (Testi *et al.*, 2004; Orgaz *et al.*, 2005; Lovelli *et al.*, 2005; Kar and Verma, 2005; Luquel *et al.*, 2005).

Following such a review of the indirect calculation of *E*, some researchers underlined (Testi *et al.*, 2004) or experimentally demonstrated (Rana *et al.*, 2005) the interest in the direct evaluation of *E*. This evaluation used the one-step approach as opposed to the two-step approach of the Eq. (1). Since it is based on a lower number of computation steps and on a lower number of error sources, the one-step approach can provide a more accurate estimation of *E*.

In the present paper, the original model proposed by Katerji and Perrier (1983), based on the hypothesis of a variable canopy resistance, will be recalled. In the following, we propose a second more operational version of the model, in which the hypothesis of a constant r_c was adopted for well watered crops, according to the approach proposed by Allen *et al.* (1998). To our knowledge, this is the first attempt to make the direct model for calculation the actual evapotranspiration more operational. This new version, in contrast with the original one, does not need the modelling of the canopy resistance. The comparison between measured and simulated *E* values with the above mentioned model will be carried out in a semi-arid region, at two time scales (hour and day), for 3 irrigated crops having contrasted height. This comparison will be evaluated with respect to another one, for the same crops at daily scale, between measured and calculated *E* using the standard FAO 56 method. In the following, we demonstrate that the studied crops showed a higher or lower sensitivity to the vapour pressure deficit of the air, which strongly characterised the climate of the semi-arid regions (Rana and Katerji, 1998).

In conclusion, a proposal for simplifying the direct model is given for application in the Mediterranean region.

II – Materials and methods

1. The direct model

The analysis of the crop actual evapotranspiration was made on the basis of the Penman-Monteith model. In this model, which is applicable to the hourly time scale, *E* is written as:

$$E = \frac{1}{\lambda} \frac{\Delta A + \rho c_p D / r_a}{\Delta + \gamma (1 + r_c / r_a)} \tag{2}$$

where A=Rn-G is the available energy (W m-2), ρ is the air density (kg m-3), Δ is the slope of the saturation pressure deficit versus temperature function (kPa C-1), γ is the psychrometric constant (kPa C-1), cp is the specific heat of moist air (J kg-1 C-1), D the vapour pressure deficit of the air (kPa), rc is the bulk canopy resistance (s m-1) and ra is the aerodynamic resistance (s m-1), λ is the latent heat of evaporation (J kg-1). The resistance ra was calculated between the top of the crop and a reference point z sited in the boundary layer above the canopy, following Perrier (1975), as:

$$r_a = \frac{\ln \frac{z-d}{z_0} \ln \frac{z-d}{h_c - d}}{k^2 u_z} \tag{3}$$

where d (m), the zero plane displacement, is estimated by d=0.67 hc, with hc mean height of the crop (m); k is the von Kármán constant, uz is the wind speed (m s-1) at the reference point z above the canopy, z0 (m) the roughness length estimated by z0=0.1hc.

The hourly variation of rc can be simulated starting from a relationship, which takes into account the associated effects of solar radiation, air vapour pressure deficit and wind speed. Katerji and Perrier (1983) proposed to simulate the resistance rc by the following relation:

$$\frac{r_c}{r_a} = a\frac{r^*}{r_a} + b \tag{4}$$

where a and b are empirical calibration coefficients which require experimental determination. r* (s m-1) is written as:

$$r^* = \frac{\Delta + \gamma}{\Delta\gamma}\frac{\rho c_p D}{A} \tag{5}$$

It can be considered as a “climatic” resistance, because it depends only on weather variables.

This model has been used to calculate E for different species: (see review in Katerji and Rana, 2008) Therefore, from the above analysis, two models of direct E calculation are tested in this work: in the first version (model 1), by adopting the hypothesis of a variable rc during the day by combination of Eqs. (2) and (4). It can be written as:

$$E = \frac{1}{\lambda}\frac{\Delta A + \rho c_p D / r_a}{\Delta + \gamma\left(a\frac{r^*}{r_a} + b\right)} \tag{6}$$

In the second more operational version (model 2), by adopting the hypothesis of rc constant during the day. In this case, the hourly E can be written as:

$$E = \frac{1}{\lambda}\frac{\Delta A + \rho c_p D / r_a}{\Delta + \gamma\left(1 + \frac{\overline{r_c}}{r_a}\right)} \tag{7}$$

The sensitivity analysis of the Penman-Monteith model is the analysis, at hourly scale, of the weight of each input variable A, D, rc and ra on the output variable E. Following the studies of the sensitivity made in the last decades, the weight of the resistance rc depends on two factors:

the height of the crops in the formulation of the aerodynamic resistance ra (Beven, 1979). This decreases when the height of the crop increases (see Eq. (3));

the soil water conditions of the crops (Rana and Katerji, 1998) which determines the values of rc, for a given micrometeorological condition.

Starting from a sensitivity analysis carried out on three crops (grass, grain sorghum, sweet sorghum) with different increasing heights of 0.1, 1 and 3 m respectively, Rana and Katerji (1998) gave the weight of each input variable on the calculated E. In fact, from this paper it can be argued that, in the case of well watered crops, rc is responsible of 10-20% (case of grass) and 40-50% (case of grain and sweet sorghum) of the E variation. In the case of water stress conditions, the variable rc is a dominant parameter in the variation of E, since it explains from 70% (grain sorghum) to 90% (sweet sorghum) of the E variation. In well watered conditions, the sensitivity of E to the input variables A and D varies also as a function of the crop height. The variable A explains 60-70% of the hourly E in the grass crop. Furthermore, the variable D explains 50% (grain sorghum) and 65% (sweet sorghum) of the hourly E. This analysis underlines a very important fact: in the case of well-watered crops the same error in the determination of rc can give errors in the estimation of E which increases as the height of the crop increases. Therefore, the different models for the estimation of E have to be validated on a large range of crops with variable height in order to define their suitability.

The two versions of the direct model can be applied both at hourly and daily scales.

2. The indirect model

In this case, the actual evapotranspiration was estimated by the Eq. (1). The reference evapotranspiration E0 was estimated by the following equation, as recommended by Allen *et al.*, (1998):

$$E_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma \dfrac{900}{T + 273} u_2 D}{\Delta + \gamma\left(1 + 0.34 u_2\right)} \tag{7}$$

Where the energetic terms Rn, G and E0 are in (MJ m-2 day-1); the other variables T (°C) and u2 (m s-1) are the air temperature and the wind speed measured at 2 m, respectively. The net radiation Rn and the soil heat flux G in this case were measured.

The coefficient Kc, for each crop, was taken for 4 growth periods from the same paper, following the “single crop coefficient” approach. The calculation of E using the standard FAO 56 method can be made only at daily time scale.

3. The site and the crops

This study was carried at a site of Southern Italy (Rutigliano, Bari, 41°0’ N, 17°54’ E, 122 m a.s.l.). The climate in Rutigliano is characterised by hot dry summers, with maximum air temperature sometimes higher than 40 °C and minimum relative air humidity often less than 20%. Mean annual rainfall is 500 mm, almost exclusively concentrated in spring and autumn.

The experiments were carried out on 3 well watered crops: grass, grain and sweet sorghum. These are annual crops (except grass) cultivated during the summer. These crops are different in height in the range of 0.1 – 3 m. For grain sorghum, the experimental period concerned only the phase when the crop completely covers the soil (LAI>2); for sweet sorghum the experimental period also included the installation phase (LAI≤2). Therefore, the problem of partially covering crops is taken into account in this study.

For grass, measurements were taken in a field of grass (*Lolium perenne* L., var. Barvestra); it completely covered the soil and was from 0.07 to 0.15 m high. The meadow was well irrigated so that the soil water content was always near field capacity. Measurements were taken in 1994 and 1995. Actual E was measured by weighing lysimeter. Details of the experiment can be found in Rana *et al.* (1994).

The grain sorghum (*Sorghum bicolor* L. Moench, cv. Aralba) was sown on 2 May 1991, with a plant density at harvest of 20 plants/m^2, in a plot of 2 ha (200 x 100 m), the distance between rows being 0.5 m. By means of drip irrigation, water was uniformly distributed all over the field. The actual E was measured by energy balance/Bowen ratio method. Details of the experiment can be found in Rana *et al.* (1997a).

The sweet sorghum (*Sorghum vulgare* L., cv. Saccharatum) field has a surface of about 4 ha, with a density of about 12 plants m-2, the distance between adjacent rows was 0.6 m and the mean distance between the plants on a row was 0.12 m; the fetch from the field edge to the micrometeorological instrumentation was about 200 m in the direction of the predominant wind (NNW). The crop was maintained under well watered conditions. The actual E was measured by energy balance/Bowen ratio method. Details about the experiment can be found in Rana *et al.* (2001).

III – Results and discussion

1. Calibration of the models

The calibration of the models was carried out using the hourly data of rc, determined during two clear days casually chosen during the experiment period. The calculation of rc was carried out by introducing the hourly data of the measured E in the Eq. (2). Figure 1 shows the hourly values of rc for the 3 crops. In general, the resistance rc showed a standard evolution during the day. It decreased from sunrise with increasing solar radiation, to reach the minimum value around 8 – 9:00 a.m.. When the solar radiation decreased again in the afternoon around 3-4:00 p.m. then the rc values increased again. Between 9:00 a.m. and 3:00 p.m., the canopy resistance varied very little in the grass crop, which is a low crop having a very high aerodynamic resistance ra. On the other hand, rc in the sweet sorghum crop, characterised by a great height and a small ra, varied significantly from 12:00 to 3:00 p.m. This was interpreted as the response of the stomata to the air vapour pressure deficit (Ferreira and Katerji, 1992). The grain sorghum showed an intermediate situation between the grass and the sweet sorghum.

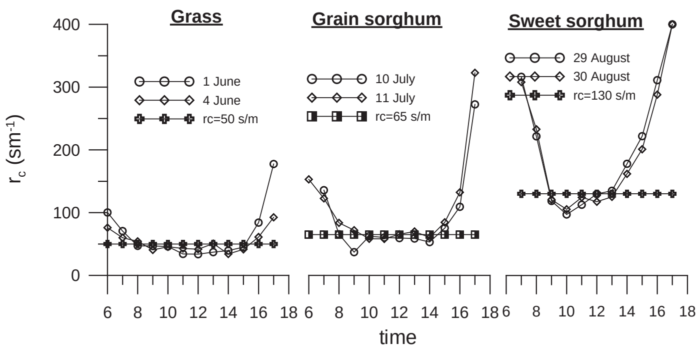

Figure 1. The measured crop resistance rc for two clear days, for the three studied crops, together with mean daily values.

The calibration of the direct model needs the determination, for each species and during the two days casually chosen for the calibration, the relation rc/ra as a function of r*/ra. Figure 2 presents, as an example, the relation found for grass. Table 1 also presents all the relations for the 3 studied crops. The mean values of the hourly rc found in the present study for the grass is about 50 s m-1 and it is in the range of values found in the literature for this species. These values ranged between 30 and 70 s m-1 (Wright *et al.*, 2002; Ventura *et al.*, 1999; Lecina *et al.*, 2003). The hypothesis followed by Allen *et al.* 1998 that rc should be constant in the different climatic conditions is not verified in practice. In the case of the other annual crops, the mean values found in the present study (between 65 and 130 s m-1) are generally greater than those found in the literature. From the current analysis it is suggested that the air vapour pressure deficit must play a major role in the environments of the region where this work was carried out, particularly for tall crops, like the sweet sorghum, compared to grass.

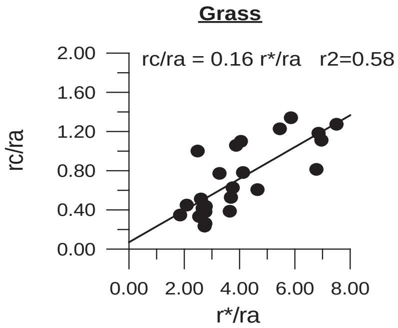

Figure 2. Relationship between the ratio rc/ra and r*/ra, at hourly scale, for the grass.

Table 1. Summary of the crop characteristics and values of coefficient a et b(see eq. 4) obtained by calibration for each studied crop.

Crop	Experimental Period	Height (m)	LAI	E measurement Method	a	B	R2
Grass	1/06 – 21/09	0.07-0.15	2 – 2.5	Weighing lysimeter	0.16	0	0.58
Grain sorghum	9/07 – 27/08	1	3.8 - 4.2	Bowen ratio	0.54	0.61	0.43
Sweet sorghum	20/04 – 18/10	1.5 – 2.8	1 – 6.4	Bowen ratio	0.845	1	0.88

Validation of the models

Figure 3 presents the comparison between hourly values of E simulated by model 1 and measured E, for the 3 studied crops. Here, as for in the other linear regressions, the intercept is fixed to 0 if it is not significantly different from 0.

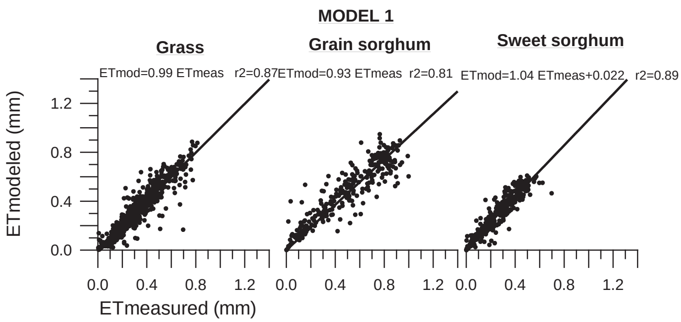

Figure 3. Comparison between measured and calculated evapotranspiration by the model 1 at hourly scale, for the three studied crops.

In all the cases, model 1 works pretty well. Therefore, the hypothesis of a variable resistance rc taken into account in the model 1 satisfactorily agrees with the hourly E measured in all the studied situations. Figure 4 shows, for the same crops, the comparison between hourly values of E simulated by model 2 and measured E. In the grass crop, the observed correlation is good, but the slope of the linear regression is around 0.85 instead of 0.99 for the case of model 1. For the other 2 studied crops, model 2 generally overestimates the actual E: furthermore, the slopes and the correlation coefficients are not satisfactory. Since the experimental error in the determination of the hourly E is about 15% (Katerji and Rana, 2008), the hypothesis in model 2 of a constant canopy resistance, locally determined, can be considered acceptable only in the case of the grass crop.

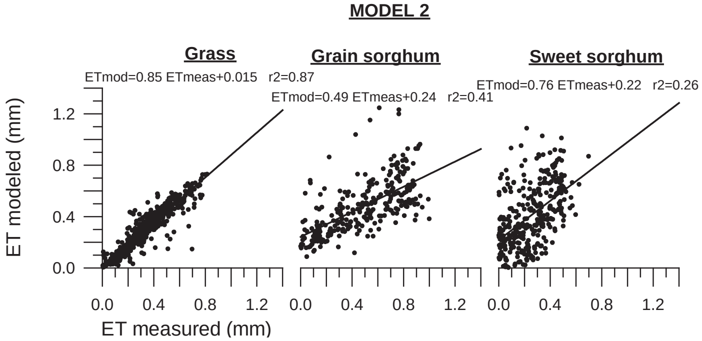

Figure 4. Comparison between measured and calculated evapotranspiration by model 2 at hourly scale, for the three studied crops.

Daily scale

The daily values E estimated by models 1 and 2 have been calculated by the sum of the hourly values simulated by the same models, from 8:00 a.m. to 6:00 p.m., for each day.

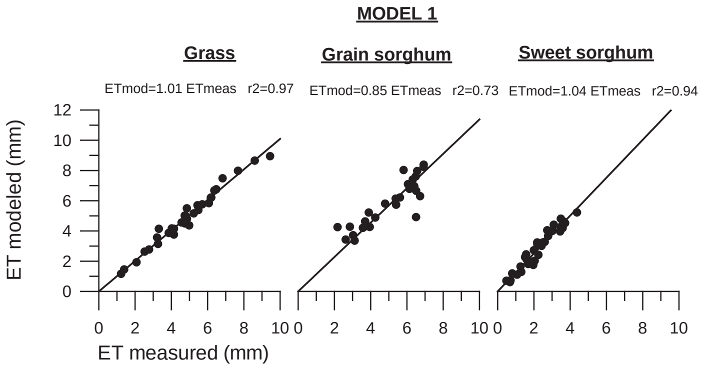

Figure 5. Comparison between measured and calculated evapotranspiration by model 1 at daily scale, for the three studies crops.

Figure 5 presents the comparison between E daily values simulated by model 1 and measured in the same period, for the studied crops. In summary, the calculation of the daily E made by model 1 gave acceptable results. Figure 6 shows the comparison between daily E measured and simulated by model 2. In this case the daily simulation of E is satisfactory only for grass. For the other studied species, the calculation is not acceptable. Figure 7 shows the comparison between daily E measured and calculated by the standard FAO 56 method. In the grass crop, the observed correlation is good, but the slope of the linear regression is around 0.78 instead of 0.99 for the case of model 1. In the case of sweet sorghum, the slope of the regression is correct, but the coefficients of correlation are low (R2=0.53). For the other crop, the slopes and the correlation coefficients are not satisfactory.

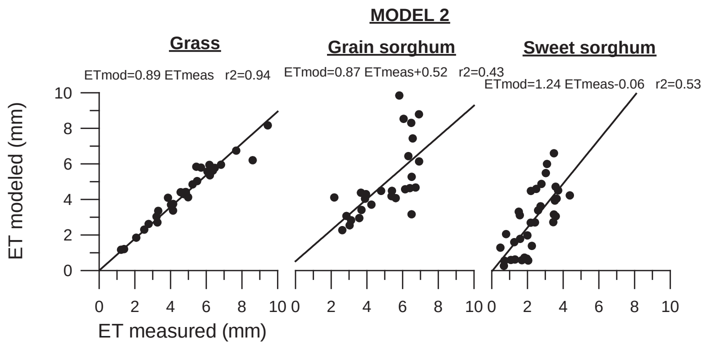

Figure 6. Comparison between measured and calculated evapotranspiration by model 2 at daily scale, for the three studied crops.

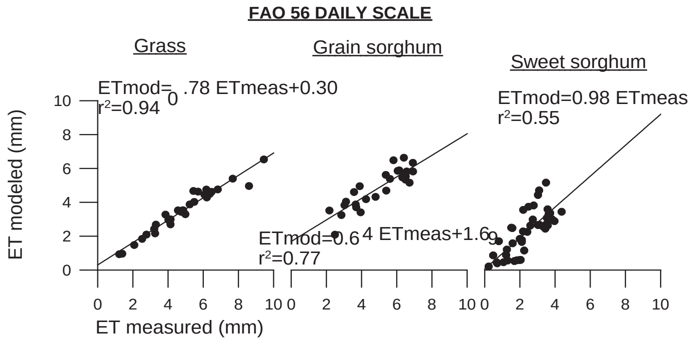

Figure 7. Comparison between measured and calculated evapotranspiration by the FAO 56 using the standard single crop coefficient approach at daily scale, for the three studied crops.

IV – Conclusions

From many works in the scientific literature, the calculation of the crop evapotranspiration by direct models seems to be more accurate than the indirect models in the calculation of the crop water requirements. The intermediate calculations of E0 and Kc needed for the indirect calculations generates significant errors, as shown in the bibliographic review presented in the introduction of this paper and the results presented in Figure 6.

Two approaches, here presented, are possible for calculating directly the E:

In the first one (model 1) the canopy resistance has been modelled as a function of three climatic variables. We checked the performances of this model for 3 crops grown in a semi-arid region, where the sensitivity of the crops to the air vapour pressure deficit is greater than in the case of humid and semi-humid environments. The results are satisfactory both at hourly and daily scales for all the studied crops. Another important advantage of the direct model 1 is the possibility to extend the modelling of E to other sites and places (Rana *et al.*, 1997b; 2001). The only difficulty of this approach is due to the necessity of modelling of the canopy resistance rc.

The second more operational approach (model 2) is based on the assumption that the canopy resistance of every crop in well-watered conditions can be considered constant. The experimental verification showed that the E is much less accurate than using model 1. The model 2 particularly failed in certain days, when the canopy resistance, rc, varied significantly during the day, mainly in the case of tall crops. Nevertheless, it gave acceptable results in the case of low crops: i.e. the grass (at hourly and daily sales). This can be due to two main reasons:

low crops have a large aerodynamic resistance ra. So these have a weak stomatal response to the variations of the air vapour pressure deficit. In this case, local calibration of the mean daily resistance rc represents an acceptable value of the single hourly resistance.

In general, for low crops, the weight of the canopy resistance rc is low in the calculation of E. Therefore, a large error in the determination of rc has a small impact in the calculation of E.

Nevertheless, the necessity of the local determination of rc deprives this approach of its main advantage. So we think that it is more interesting to model the resistance rc as for model 1. Moreover, this modelling does not need the determination of supplementary parameters or input variables. On the contrary, it increases the accuracy of the calculated E also in the case of tall crops. However, the direct models need the measurement of weather variables above the crop, not easily feasible in routine. Thus, it is surely interesting to study another further version of the model which needs the determination of the weather variables collected in a standard agro-meteorological station. This last path of research, permitting to obtain an analogous more operational version of the direct model, has been recently studied by Rana and Katerji (2009). Actually, these authors showed that it is possible to determine E with high accuracy, at least at daily scale, on a large range of crops, simply using climatic variables collected in a standard agro-meteorological station.

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Estimating and monitoring seasonal water consumption of olive orchards in a semi-arid region (Morocco) using the Eddy-covariance system

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Abstract. Planning and management of water resources have become a very important issue in arid and semi-arid regions. Accurate measurements of heat and water fluxes are required for optimizing water management and for validating models simulating crop water consumption. For the olive orchard, which is the dominant crop in Mediterranean regions, very little information exists on the exchange of heat and water fluxes between the vegetation and the atmosphere. In the context of SUDMED project, an experimental setup was conceived to monitor seasonal water consumption of olive orchards located near Marrakech, Morocco. For this purpose, an Eddy-Covariance (EC) system, a meteorological station, as well as measurements of soil moisture and temperature were continuously operated during more than one year over an irrigated olive yard, i.e. tall, sparse vegetation. The total annual rainfall and irrigation amount were around 354 and 800 mm respectively. The yearly cumulative evapotranspiration measured from eddy-covariance system was 824 mm. By using the water balance equation, the result showed also that a large quantity of water (around 330 mm) was lost due to deep percolation, infiltration and runoff. This loss is essentially due to the irrigation method (flood) which has an irregular pattern in space and time. On the other hand, the water requirements calculated following the FAO-56 procedure were 920 mm. Although the sum of irrigation and rainfall was greater than ET_c, the stress event occurred. Such behaviour can be explained by the fact that the irrigation monitoring is done by observing the physical conditions of the plant which is not sufficient to manage the irrigation.

Keywords. Eddy Covariance – Evapotranspiration – Energy Balance – Olive-Flood Irrigation – Water Balance.

Evaluation et suivi de la consommation saisonnière d'eau dans les vergers d'olivier en région semi-aride (Maroc) utilisant la méthode covariance turbulence

Résumé. *La planification et la gestion des ressources en eau est devenue une question de toute première importance dans les régions arides et semi-arides. La mesure correcte de la chaleur et des flux hydriques est indispensable pour optimiser la gestion de l'eau et valider les modèles qui simulent la consommation d'eau pour les différentes cultures. Quant à l'olivier, qui est la culture dominante en Méditerranée, les informations sur l'échange de chaleur et les flux hydriques entre la végétation et l'atmosphère restent insuffisantes. Par conséquent, dans le cadre du projet SUDMED, un dessein expérimental a été mis au point pour suivre la consommation saisonnière d'eau dans les vergers d'olivier de la zone autour de Marrakech, au Maroc. A cette fin, la méthode covariance turbulence a été appliquée et des données météorologiques et des mesures de l'humidité du sol et de la température ont été suivies pendant plus d'un an sur un couvert végétal clairsemé et développé en hauteur. Au total, les précipitations annuelles et la quantité d'eau apportée par l'irrigation ont été estimées à 354 et 800 mm, respectivement. L'évapotranspiration cumulative annuelle, mesurée par la méthode covariance turbulence, était égale à 824 mm. Les résultats obtenus en appliquant l'équation du bilan hydrique ont montré qu'une grande partie de l'eau (environ 330 mm) était perdue à cause des effets de la percolation profonde, de l'infiltration et du ruissellement. Ces pertes étaient essentiellement imputables à la méthode d'irrigation (par déversement) utilisée qui suivait un cours irrégulier dans l'espace et dans le temps. Par ailleurs, les besoins en eau estimés par la procédure FAO-56 s'élevaient à 920 mm. Bien que l'eau* *d'irrigation et les précipitations ensemble soient plus élevées qu' ET_c, un problème de stress est intervenu. Un tel phénomène peut être expliqué par le fait que le suivi de l'irrigation a été réalisé en n'observant que les conditions physiques de la plante, ce qui n'est pas du tout suffisant pour gérer l'irrigation.*

***Mots-clés.** Covariance turbulence – Evapotranspiration – Bilan énergétique – Olivier-Irrigation par déversement – Bilan hydrique.*

I – Introduction

In arid and semi-arid regions, water availability is a serious limitation for crop production due to poor and irregular rainfall, high evaporative demand and inadequate management. Morocco which is classified as part of these regions suffers from limited water supply and water resources. Therefore, to manage this scarce resource under those conditions, the farmers should know at least two aspects: when do they have to irrigate and how much water do they have to apply on the ground?

Cereals and orchards are the dominating crops types in Morocco. This agriculture uses up to 80% of the total available water. Olive is the main component of the orchard, due to its resistance to drought; therefore the monitoring of olive irrigation and water balance at a regional scale is a major challenge for a sustainable development of agriculture. In this regard, the Sudmed (Chehbouni *et al.*, 2004) and Irrimed (http://www.irrimed.org) projects focus on the south Mediterranean regions within the Tensift river basin (Central Morocco) as a main region of interest. The basin size is about 30000 km^2 which includes the Atlas mountain range (headwater) and the semi-arid Haouz plain in the surrounding of the city of Marrakech. The plain spreads on a surface of 4500 km^2. In this region, the climate is characterized by low and irregular rainfall with an annual average of about 240 mm, whereas the evaporative demand is very high, around 1600 mm per year according to reference evapotranspiration estimates (Allen *et al.*, 1998). The Haouz plain contains about 85392 ha of olive and they plan to increase the surface to 95000 ha in 2010. A fundamental requirement for accurate irrigation scheduling is the determination of actual olive evapotranspiration. The most common method to calculate the evapotranspiration (ET) is a meteorological method such as Eddy-covariance, Bowen Ratio, water balance method, and sap flow combined with isotopic method. The scientific efforts in measuring or estimating the evapotranspiration of olive orchards or its components are all quite recent. Testi *et al.* (2004) used the Eddy-covariance technique which allows a direct measurement for the evapotranspiration for three years for assessing the ET of a young irrigated olive orchard in south Spain. Williams *et al.* (2004) used the sap flow method to measure the plant transpiration combined with the isotopic method to infer the evapotranspiration over olive orchards in current study area (olive yard of Agdal, Marrakech). The ET can be also simulated by using the FAO-56 model which is based on the concepts of reference evapotranspiration ET_0 and crop coefficients K_c (for more details, the reader can refer to Allen *et al.*,1998).

In this study, we used the Eddy-covariance system to measure the evapotranspiration over the olive orchards. This site is specific in several ways: the irrigation method (flood) which has an irregular pattern in space and time, heterogeneity along the site mainly caused by vegetation cover and the soil characteristics, and the surrounding orange orchards and buildings.

The objective of this paper is two-fold: 1) To analyze the energy-balance closure and seasonal variation in the olive evapotranspiration. 2) To investigate the feasibility of using the Eddy-covariance system to monitor water consumption of olive orchards. The paper is organized as follows: the area of interest and experimental data set are presented first. Then field data are analyzed. Lastly, we conclude by discussing the potential of the eddy-covariance system to monitor the water consumption over semi arid land.

II – Site description and experimental setup

The present study took place in a semi-arid basin in central Morocco (Tensift basin, see Fig. 1) within the framework of the SUDMED Program (http://www.irrimed.org/sudmed). In this region, the climate is a typical semiarid Mediterranean; precipitation falls mainly during winter and spring, from the beginning of November until the end of April with an average ranging from 192mm to 253mm. The atmosphere is very dry with an average humidity of 56% and high evaporative demand (1600mm per year), greatly exceeding the annual rainfall. The experiment was carried out between Day Of Year (DOY) 323 in 2002 and DOY 323 in 2003, at the 275 ha Agdal olive orchard, located southeastern of the Marrakech city, Morocco (31°36' N, 07°58' W). The average height of the olive trees is 6m with an average coverage that reaches approximately 55%. Two water basins are used for irrigation. Water is diverted manually to every tree through a network of ditches, each tree is surrounded by a small earthen levy that retains the irrigation water, allowing application of irrigation water to every tree. The amount of water used during each irrigation event was about 80 mm. Irrigation starts on the southern border of the field, and, depending on the available manpower, progresses towards the northern border of the site in approximately 12 days.

The field was equipped with a set of standard meteorological instruments to measure wind speed and direction (Young Wp200), air temperature and humidity using vaisala HMP45AC probes at 9 and 3.7m and radiation. The net radiation side was measured using a CNR1 (Kipp & Zonen) placed at 8.5m. The soil heat flux density was measured using heat flux plates (HFT3-L, Campbell Scientific Ltd.) at three locations differing in amount of radiation reaching the soil. The measurement depth was 1 cm. The plates were placed: one below the tree near the trunk in order not to be exposed to solar radiation; one was exposed directly to solar radiation, the last one in an intermediate position. An average of these 3 measurements was made to obtain a representative value. Soil moisture was measured at different depths (5, 10, 20, 30 and 40cm) using 5 CS616 water content reflectometers (Campbell Scientific Ltd.). All meteorological measurements were sampled at 1 Hz and averaged over 30 minutes. The prevailing wind direction is northwest.

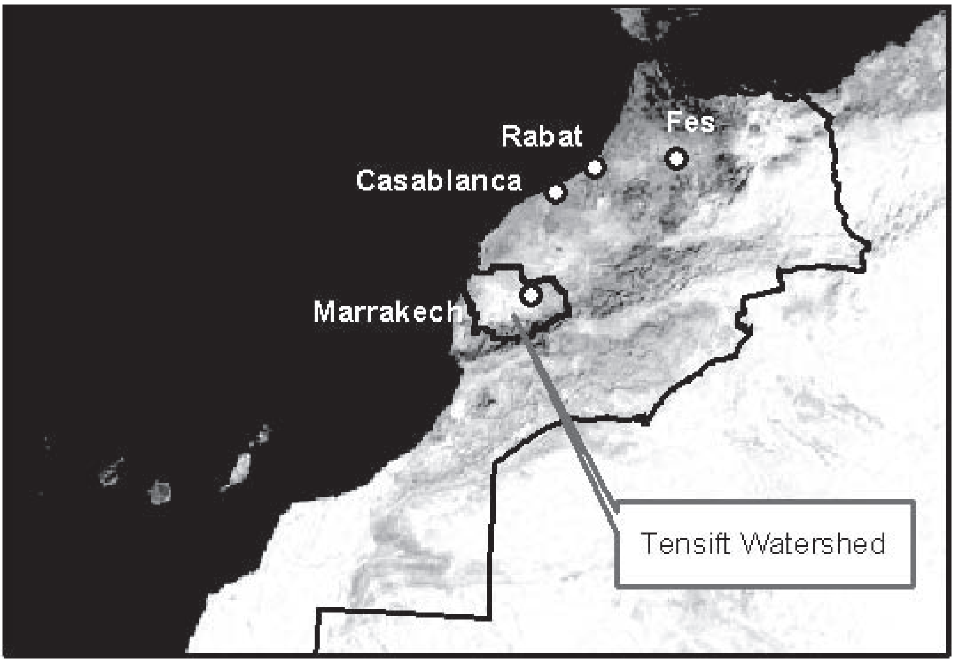

Figure 1. The study area.

An eddy-correlation system (EC) was installed to provide continuous measurements of vertical fluxes of heat, water vapour and carbon dioxide CO_2 at 3 m above the top of the canopy on the 9.2m tall instrument tower (see figure1). The EC system consisted of a 3D sonic anemometer (CSAT3, Campbell scientific Ltd.) which measured the fluctuations in the wind velocity components and temperature, and an open-path infra-red gas analyzer (Li7500, Licor, Inc.) that measured concentration of water vapour and carbon dioxide. A CR5000 datalogger (Campbell Scientific Ltd) was used for the storage of raw 10 Hz data. The half-hourly values of fluxes were later calculated using the software 'ec-pack' developed by the Meteorology and Air Quality group at Wageningen University. The software is available for download at http://www.met.wau.nl/. The annual evolution of daily reference evapotranspiration ET_0 calculated following the FAO-Penman-Monteith (Allen *et al.* 1998) during the experiment was presented in Figure 2. As can be seen in this figure, the temporal pattern of $ET0$ values is typically that of a semi-arid continental climate type. It is characterized by a high climatic demand, with a maximum value in the summer (6.77mm) and a minimum value in the winter (0.68mm).

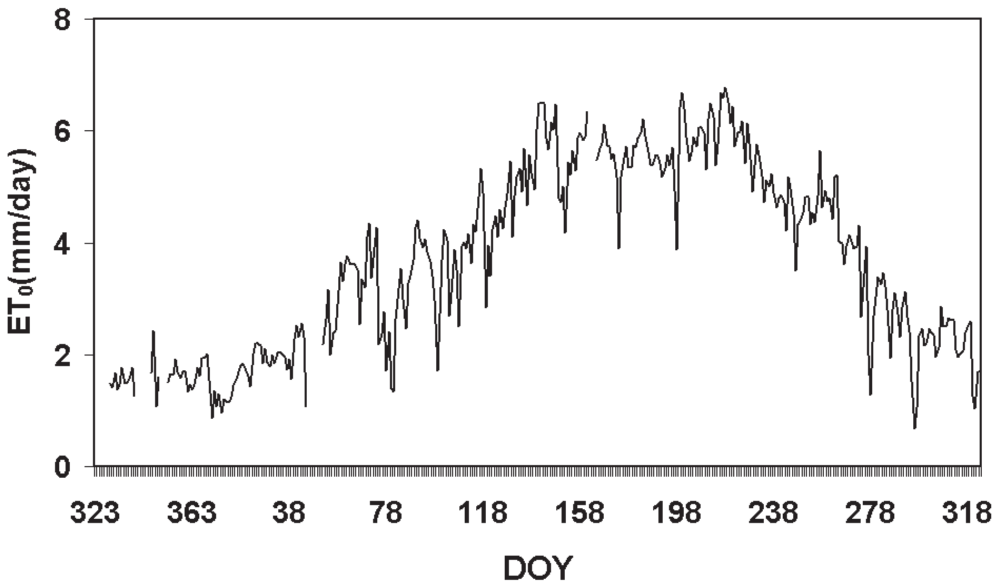

Figure 2. Annual evolution of daily reference evapotranspiration ET0 calculated following the FAO-Penman-Monteith during the experiment.

III – Results and discussion

In this section, the closure of the energy budgets of the eddy-covariance data sets was presented first. After that we present the flood irrigation effects taking into account the amount of irrigation given by the manager and the ORMVAH regional public agency ('Office Régional de Mise en Valeur Agricole du Haouz'), and we compare the irrigation events applied by the farmer and those simulated by the FAO-56 model.

1. Flux data quality assessment

The energy balance closure is the widespread method used for evaluating atmospheric flux measurements. By neglecting the heat stored in the biomass and the air below the sensors, the one-dimensional balance for the olive can be written as: $R_n - G = \lambda E + H$, where R_n is the net radiation, G the soil heat flux which was taken as an average of the three measurements (below the tree, exposed to solar radiation and at an intermediate position), and λE and H are sensible heat fluxes, respectively. As a measure of how the energy balance was closed in our observations, the sum between the turbulent fluxes, $(L_v E + H)$ was plotted against the available energy $(R_n - G)$, for daily total fluxes when fluxes were available for the 24 half-hour period in the day (see Figure 3). The linear regression (forced trough the origin) yields [W.m-2]: $R_n - G = 1.05H + L_v E, R2 = 0.86$, with RMSE = 17 Wm-2. The difference in terms of the sources areas of the different instruments has the biggest impact on the closure of the energy balance especially over sparsely vegetated surfaces. The source area sampled by Eddy-covariance is much larger than that of net radiation and soil heat flux and it can change rapidly depending on wind speed and direction and on surface conditions. However, comparatively to what has been reported in the literature (Twine *et al.*, 2000), the closure can be considered as fairly good. Therefore, we were confident that the Eddy-covariance measurements accurately measured H and $L_v E$.

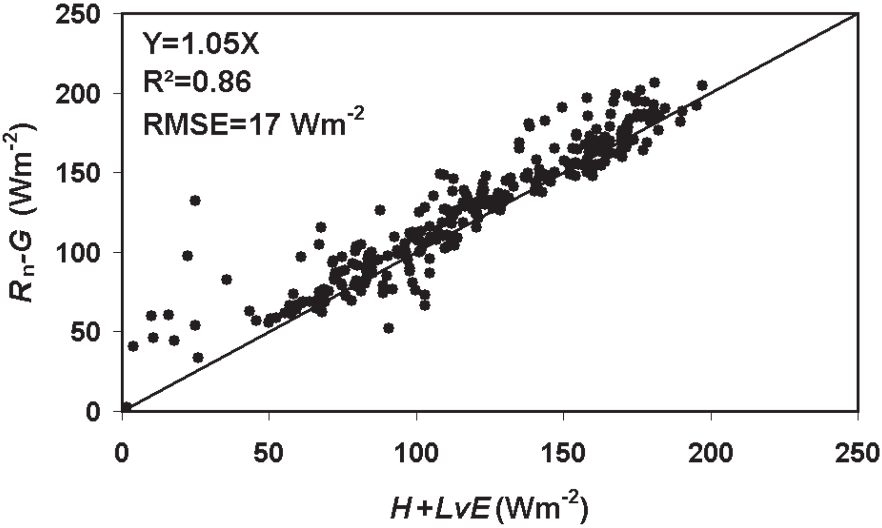

Figure 3. Daily energy balance closure, H : sensible heat flux, LvE : latent heat flux, Rn : net radiation, G : soil heat flux.

2. Irrigation efficiency assessment

Total rainfall during the experiment was 353.6 mm, while the average annual in the Tensift river basin is 240 mm. The total irrigation water applied to the orchard was around 800 mm over 10 irrigation cycles. In contrast, the yearly quantity of irrigation applied by the ORMVAH in the same conditions was about 680 mm. This quantity depends on the total available water. It decreases in case of water shortage. The yearly cumulative ET measured with the Eddy covariance system during our experiment was 824 mm. At operational basis, the FAO-56 model was applied to estimate water consumptions of olive orchards (Er-Raki *et al.*, 2004). FAO-56 model is based on the concepts of reference evapotranspiration ET_0 and crop coefficients K_c, the cumulative ET_c calculated with the FAO-56 was 863 mm and the annual reference evapotranspiration was 1269 mm (Allen *et al.*, 1998). The accumulated ET_{EC} and ET_c for olive season are shown in Figure 4. By analyzing this Figure, the accumulated ET_{EC} and ET_c curves are close over the period DOY 323 to

DOY 190. For the remaining days, ET_C was higher than ET_{EC}. This is due to the stress induced by irrigation delay. It can be noticed also in this figure, that although the sum of irrigation and rainfall was greater than ETc, one stress event occurred (from DOY 190).The frequencies of irrigation applied by the farmer and simulated by the FAO-56 were presented in Figure 5. The rainfall was presented in the same figure. For the FAO-56 model, the simulation was performed only from the 1st of March (DoY 60) through the 25th of November 2003 (DoY 329). By analyzing Figure 5, one can see that the farmer does not take into account the climatic and soil characteristics in the irrigation distribution. In general, the irrigation event should increase in the summer and decrease in the winter. On the contrary, we noticed that the farmer applied less water in the dry season. For example, the farmer made 46 days between two irrigations 169(2003) and 214(2003) while the FAO-56 model simulated three irrigations between those dates with a water amount of 64 mm, because this time period was very dry and no rainfall was recorded. The dates of the irrigation events simulated by the FAO-56 model were very different from those applied by the farmer. Sometimes, they irrigated just after heavy rainfall (four irrigations were applied in this case: days 353(2002), 109(2003), 169(2003) and 303(2003)). Some of those irrigations should be delayed (169(2003), 309(2003), 109(2003)) and the first irrigation (353(2002)) was unnecessary because it was rainy for a long period. Using the water balance equation of the FAO-56 method and ignoring the variation in the water storage in the study area (the initial conditions were similar to the conditions in the end of the experiment), the quantity lost by percolation, infiltration and runoff was approached to the sum of the total precipitation and irrigation minus the cumulative of simulated ET. The result showed that the yearly water lost by percolation, infiltration and runoff was 330 mm and 254.6 mm by taking the quantity given by the farmer and ORMVA respectively. The result revealed that the farmer applied a large amount of water and the irrigation system was not appropriate for the orchard conditions. During the winter, the soil was very wet so a substantial part of the rainfall was lost by runoff. During the dry-phase, large cracks were observed. So during the irrigation, a considerable amount of water was immediately lost by seepage through cracks. The result shows also that the monitoring irrigation amounts are not based on weather forecast, for example it was rainy directly after the third and last irrigation.

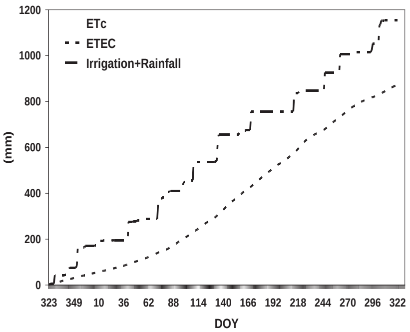

Figure. 4. Accumulated crop evapo-transpiration (ETc), Evapotranspiration derived from the EC (ETEC), irrigation applied by the farmer and sum of irrigation and rainfall.

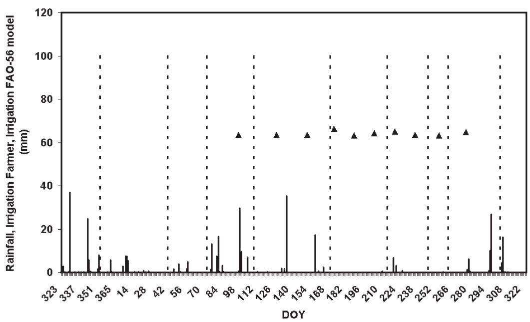

Figure 5. Irrigation interval applied by the farmer (dotted line) and those simulated by the FAO-56 model (triangles). Also the rainfall events (solid line) were shown.

IV – Conclusions

Several successful studies have investigated the use of the Eddy-covariance system in measuring the area-average sensible and latent heat fluxes. The objective of this study was to test the performance of the Eddy-covariance system to monitor the water consumption in difficult environmental conditions (tall vegetation, irrigation method which has an irregular pattern in space and time, the vegetation cover and the soil characteristics). An experiment was conducted over the irrigated oliveyard of Agdal which is located in Marrakech (Morocco). An Eddy correlation system and meteorological station were installed in oliveyard to provide continuous fluxes measurements. The analysis of the closure energy budget yielded an excellent relationship between the available energy and the turbulent fluxes with RMSE=13.12 Wm-2. So we are confident from this study that eddy-covariance systems provide reliable measurements of fluxes. The result showed also that a big amount of water (330 mm) was lost by percolation, infiltration and runoff. In contrast by taking the amount given by the ORMVA, the loss decreases to 209.6 mm. Most olive orchards are in areas where water is scarce and sometimes of low quality. So to save the water lost by evaporation from the ground, we must wet the maximum volume of root zone and the minimum soil surface.

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Possible water saving opportunities in Turkey

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Abstract. Water scarcity has been a major concern in Turkey since the 1960's. Agriculture is the major water consuming sector with an average of 70% out of the country's total water consumption. Many studies have been conducted to ensure a more efficient use of water for a sustainable agricultural development through a better management of the irrigation schemes by the local authorities and Water Users Organizations (WUOs). Irrigated agriculture is the most effective means for making rapid increases in crop production. The results from all research activities on irrigation in Turkey have been collected in the last 10-15 years. Statistical aspects of the collected results are presented to provide information and knowledge on irrigation science, to assess the past and current experiences and identify relevant gaps and problems in Turkey. Also, overviews of some scientific results are given on the main irrigation topics such as crop-water-atmosphere relationships, irrigation scheduling techniques, comparison of irrigation methods, and empirical yield response factors for some main crops.

Efforts were carried out to collect the results of all research activities on both irrigation and water saving opportunities to sustain irrigated agriculture in Turkey. However, published data and other activities on all studies could not be obtained due to the deficiencies in the archive system. Therefore, the assessment of all the studies conducted is limited.

Keywords. Water scarcity – Water saving – Water use efficiency – Yield response factors.

Opportunités possibles d'économiser l'eau en Turquie

Résumé. *En Turquie, la pénurie d'eau représente un souci majeur depuis les années 60. L'agriculture est le secteur qui consomme le plus d'eau, avec une moyenne de 70% de la consommation totale à l'échelle nationale. De nombreuses études ont été réalisées afin d'assurer une utilisation plus efficiente de l'eau et favoriser le développement d'une agriculture durable à travers une gestion plus raisonnée des périmètres irrigués par les autorités locales et les organisations d'utilisateurs d'eau. L'agriculture irriguée constitue le moyen le plus efficace pour accroître rapidement la production des cultures. Les résultats de toutes les activités de recherche menées dans le domaine de l'irrigation en Turquie ont été collectés ces 10 à 15 dernières années. L'accent est donc mis sur les aspects statistiques de ces résultats pour donner des informations et promouvoir la connaissance de la science de l'irrigation, évaluer les expériences passées et actuelles et identifier les faiblesses et les problèmes qui se posent à l'échelle nationale. Parallèlement, certains résultats scientifiques sont passés en revue concernant les questions principales de l'irrigation comme, par exemple, la relation plante-eau-atmosphère, les techniques de programmation de l'irrigation, la comparaison des diverses méthodes et les facteurs empiriques de réponse du rendement pour certaines des principales cultures.*

Des efforts ont été déployés pour rassembler les résultats de toutes les activités de recherche portant sur les opportunités de l'irrigation et l'économie d'eau pour soutenir l'agriculture irriguée dans le pays. Cependant, il n'a pas été possible de repérer toutes les données publiées et les informations utiles sur les différentes activités menées à cause des insuffisances dans le système des archives. Par conséquent, l'évaluation des études reste encore limitée.

Mots-clés. *Pénurie d'eau – Économie d'eau – Efficience d'utilisation de l'eau – Facteurs de réponse du rendement.*

I – Introduction

Irrigated agriculture is the most effective means for making rapid increases in crop production. Improvements in irrigation can result in higher levels of living in low income nations because they have approximately 80% of the world's irrigated land. The introduction of irrigation is one of the turning points of the human history in that those men who learned how to use seeds and to sow them in the soil understood that a greater yield could be obtained by irrigation. Water management in agriculture is the process by which water is manipulated and used in the production of food and fiber.

There is no doubt that for developing countries of the Mediterranean region, with erratic rainfall pattern, efficient control and management of water use has to be an essential requirement for this continued development. Without proper water management, autonomy in food and energy will continue to be a mirage for most of these countries. Due to increasing population which leads to growing demand for water resources, and pollution that reduces fresh water yield, most of the Mediterranean Countries have serious water scarcity problems for agricultural production and urban/industrial consumption. Scarcity of water and reliability of its supply are major constraints for agriculture development in those countries.

In the developing countries of the Mediterranean area, the major challenge facing water planners and managers at the end of the 20th century is that while physical availability of water is fixed, its demand will continue to increase steadily in the foreseeable future. Accordingly, the problem is how to balance demand and supply of water under those difficult conditions. In addition, the issue of potential climatic change due to global warming and what its impacts could be on natural resources including water, are basically unknown factors at present (Hamdy and Lacirignola, 1999).

Today, agriculture is the main consumer of freshwater in the Mediterranean countries and the withdrawal for agriculture is about 80% of the total freshwater sources. In the world with an urban/industrial culture today, agriculture still continues to be the biggest consumer of water. For this reason, water saving opportunities should be considered. Water saving in agriculture ranges from genetics to agronomic, engineering, and different management options, including the use of non-conventional water resources.

Irrigation has a vital role for increasing and stabilizing agricultural production in Turkey because of scarcity and unreliability of rainfall conditions prevailing during the growing season in most part of the country. 36.5% of the total land (77.95 Mha) in Turkey is suitable for agriculture (28.05 Mha). Of the total irrigable area (25.85 Mha) 16.6% is being irrigated (4.3 mha) while 65% is not. Only 16% of total water resources are used for irrigation and other purposes. Economically viable irrigation is possible for only 8.5 million hectares.

The annual potential surface runoff from rivers are calculated as 186 billion cubic meters and a certain level of runoff is to be allocated for water requirements of neighbouring countries. The amount of flow that can be used for consumptive purposes is estimated to be around 95 billion cubic meters. Together with 13.66 billion cubic meters of useable ground water resources, the total available water resource of Turkey is around 108.66 billion cubic meters. Today, Turkey can not use soil and water resources effectively, due to coordination, political and economic problems.

However, during the next 20-30 years, Turkey will necessitate to irrigate all the irrigable lands and the population will reach 80 million by 2010 and 90 million in 2025; if 400 kg of grains for one person, the total grain demand will be around 32 million tons by 2010 and 36 million tons by 2030 (Hamdy and Lacirignola, 1998). To meet this demand, the irrigation area should be increased. It should be up to 4.77 million ha by 2010 (a net increase of 0.47 million ha more than the current), and 5.4 million ha by 2025 (a net increase of 1.1 million ha more than the current). This will cause the agricultural water consumption to increase dramatically. Currently in Turkey, about 31

500 km^3 of water is used by agriculture, in which 70 per cent, that is, about 22 050 km^3, is for the grain production (SPO, 2001). As a result, sustainable quantities of freshwater supplies will be diverted from agriculture to industry and households in the country. Irrigated agriculture will face two problems of water shortage and reduced financial resources. Despite these problems, irrigated agriculture has not only to supply the other sectors with their water demands, but has also to provide 70-75% of the additional food grain requirements to the increased population. This will not be possible without the implementation of water demand management in all sectors, and particularly, the agricultural one. There is a great need to find appropriate ways to achieve greater efficiency, better saving in water losses, and an equitable distribution in the irrigation sector. This will require a wider range of alternative approaches to be developed, tested and implemented with greater imagination and flexibility on the part of irrigation policy makers, managers, and planners.

In this report, water scarcity and possible water saving in Turkey are discussed and some scientific results on water saving opportunities taken from some experiments carried out in the different regions and crops.

II – Possible water saving in Turkey

There is a great opportunity for saving significant volumes of water losses through a better use of technical and economic tools as well as the institutional and human resources capacities Turkey already has. It is possible to reduce losses and leaks in drinking water in industry; through recycling, it is possible to reduce water consumption. However, in spite of the water saving that could be achieved in both drinking and industrial sectors, yet, the most beneficial saving in terms of volume would be in the irrigation sector.

In Turkey, where more than 72% of its water resources are allocated to agriculture, major efforts should be directed to increase the efficiency in the field, as the opportunity of water saving is notably higher compared to other water use sectors. For instance, in the irrigation sector, the reduction of conveyance losses and the improvement of irrigation efficiency can result in water saving.

In this section, some summarized results, which showed the water saving approaches and total saved water amount, are given. The results are taken from experiments carried out in the different regions and different topics. These are the new mechanisms which are to protect the resource and allocate diminishing water supplies to increasing and competing uses.

1. Deficit Irrigation

Generally, irrigation and irrigation water requirement of crops were determined without any consideration of likely water limitation of available water supplies. In arid and semi-arid regions, because of increasing allocations of water for municipal and industrial use, major changes came about in water use under irrigated agriculture. New innovations had to be tested and adapted to increase effective use of decreasing water allocations for agricultural use (Hanks, 1983).

Research effort has focused on developing new techniques to receive high returns from restricted supply of water. Among the techniques of increasing effective use of water, deficit evapotranspiration should also be used. Deficit irrigation can be used either through agronomic practices or through changing management schemes to decrease crop evapotranspiration (Kanber *et al.*, 1993). The end result is the so-called "deficit irrigation" (Vaux and Pruitt, 1983). To save irrigation water, crops are exposed to water stress either throughout the whole growth season or at certain growth stages. With this application, water saving is obtained without significant yield decrease and also irrigated area can be increased without additional water supply available (Merriam, 1965). Deficit irrigation is promoted widely and used for some crops in Turkey. Experiments on the deficit irrigation of crops are being considered in different ways: 1) To spread water deficiencies equally through the growing season. For this reason, different approaches are being considered such as using different soil depths for wetting, decreasing irrigation water as control treatment, using different plant-pan coefficients, different irrigation intervals, different furrow spacing in surface, lateral and trickle spacings in drip irrigation systems, and line source sprinkler irrigation technique. In some deficit irrigation experiments, crops are exposed to water stress in different growth stages. This technique is named as omitted irrigation. In all the deficit irrigation experiments, yield response factors (Ky) given by Stewars Equation are elaborated to be calculated. Yield response factors for some main crops are given in the Table 1.

Water saving with deficit irrigation approach is used in different ways in some experiments. For instance, in some studies, different irrigation season lengths are used while in others evapotranspiration losses are prevented by chemical applications.

Different irrigation season lengths were used for cotton under Seyhan Plain conditions (Kanber *et al.*, 1994). In this study, different irrigation intervals, first and last irrigation, are considered. According to the results, different yield reductions and irrigation water savings were obtained depending on irrigation season lengths. When the last irrigation was applied at the ball diameter of 1-2 cm, the maximum water saving measured was 46-62 percent.

Table 1. The Empirical Yield Response Factors for Some Main Crops.

Crops	Ky Values, Growth stage / Irrigation Method	Region	Sources
Cotton	0.76 (flowering-yield formation) 0.99 (seasonal, Furrow) 0.93 (seasonal, furrow) 0.86 (seasonal, drip) 0.72 (sprinkler, sprinkler) 1.22 (sprinkler, Seasonal)	Çukurova Çukurova Harran	Baştuğ, 1987 Yavuz, 1993 Kanber *et al.*, 1991
Pistachio	0.62 (Seasonal, Surface 0.77 (seasonal, drip)	Şanlıurfa Gaziantep	Kanber *et al.*,1993 Aydın, 2004
Maize	0.98 (Seasonal, Furrow) 0.85 (seasonal, sprinkler) 0.69 (Vegetative) 1.03 (Blister) 1.00 (Milk stage) 0.66 (Ripening) 1.14 (Seasonal, surface)	Tarsus Tarsus Thrace	Kanber *et al.*, 1990 Köksal, 1995 Çakır, 1999
Wheat	0.87 (Seasonal, surface) 1.14 (seasonal, sprinkler) 0.76 (Seasonal, surface) 0.32 (seasonal, surface)	Southeast Southeast Central Anatolia East Anatolia	Karaata, 1987 Sezen, 2000 Madanoğlu, 1977 Sevim, 1988
Sunflower	0.62 (Seasonal, surface)	Thrace	Karaata, 1991
Bean	1.3 (Seasonal, Sprinkler)	Central Anatolia	Bahçeci, 1995
Soybean	1.1 (seasonal, sprinkler)	Southeast	Kara, 1995

In some places where the evaporation losses are very high, chemicals were applied to reduce evapotranspiration of cotton. In this study, the effects of irrigation intervals and antitranspirant doses on evapotranspiration, yield, and water use efficiency of cotton were investigated in the plots in Harran Plain for 4 years (Kanber *et al.*, 1992). Different irrigation intervals (I1: 7, I2: 14, and I3:21 days) and four antitranspirant doses (D0: 0; D1: 40 g/ha; D2: 80 g/ha; and D3: 160

g/ha) were tested. The antitranspirant that contains N, N, N-tributtill-3- (trifluoromethyl) benzene methananium chloride as the effective substance was used in the sub-plots of the experiment. The antitranspirant application was made in two times when the reddish colour on the main stem of cotton, 5-7 cm high, reached the top bud (as first application) and on the 5^{th,} 7th day of ball formation (as second application) during the growing season. The irrigation programs got started after the first application of antitranspirant and 90 cm soil depth was wetted in irrigation events.

Results show that the frequent irrigation increased evapotranspiration (ET) and net irrigation water requirement (IR). The maximum ET and IR values were found to be 1670 and 1555 mm, respectively in treatment I1 (Table 2). The highest WUE values, although not statistically significant, were obtained from I2 as 2.41 and 2.69; and from D1 as 2.34 and 2.60.

The application of various antitranspirant doses had no significant effect both on seasonal ET and WUE values. The irrigation intervals have significant effect on the yield and quality of cotton. The maximum cotton yield was obtained from frequent irrigations. Frequent irrigation applications increased lint length, whereas infrequent irrigations and antitranspirant doses resulted in shorter and thicker lint.

2. Use of Unconventional Water

Applying deficit irrigation programs including supplemental irrigation and managing irrigation systems according to deficit irrigation approach can be considered as the best solution. However, this solution is very expensive and requires new approaches.

Table 2. Results from the experiment on antitranspirant doses and irrigation program.

Treat.	No of ırr.	IR mm	ET mm	IWUE	TWUE	Average Values					
						Yield* kg/da	No of irr.	IR	ET	IWUE	TWUE
I1D_0	13	1555	1670	2.45	2.28	384a	8 (D_0)	1201 (D_0)	1322 (D_0)	2.51 (D_0)	2.26 (D_0)
I1D_1	13	1555	1670	2.55	2.36	394a	8 (D_1)	1182 (D_1)	1310 (D_1)	2.60 (D_1)	2.34 (D_1)
I1D_2	13	1555	1670	2.39	2.23	361a	8 (D2)	1172 (D_2)	1290 (D_2)	2.54 (D_2)	2.29 (D_2)
I1D_3	13	1555	1670	2.35	2.18	376a	8 (D_3)	1196 (D_3)	1312 (D3)	2.49 (D3)	2.25 (D3)
I2D_0	7	1113	1234	2.62	2.34	295b					
I2D_1	7	1113	1234	2.76	2.48	302b					
I2D_2	7	1113	1234	2.65	2.36	298b					
I2D_3	7	1113	1234	2.74	2.46	304b					
I3D_0	5	894	1019	2.45	2.15	223c					
I3D_1	5	894	1019	2.48	2.18	224c					
I3D_2	5	894	1019	2.57	2.27	227c					
I3D_3	5	894	1019	2.38	2.11	209c					

*$S\bar{x}$ =20.94 and 9.77; the yield groups were statistically obtained by the orthogonal comparison methods

On the other hand, to find new water resources for different purposes including irrigation is another possibility to solve the problems related with insufficient water resources. Using unconventional water such as brackish water (treated waste water, drainage water, and ground water table), shallow ground water and saline water supplied from different resources is considered to be one of the best solutions. Table 3 shows the waste water amount in Turkey from urban and industrial consumption in 2001.

Table 3. Waste water amount from urban and industrial consumption in 2001 (DIE, 1995)[1].

Resources	Amount, km3
Urban waste water	3.700
Industrial waste water	3.000

[1]The values of 1995 are updated for 2004.

The use of drainage and saline water for irrigation seems to be an attractive alternative for solving water scarcity problem. Saline water is a potential source for irrigation. The use of saline water for irrigation increases the quantity of water available for agricultural production if the sustainable management strategies for their utilization have evolved. Such water occurs extensively in the arid and semi arid parts of the Mediterranean, Central and Southeast Anatolia regions and are being used for irrigating some summer crops which are tolerant to salinity. Sometimes saline water is blended with fresh water with different quantity and used to irrigate the salt sensitive crops. There is enough evidence taken from several studies carried out either in Turkey or in other countries to show the potentiality of using water with salinity up to 6 dS/m for major cereal crops (Hamdy, 2002). Unconventional water use for irrigation gradually increases in a lot of countries where irrigation is evitable but water resources are scarce.

3. Use of waste water

In spite of the standards which are prepared in Turkey, waste water is not widely used in irrigation except in a pilot project in the GAP areas and in a few small industries. Enough water is being supplied for irrigated areas; therefore, the total irrigated areas did not reach the marginal limit value for the water resources. Frankly, farmers can still find enough water for irrigation. The experiments on the use of waste water for irrigation purposes persist (Sarikaya, 1994). A study using urban waste water treated by Çiğli treatment plant for irrigating Menemen plain (Eagen Region) has been carried out for a long period. On the other side, in the GAP areas two experiments on the use of waste water and drainage water for irrigation were carried out (Altınbilek and Akçakoca, 1997).

Bilgin *et al.* (1997) carried out studies to determine the effects of Ankara stream-water which is polluted by urban and industrial wastes on soil, plants (lettuce and broccoli) and environment. Moreover, they examined the chemical composition of stream water i.e. heavy metals, microbiological pollution, etc, in the sites where the samples were collected. The experiment was conducted in the open areas and greenhouse conditions. According to the results, heavy metal concentrations of Ankara stream were found to be not hazardous to plants and soils. However, microbiological pollution of the water turned to be too high. Irrigations caused to the yield decreases due to the detergent content of the stream flow.

4. Use of drainage water

Yarpuzlu (1999) studied the response of cotton and wheat grown in a clay soil in a sequence of drainage water applications with different leaching fractions (5 treatments in 1991-1995; in 1996-1997), three different irrigation water sources (drainage canal water, collector water and Seyhan canal water with different leaching fractions were utilized); the salinity build-up in the soil profile was evaluated during each growing season in Tarsus plain. The results of the study showed that the effect of irrigation with different leaching fractions were not statistically important on the yield of wheat crop; the effect of different leaching fractions on cotton yield was statistically significant at 99 signification level. Drainage water applications in the wheat sowing periods did not cause salt accumulations in the soil; however, in the cotton sowing periods it did cause salt accumulations.

Bahçeci (1991) examined the effect of groundwater used in irrigation, the accumulation of salts, sodium and boron in the Konya-Yarma district soils for wheat and sugar beet crops. The trial was designed in randomized block with three replications. According to the results, the salt accumulation wasn't significant but both the boron amount in the soil increased and the increasing amount of exchangeable sodium was statistically significant. The exchangeable sodium accumulation was taken into consideration as a trend function and YB= 0.193+0.309X relationship obtained. This relationship showed that only 20 years later the amount of ESP with a 90 percent probability would be reached to 23 - 47 percents limits.

Bahçeci (1993) studied the quality and the suitability of the main drainage channel waters for irrigation of Konya. In the research, the drainage water of Alakova and Arapçayiri branches of the main drainage channel were tested. The results showed that drainage waters may cause salt and boron accumulations in the soil. Besides the study also determined that Keçeli branch of the main drainage channel in the region was polluted from urban areas and reuse of this drainage water may cause environmental problems.

5. Use of saline water

There are various studies regarding the use of saline water for irrigation purpose. In these studies, surface and pressurized irrigation methods are used with saline water which is diluted at different levels. Diluted-saline water is used with various irrigation systems such as drip, sprinkler and surface methods. In surface irrigation methods, different amount of irrigation water with different saline levels are directly applied to plots whereas in pressurized systems, different salinity levels of irrigation water were used with line source sprinkler and drip which had different line and trickle head spacing (Sönmez and Yurtseven, 1995). Line source sprinkler system and drip system which has different trickle intervals can be shown as examples (Kanber and Bahçeci, 1995; Ödemiş, 2001). The results on saline irrigation of some crops in Turkey are given in Table 4 (Yurtseven *et al.*, 1999a and b; Yurtseven *et al.*, 1996; Yurtseven and Bozkurt, 1997; Çizikçi, 1998; Yurtseven and Baran, 2000; Yurtseven *et al.*, 2001a and b; Yurtseven and Öztürk, 2001; Yurtseven *et al.*, 2002). This table contains both threshold and zero yield values of crops.

Table 4. The Results of Saline Irrigation for Various Crops.

Crops	Threshold Value, dS/m	Zero Yield Value, dS/m
Maize	0.81	4.0
Tomato	2.7	11.0
Pepper	1.8	7.0
Lettuce	1.5	7.0
Broccoli	3.5	9.0
Radish	1.5	7.0
Rape	2.3	9.0
Spinach	3.5	
Cotton	5.7	

The values in Table 4 are close to values given in some papers; however, some little differences may be inferred based on irrigation programs, soil properties and other factors.

III – Conclusions

As the demand for the limited water resources continues to rise, the irrigation comes to be caught in the middle: on one side, with the development of the industry and agriculture and acceleration of the urbanization process, agriculture will have to give way for the industry and urban living; on the other side, in order to feed the increasing population, the new irrigation area must be expanded while maintaining the current irrigated area and guarantee rate, and more water will be needed. This is why for a sustained development, Turkey's agriculture must stick to economy and efficiency.

As the irrigation water-using efficiency in Turkey is much lower than that in western countries, if the water-saving irrigation techniques are practiced generally, the potential to save water will be very prospective. Adopting canal lining or water pipes will increase the water delivery efficiency in a canal system; furrow and border irrigation for dry farmlands will improve the usage of field water; the sprinkling irrigation and micro irrigation will improve the usage of water at its delivery section and in the field, and improve the evapotranspiration environment and reduce evapotranspiration.

As a technical measure, the water-saving irrigation method is employed to make full use of irrigation water resources, to improve water usage efficiency, and achieve high yield and efficiency in grain production. It is an integrated technical system, combining water-saving techniques concerning water resources, engineering, agriculture, management and other links. With it, the overall using rate of irrigation water resources will be improved, the grain production at unit area or total area will be heightened, and the sustained development of agriculture can be guaranteed.

Agriculture is the basis of the national economy, providing necessary agricultural products and industrial raw materials for the living of 72 million people. Because of the special topographic characteristics and climate of Turkey, its agriculture production mostly depends on irrigation, and appropriate irrigation measures will result in a stable and high yield. Due to the serious lack of water resources, the traditional irrigation methods cannot catch up. Hence, water saving is a prerequisite for the sustained development of the national agriculture and national economy.

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Water value, water demand and WFD implementation in an olive intensive Guadalquivir SUB-BASIN

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Abstract. Guadalbullon river sub-basin belongs to the Guadalquivir basin and is an example of intensive olive cultivation. The value of water in the sub-basin is analyzed under different scenarios by integrating an agronomic model (water production function of olive), an economic model of farm results and a sub-basin hydrologic model of water use and river flow. The result shows that the value of water for olive oil production (net margin per m^3) is in the range of 0.60 €/m^3 – 2.0 €/m^3. The impact of minimum flow requirement constraints supposes a reduction of the gross added value of the irrigated olives equalling some 1.2 million Euros per year at sub-basin level.

Keywords. Water value – Ecological flow – Olive tree irrigation – Water framework directive.

Valeur de l'eau, demande en eau et application de la Directive Cadre sur l'Eau dans un sous-bassin du Guadalquivir avec culture intensive de l'olivier

Résumé. *Le sous-bassin de Guadalbullon relève du bassin du Gudalquivir et il constitue un exemple de culture intensive de l'olivier. La valeur de l'eau dans le sous-bassin est analysée en prenant en compte différents cas de figure qui intègrent un modèle agronomique (fonction de la production de l'eau sur olivier), un modèle économique des résultats de l'exploitation et un modèle hydrologique de l'utilisation de l'eau et du débit du fleuve dans le sous-bassin. Les résultats montrent que la valeur de l'eau pour la production de l'huile d'olive(marge nette par* m^3*) se situe entre 0,60 €/*m^3 *et 2,0 €/*m^3*. L'impact de la contrainte du débit minimum implique une réduction de la valeur ajoutée brute des oliviers irrigués qui s'élève à 1,2 millions d'Euros par an à l'échelle du sous-bassin.*

Mots-clés. *Valeur de l'eau – Débit écologique – Irrigation de l'olivier – Directive Cadre sur l'Eau.*

I – Introduction

In developed countries, water scarcity[1] is generally a consequence of the demand for economic uses which is higher than the available supply; this is frequent in the Mediterranean countries as water resources (surface and groundwater) cannot satisfy economic uses (agriculture, urban, industry and the services) and environmental flows. In the Guadalquivir Basin, in Southern Spain, as in most Mediterranean regions, the main use of water is irrigation. Analysis of water balance since 1992 has shown that percentages of use by sector have not changed significantly with industry representing 2% of the total volume; urban (domestic and services) 13% and agriculture up to 85% (mainly irrigation).

The importance of the irrigation on water use is around 6.5 times increase in the productivity of rain fed land, measured by Gross Value Added per hectare (GVA), and about 4.4 times measured as Net Margin for irrigated lands versus rain-fed crops. Irrigation in agriculture is an essential generator of wealth and an important rural development stimulator in the region. At present, in the Guadalquivir RB, 25% of the agricultural area is irrigated and produces 61% of the agricultural GVA in Guadalquivir. Scenarios for 2015 evolution of Guadalquivir agricultures project that the percentage of agricultural GVA produced by irrigation will reach 70% of the total basin agricultural GVA, which points out two ideas: first, the increasing strategic importance of irrigation for the regional economy and second the evolution towards a growing intensity in farm production and an increased value of irrigated farming.

Guadalquivir, with around 800,000 ha irrigated, is an example of a mature basin where the strategy of increasing supply was over in the 90's, with the possibility of new dams officially finished, and the focus turned to saving and efficiency in water management, which is now under implementation.

The Water Framework Directive (WFD) is an environmental norm and its main purpose is the sustainability of water by a long-term protection of resources; however, the scarcity of the resource implies the need to balance environmental protection with regional development (Water Act Art 40). Since the approval of WFD (2000) in Spain, the increasing water demand has produced a more intense struggle between industrial and commercial consumers and a global alarm because of environmental problems.

Currently, the water policy debate has started public participation in policies for allowing flexibility of water allocation through administrative measures and water markets. The public participation around the allocation of water to economic vs. environmental uses, and between different economic sectors might be supported with the tool of water's valuation. Irrigation of olive for oil production is probably the most recent driver on increasing pressure on water resources as irrigated olives have grown from zero in the 80's to almost 50% of irrigated land in the basin in the last 25 years (close to 400000 ha).

This paper illustrates the value of water for irrigation in an olive intensive sub-basin which is the Guadalbullon Sub-basin, in the Guadalquivir River Basin.

1. Case study

The Guadalquivir river basin in southern Spain has a surface of 57,527 Km^2 and a population of more than 4.2 million people in 476 municipalities. The Hydrological Plan for Guadalquivir outlines the general management of the basin and indicates that the average basin's renewable water resources (surface and groundwater) are around 6,300 hm^3/year (Ministerio de Medio Ambiente, 2006), while the 'unrestricted' gross consumption for 2002 was estimated at 3.583 hm^3/year (82% surface and 18% groundwater). The basin is highly regulated, and irrigation depends upon reservoirs regulating 35% of natural superficial resources. The level of water abstracted is high and rainfall fluctuates; therefore, the guarantee for accomplishing user's water allocation rights is low. Agriculture with 86% of water use is by far the biggest consumer of water.

The irrigated area is currently 752000 ha and expected to be 800000 by 2015. Water for this area originates from regulated rivers (49%), unregulated rivers (17%), groundwater (33%), and from the reuse of wastewater (2%). Six crops represent 89% of the irrigated area and 90% of water demand for irrigation. Regarding the irrigated land, olive tree covers 42% of the area (39% of water use), cotton 9% (12% of water use); rice 5% (17% of water use); maize 7% (11% of water); winter cereals (mainly wheat) 7% (4% of water) and vegetables 6% (7% of water).

Water availability patterns in semiarid regions are extremely variable. Even in basins with a highly developed infrastructure, users are subject to unreliable water supplies, incurring in substantial economic losses during periods of scarcity. The Reform of the Spanish Water Law (Law 1/2001) allows for water markets between users with active water rights (to avoid new entrants that have not been previously under Water Agency control). Most of the water rights in Spain belong to user associations, mostly collective organizations (with a greater presence for surface water). The last severe drought urged the Government to promote additional reforms of the Water Law supporting Water Banks and allowing for water transfer between basins.

The main characteristics of agriculture evolution in the years 1992- 2005 are the decrease in rain-fed land (400000 has), and in the number of farms (average farm size from 13.45 ha to

19.94 ha.) Another key factor is the important increase in the olive growing area that is now the most important crop with 41% of the total agricultural area, 42% of irrigation and 35% of water consumption.

The current policy in the basin is to improve irrigation systems, (changing to trickle irrigation) and also to improve the distribution system level (pressurized networks). Each farmer receives an amount of water assigned by the water authority as a 'water right' or concession. Water concessions are usually assigned for a 'standard year' at 6000 m^3/ha; however, in the Guadalquivir, they rarely receive the full right and are often allowed to use only a much smaller allocation. It should be noted that the amount of 6000 m^3/ha is an average from the different administrative allocations that varies according to both area and crops (e.g. rice receives around 12000 m^3/ha while some olive growing areas 2500 m^3/ha). Evolution of allocated water for irrigation has decreased continuously during the last 20 years from 7000 m^3/ha in the 80's to 5000 m^3/ha average in 2000-2005.

Irrigation water supply has the lowest priority (it can be considered as the 'residual' use) because water for agriculture will be the last to be allocated after the top priority uses are fully satisfied (urban, environmental minimum flow). The use of water in the Guadalquivir Basin for the currently irrigated 752000 ha[2] is based on administratively assigned water rights equal to 3.365 hm^3; however, this level of water use implies that crops do not receive the optimum water supply as the resources are lower than the theoretical irrigation needs for a normal hydrological year (computed according to Penman's ETP) and estimated as 3.857 hm^3. Therefore, even in a good hydrological year (unrestricted supply of administrative water rights) irrigated agriculture cannot use of total demanded water (deficit irrigation).

The environmental flow is defined as a 'constraint' upon the rest of economic uses (Water Act 11/2005). The purposes of the environmental flows are: (a) to provide habitat conditions for flora and fauna; (b) to provide temporary regime of flows. Models are adapted to intermittent rivers, seasonal rivers and estuaries, as well as heavily modified water masses. In Guadalquivir River, environmental flows were made for two seasons: humid (Dec. - April) and dry (May- Nov.)

The case study focused on Guadalbullon Sub-basin that is a good example of olive irrigation supplied by an unregulated river. Agricultural area in this sub-basin is 70,494 ha, with 21,479 (30%) irrigated. The most important crop is olive tree, with 91% of the total rain-fed cultivated area and 86% of the irrigated area (30% of olive groves are irrigated in this sub-basin). The rest of the area is grown with cereals, 4% of the area (16% is irrigated, 2% of the total irrigated lands); industrial crops, potatoes and vegetables (2% respectively) standing for the remaining 6% of the total cultivated area and 10% of irrigated lands.

Additionally to irrigation, the sub-basin water consumption is reported in table 1 showing that 'unrestricted' water rights in agriculture would use, in a good hydrological year, 70% of water in the basin (59.3 hm^3), but practically the real yearly average use is around 41 hm^3. An average irrigation/year takes 69% of the 'administrative water rights'.

The basin uses more water than the sustainable amount and the consequence is that the environmental flow is not respected and during around 10 days per year the river is dry (no water in the river). This is a social and environmental undesirable situation and requires some water saving measures. Nevertheless, opportunities for water saving in non-irrigation sectors (urban, industry) are a few and the significant savings should be mainly focused on controlling irrigation.

Table 1. Summary of water consumption.

Use	2005 Consumption (hm3)	GVA (x 1.000 €)	Main variable
Urban- Domestic	18.38	18.380	Population 158.453
Industrial	3.85	9.716.093	
Agrarian(1)	59.31	66.872	21.541 ha irrigated
Livestock	0.74	n/d	10.228 Livestock units
TOTAL	78.63	9.801.345	

(1) Administrative water rights.
Source: Draft Program of Measures- Confederación Hidrografica del Guadalquivir (2008).

Table 1 shows that the administrative water rights total 78.6 hm^3 which supposes 66% of the estimated renewable resources in the basin equalling 121.8 hm^3 (CHG-MMA Draft Hydrological Plan, 2008). The literature suggests that an extraction of water over 40% of renewable resources may be a target for a sustainable management of resources, but this is not a 'legal target' or constraint because the current legal constraint is the minimum environmental flow that is defined for this sub-basin in the level of 700 l/s (July-January) and 1.420 l/s (February-June).

The following section analyzes the value of water as an indicator of water demand for the implementation of economic instruments to control water consumption in accordance with WFD regulations.

II – Methods

This research tries to valuate irrigation water for olive groves and analyze the consequences of this valuation for the implementation of WFD and the achievement of sustainable management. As to the valuation of irrigation water, Young (2005) offers a complete revision of available methods. This research selects the production function method which is deductive based upon the integration of three models:

Agronomical: Production function

Financial: Profitability analysis of farms

Hydrological: Annual availability of irrigation water.

The first model is based on Moriana *et al.* (2003) who obtained the following production function for an olive grove for the years 1996-99 in Cordoba (Spain).

$$q = -2{,}78 + 0{,}011ET - 0{,}006*10\text{-}3ET2 \qquad R2 = 0{,}59 \qquad (1)$$

Where:

q = Oil production, in metric tons per hectare

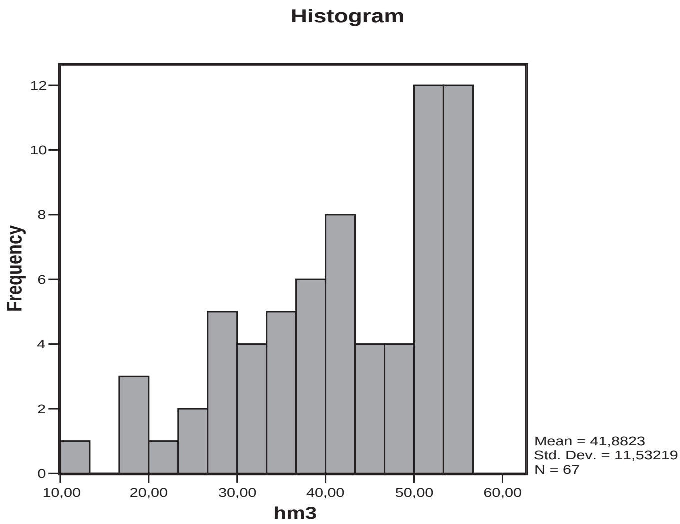
ET = evapotranspiration, in millimetres

This function is based on ET, and should be related to net irrigation. For this calculation, the effective rain is estimated as 70% of rainfall (Pastor *et al.*, 1999). The olive oil production is converted into financial returns by integrating the income and cost analysis for the crop in this area. This will be done for the present and future scenarios, specifically:

– Scenario 2005 is defined with the CAP subsidies and prices previous to the last reform. The financial model is based on data obtained from Farm Accountancy Data Network (FADN).

– Scenario 2015 is obtained with the new aids and prices scenarios. A tendency scenario is considered from the compiled data of the consulted sources (European Comission, OECD-FAO, FAPRI, USDA). For further details, it is recommended to consult Mesa-Jurado *et al.* (2008), where the different indicators used to construct this scenario are described. Water cost is variable, since it depends on the used volume; also, in the specific case of this sub-basin, it was necessary to input the cost of a recently-made pond.

Finally, to know the unrestricted and average use of water, the hydrological model simulates the last 67 years with the available climatic data and extrapolates irrigation water use once the priority uses are satisfied (domestic, industrial, livestock and environmental flow). The result is shown in figure 1 where the irregularity of water resources can be appreciated.



Observations		67
Average (hm3)		41,9
Median (hm3)		43,0
Mode (hm3) 5		5,7
Percentages		
	10	24,4
	20	30,8
	25	34,3
	30	36,4
	40	40,0
	50	43,0
	60	48,4
	70	51,6
	75	52,7
	80	53,0
	90	55,6

Source: Own elaboration based on Guadalgua.OPH-CHG data
Figure 1. Guadalbullon RB Irrigation supply histogram (hm3).

WFD working procedures aim to reach good environmental status for the year 2015; therefore, there is a need to analyze the 2015 demand scenario. This research will use the following scenarios.

– Water supply is equal to unrestricted authorized uses (59.3 hm^3)

– Water supply is equal to average supply without respecting environmental flows (41.8 hm^3)

– Water supply is equal to average supply respecting environmental flows (39.6 hm^3)

– Water supply is equal to average supply respecting environmental flows (39.63/2 = 19,81hm^3)

– No irrigation (W = 0)

The following section applies the methodology to the available data.

III – Results

Using the production function [1], price of oil and production cost, the net margin (NM) related to irrigation water is computed in [2].

$$\mathbf{NM = (p\text{-}k_1)\ Q - CF} \qquad (2)$$

Where:

NM: Net Profit, expressed in euros per hectare

p: price of the olive, expressed in euros per kilogram. For the year 2005, the average price was 0.49 €/kg., with an estimated value of 0,51 €/kg for the scenario 2015.

k_1: variable costs coefficient. Values used in the study are k_1: 0.1558 for the year 2005 and 0.1667 for the year 2015[3]

Q: olive production, in kilograms per hectare

CF: fixed costs, in Euros per hectare. For this study case, the average value is 52 €/ha.

By replacing q, obtained from expression [1] we find that:

$$\mathbf{MN = (p\text{-}k1)\ (-2{,}78 + 0{,}011ET - 0{,}006*10\text{-}3ET2) + CF} \qquad (3)$$

Where: ET: evapotranspiration in millimetres

We have:

$$\mathbf{ET = R/10^4\text{-}PE}$$

Where:

R: Irrigation amount in cubic meters per hectare

PE: Effective rainfall in millimetres.

By taking derivative from irrigation, we get the following equation:

$$\mathbf{\Delta MN/\Delta\ rainfall = (p\text{-}k1)0{,}011 - (p\text{-}k1)0{,}012*10\text{-}3(R/10\text{-}PE)} \qquad (4)$$

Equation [4] is a linear function that depends only on the irrigation amount, and where the rest of variables are taken as known and constant.

Results of the three models application are detailed in appendix 1. From these, the opportunity cost of establishing the environmental flow results in 56 €/ha (3315-3259), that is equivalent to 1.8% of the Net Margin for an irrigation farmer. At aggregate basin scale, it represents approximately 1,2 million Euro.

The following graph shows how the net profit would drop from 2005 to 2015 scenarios.

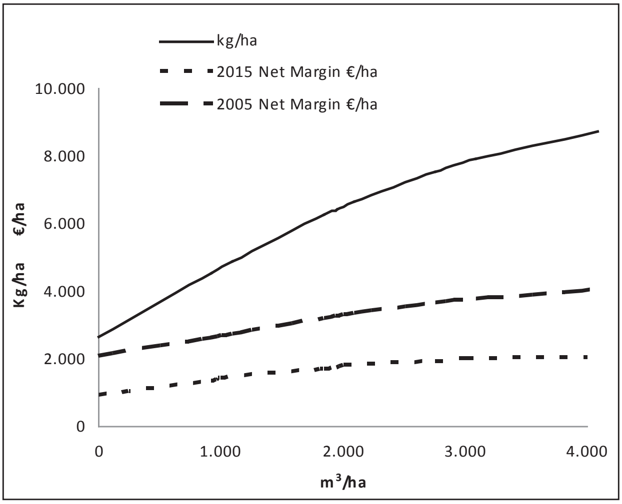


Figure 2. Assessment of irrigation value in olive tree production in Guadalbullón RB.

IV – Discussion and conclusions

The resulting water values can be compared to the ones from other studies; Berbel and Mesa (2007) obtained, through the Quasi-Hedonic Pricing Method, a value in the range of 0.14 to 0.35 €/m^3 for mills' of olives; Berbel and Pistón (2008) estimated an average of 0.19 €/m^3 through the Residual Value Method (not including the CAP aids). So, we conclude that the use of agronomical models shows higher values for water since the response of the olive grove to water is remarkably characteristic of this species.

With the production function form, it is advisable to make a detailed analysis of water value in marginal and not in average terms. When the opportunity cost for establishing the environmental flow, as marginal values are used instead of averages, the value of water increases and value in the margin goes from average value of 1.843 to marginal value of 1.948 m^3/ha, increasing the real financial opportunity cost of saving water to 0.54 €/m^3 or 57 € per ha.

Previous calculations make an estimation of approximately 1,2 million Euros as net profit lost by farmers; however, this loss should be compared to the gains in terms of welfare that the society gets from a better environment. This benefit should be quantified as the relation between it and the value that the society gets from the flow maintenance.

Finally, it is necessary to introduce the present research into Basin Plans and Cost-Effectiveness Analysis of Measures as presented by the WFD. Thus, we can compare the rise of welfare based on the improvement of river flows, to the decrease of the local agrarian sector production.

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[1] Shortage = Water demand over the available offer, what makes it necessary to use instalments or administrative systems to balance both of them. Drought = Drastic reduction of water offer that makes it necessary to apply exceptional measures. Rainfall is the atmosphere's water contribution as rain, snow or hail.

[2] Provisional data, the estimated figure is 751.785 ha for December 2007.

[3] In the year 2015, water cost is calculated based on the price of water, adding the cost of a pond. Then, the cost of water is: (0,0382+0,001+0,2) €/m^3*Total used water (m^3/ha)

[4] This is used to convert the irrigation units. It is changed from cubic meters to hectares per millimetre.

Appendix 1

Table A1 2005 Data.

	Hm^3	m^3/ha	mm ETP	Olive Kg./ha	Net Margin (€/ha)	Δ Net Margin (€/ha)	Paid Labour (€/ha)	Family Labour (€/ha)	Total Labour (€/ha)	GVA (€/ha)
Unirrigated	0	0	391	2.640	2.120	--	187	72	259	2.307
50% Available Uses	19,81	922	483	4.536	2.686	0,61	322	124	446	3.076
Available Average Use	39,63	1.843	575	6.250	3.259	0,62	443	171	614	3.770
No environmental flow	41,88	1.948	586	6.420	3.315	0,54	455	175	631	3.839
Authorized Uses	59,36	2.761	667	7.552	3.694	0,47	536	206	742	4.297

Tabe A2. 2015 Scenario Data

	Hm^3	m^3/ha	mm ETP	Olive Kg./ha	Net Margin (€/ha)	Δ Net Margin (€/ha)	Paid Labour (€/ha)	Family Labour (€/ha)	Total Labour (€/ha)	GVA (€/ha)
Unirrigated	0	0	391	2.640	905	--	187	72	259	1.092
50% Available uses	19,81	922	483	4.536	1.334	0,47	322	124	446	1.876
Available average use	39,63	1.843	575	6.250	1.701	0,40	443	171	614	2.585
No environmental flow	41,88	1.948	586	6.420	1.734	0,31	455	175	631	2.655
Authorized Uses	59,36	2.761	667	7.552	1.927	0,24	535	206	742	3.122

Rational use of water resources in Cyprus

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Abstract. For Cyprus, water is the most important resource and a prerequisite for progress. Its scarcity has acted as a limiting constraint for the development of agriculture and for other economic activities such as tourism. Irrigated land accounts for 35.100 hectares or 16,2% of the total area; 57% of the annual amount of water for irrigation purposes is provided mainly from Government Irrigation Schemes. In the Government schemes, the sources of water used are surface water, groundwater and reclaimed water. As a rule, the water demand in the non-Government schemes is satisfied by groundwater. The scarcity of water together with the high cost associated with collecting and using the limited surface rainwater for irrigation, has become a real constraint for our irrigated agriculture. This is why, particular emphasis is placed on the water use efficiency and modern irrigation technology. Modern irrigation systems have been used in Cyprus agriculture for the last 40 years. It is estimated that currently over 95% of the total irrigated land of the country is being served by modern irrigation methods. Recently, particular emphasis has been laid on protected cultivation and more specifically on the cultivation of vegetables and flowers in substrates and soilless cultures (closed and open systems with minimum drainage). At the Agricultural Research Institute, the use of local materials i.e. perlite, mixtures of perlite with pomace, almond shells, pine bark etc. have been tried successfully. In this paper, results of the application of modern techniques, hydroponic cultures, re-circulation of irrigation water and nutrient solution in closed systems and control of the climatic conditions in the greenhouse are discussed. In making the supply meet the demand the Government policy has encouraged and adopted management measures as water rationing, increase in public awareness for water conservation measures and water pricing for improvements in the water use efficiencies. The main measures, as well as the new Government water policies, are discussed in this paper.

Keywords. Water saving – Water management – Irrigation water – Irrigation methods – Water supply – Water demand – Water policies.

Utilisation raisonnée des ressources en eau à Chypre

Résumé. *Pour Chypre, l'eau constitue une ressource fondamentale et une condition incontournable pour le progrès. La pénurie d'eau est donc une contrainte majeure pour le développement de l'agriculture et des autres activités économiques telles le tourisme. Les terres irriguées s'élèvent à 35.100 hectares soit 16,2 % de la superficie totale ; 57 % de la quantité annuelle d'eau d'irrigation est fournie principalement à travers les Périmètres d'Irrigation Gouvernementaux. Dans ces derniers, les sources utilisées sont les eaux de surface, les eaux de nappe et les eaux assainies. En règle générale, la demande d'eau dans les périmètres non gouvernementaux est satisfaite en utilisant l'eau de nappe. La pénurie d'eau et les coûts élevés liés à la collecte et à l'utilisation des eaux de pluie limitées pour l'irrigation représentent un obstacle réel pour l'agriculture irriguée dans ce pays. Par conséquent, on accorde une attention particulière à l'utilisation efficiente de l'eau et aux technologies d'irrigation modernes. Ces 40 dernières années, des systèmes d'irrigation modernes ont été employés dans le domaine de l'agriculture à Chypre. On estime qu'à l'heure actuelle, plus de 95 % de la superficie irriguée totale est desservie par des méthodes d'irrigation modernes. A présent, on s'intéresse de plus en plus aux cultures protégées et notamment, à la production de légumes et de fleurs sur substrat et en culture hors-sol (circuits clos et ouverts avec un drainage minimum). Différents matériels locaux tels la perlite, les mélanges de perlite et marcs, coques d'amandes, écorce de pin etc., ont été testés avec succès à l'Institut de recherche agricole. Les résultats de l'application des techniques modernes, des cultures hydroponiques, de la recirculation de l'eau d'irrigation et des solutions nutritives dans des systèmes clos et du contrôle des conditions climatiques en serre sont passés en revue. Pour pouvoir faire face à la demande, le Gouvernement a entrepris une politique d'encouragement et a adopté des mesures de gestion comme le rationnement de l'eau, la sensibilisation à la préservation de l'eau et la tarification de l'eau pour accroître l'efficience d'utilisation. Enfin, on illustre les mesures principales et les nouvelles politiques de l'eau mises en place.*

Mots-clés. *Économie d'eau – Gestion de l'eau – Eau d'irrigation – Méthodes d'irrigation – Approvisionement en eau – Demande d'eau – Politiques de l'eau.*

I – Irrigated agriculture

Cyprus is the third largest island in the Mediterranean with an area of 9251 km^2 (925000 ha). Presently, the agricultural land consists of 216000 ha. The irrigated land amounts to 35100 ha (16.2% of the total agricultural land - Agricultural Statistics 2002) with provision to be expanded. The irrigated agriculture in semi-arid countries like Cyprus demands large amounts of water and faces the serious challenge to increase or at least sustain agricultural production while coping with less and/or lower quality water.

There is an increasing concern about the effective and efficient utilization of water for agriculture and water conservation in general. The promotion of effective water use and on-farm water management were identified as important contributions to the management strategy (Chimonides, 1995), needed to address problems of water scarcity and practicing intensive agriculture on environmentally sound grounds. Improving the water use efficiency at farmer's level is the major contributor to increase food production and reverse the degradation of the environment or avoid irreversible environmental damage and allowed for sustainable irrigated agriculture (Papadopoulos, 1996). The overall target is to maximize positive impacts of irrigation and minimize potential environmental hazards. The interaction between agricultural production and the environment should be complementary rather than competitive for balanced development of both. In the same line, in scheduling irrigation it is also important to identify the critical periods (stages) during which plant water stress has the most pronounced effect on growth and yield of crops, since this is also directly related to the nutrients requirement by the crop (Chimonidou, 1996).

Hence, the Government decided to improve the situation by creating and strengthening, with personnel and equipment, the Water Use Section of the Department of Agriculture in 1960 and by applying the water Use Improvement Project in 1965 and water supply (Special measures) Low No. 35 of 1965. With the creation of the Agricultural Research Institute in 1965 experiments were carried out on basic concepts of soil-water plant relationships (Chimonides, 1995).

1. Irrigated crops (permanent, annual)

The percentage of water demand for permanent and annual crops is 59% and 41%, respectively. This accounts for 95,8 MCM/year and 65,5 MCM/year.

From 35.100 hectares of irrigated crops, 19.100 refer to temporary crops, while 16.000 refer to permanent crops. The main irrigated temporary crops are vegetable and melons with 27,6%, followed by fodder crops with 12,8% and cereals with 11,4%. The main irrigated permanent crops are citrus with 15,3% followed by fresh fruits with 10,2%, olives and carobs with 9,4% and Vines with 7,1% (Agricultural Statistics, 2002).

2. Origin of irrigation water

A percentage of 57% of the annual amount of water for irrigation purposes is provided mainly from Government Irrigation Schemes. In the Government schemes the sources of water used are surface water, groundwater and reclaimed water. As a rule, the water demand in the non-Government schemes is satisfied by groundwater.

Surface Water: Surface Water: Although the capacity of all main dams is 273.6 MCM, the average annual amount of water available for use is estimated to be about 112.5 MCM. Out of the 112.5 MCM, 93 MCM are used within Government Projects, 14.5 MCM for domestic use (after treatment) and 5 MCM for ecological areas.

During the dry year of 2005, the contribution to irrigation of all dams was 63 MCM while for 2006 it was only 39.5 MCM. Today the situation is very difficult since in our dams the stored capacity is only 13.5 MCM (August 2008).

Groundwater extraction is estimated to be about 127.4 MCM on an annual basis. Such figure does not mean the safe yield of the aquifers, which is much lower. From this amount, 100.4 MCM are used for agriculture (26 MCM are within the Government Irrigation Schemes and 74.4 MCM are outside the Government Schemes).

Springs contribute very little, amounting to 3.5 MCM per year, for domestic use in the mountainous villages.

At present, desalination units contribute up to 33.5 MCM per year.

Treated sewage effluent: Presently, only about 3.5 MCM are used, from which 2 MCM for agriculture and the rest for landscape irrigation.

II – Methods of irrigation and irrigation technology

Modern irrigation systems have been used in Cyprus agriculture for the last 30 years. Due to the relatively high installation cost, the drip method was initially used for irrigation of high value crops, such as greenhouse vegetables and flowers. At a later stage the installation cost was reduced, and the use of drippers, minisprinklers and low capacity sprinklers was expanded for irrigating trees and field vegetables. Proper hydraulic design of the irrigation systems, offered free of charge by the Ministry, coupled by a subsidy of the installation cost, resulted in a rapid expansion of the new irrigation systems.

Farmers have extensively adopted modern irrigation systems. The new technology introduced is continuously being tested by the Agricultural Research Institute in order to evaluate the different systems under local conditions and select the appropriate irrigation method for each cultivation (Metochis and Eliades, 2002).

For densely spaced field vegetables like potatoes, carrots, beans, etc. the permanent low capacity sprinkler system is recommended for irrigation. However, in case of limited financial resources, the portable sprinkler system can be used instead, although it requires more labour.

Drip irrigation is the only applicable method for irrigation of row vegetables grown in greenhouses, low-tunnels and in the open field, spaced at a relatively great distance on the row and between rows. One nozzle is usually installed to deliver water to each plant. Among permanent plantations, drippers are mainly recommended for banana, grapes and several other crops, like aromatic plants. Generally, unless there is a particular problem, drippers with larger nozzle opening are preferred, because they are not easily blocked by impurities; therefore, they require less filtering and they are characterized by higher uniformity in flow.

For irrigation of permanent tree plantations both drippers and minisprinklers can be successfully used. No differences have been observed concerning crop development and production; therefore, the choice of the irrigation method depends on several other factors. Minisprinklers are generally preferred and are more widely used for irrigation of trees, mainly due to lower installation cost. Moreover, as nozzle opening is relatively large, they are not easily blocked by impurities present in the irrigation water.

The introduction of modern irrigation systems in Cyprus resulted in the expansion of irrigated agriculture, increase of water use efficiency and production, and improvement of yield quality. Continuous testing of new technology and instrumentation is always required for further improvement of the design and management of the systems.

It is estimated that currently over 95% of the total irrigated land of the country is being served by modern irrigation methods. With the improved irrigation systems and the scheduling of irrigation based on experimental work of the Agricultural Research Institute, the overall water use efficiency at farmers' level is above 80%.

1. Modern irrigation technology

Modern irrigation technology has moved very rapidly from an experimental technique to a commercially significant method of irrigation. The ability to carefully control water application not only offers improved efficiency in the use of an increasingly scarce natural resource for agriculture, but also opens the door to new and more efficient ways to manage fertilizers and other agricultural chemicals.

Perhaps the most significant trend has been towards greater control and automation of the frequency and amount of water application, using programmable computer-based systems and including such devices as sequential metering valves and sensors to monitor weather and soil moisture variables. More recently, new drip-irrigation systems have been introduced for use with wastewater in both agricultural and garden settings. The rubber tubes of these pipes have a labyrinth "toothed" water passage, which facilitates superior filtration. Chemigation and particularly fertigation are yet other developments of major importance (Papadopoulos, 1996).

2. Protected cultivation and Soilless culture

In most Mediterranean countries the problem of an adequate water supply to meet the present and future demands of irrigated agriculture is very important. Water supply must be used in the most efficient way especially in countries where water is scarce, of high cost and in most cases of poor quality.

The area under protected cultivation represents only 1% of the total area, uses the minimum quantity of water and gives the highest return/income compared to the rest of the irrigated cultivations. The greenhouse cultivations represent the most profitable crops per volume of water (m^3). This is a very important consideration in countries of the Mediterranean region since water is the limiting factor in agricultural production (Chimonidou, 2000).

The scarcity of water, together with the high cost associated with collecting and using the limited rain water for irrigation, has become a real constraint for our irrigated agriculture. Because of this, alternative water resources, innovative approaches and new technologies are sought to help solve the problem. Development of more efficient irrigation methods to save water, better utilization of marginal quality water, and the turn to intensive irrigated agriculture, protected cultivation and soilless culture are promising alternative and innovative approaches (Chimonidou, 2000).

Recently, particular attention was given to soilless cultivation and the area under soilless culture is rapidly expanding. Experiments at the Agricultural Research Institute showed that the local materials (i.e. perlite, pomace, almond shells and pine bark) can be also used as substrates for rose cultivation without any reduction in the total productivity or the quality of the roses produced. On the contrary, higher productivity was recorded in the substrate of pine bark and almond shells (50:50), followed by the substrate of perlite and pomace (50:50). Significant differences were observed also on the weight of the flower stems of the roses produced on the substrate of pine bark and almond shells (50:50). Irrigation levels of 800 ml (6 times/day X 2 min) and 530 ml (4 times/day X 2 min), irrespective of substrate, did not have any significant effect on the quality or quantity of the roses produced (Chimonidou *et. al.*, 2007).

Experiments conducted on other cut flowers (i.e. Lysianthus) showed that no significant differences existed between the different substrates or the stressed and not stressed plants with respect to total productivity (number of stems) or the quality characteristics (number of flower buds, stem length and fresh weight) of the variety Eustoma grandiflorum. On the contrary, the plants under the low level of irrigation (530 ml/ day = reduction 33%) lasted more days in vase with or without preservative (Chimonidou *et al.*, 2003).

3. Hydroponic systems

The open system for soilless culture is at present the most favoured commercially in Cyprus due to its simplicity, mainly in managing the nutrient solution.

Pollution of the environment (underground water), waste of fertilizers and water are though only some of the problems faced in open hydroponic systems. The leachate is usually collected in a reservoir and is used for the fertigation of open cultures or greenhouse cultivations in the soil. This results in approximately 30% loss of fertilizers and water from the system.

For this reason ARI started a research program in order to develop a locally adopted closed hydroponic system, using locally available inert substrates, like crashed gravel produced in a copper mine in Cyprus. The leachate from the substrates is collected in a tank and is recirculated after being sterilized passing through a UV lamp. The EC and pH of the water are regulated using an automatic fertilizer-mixing unit as by the open system. The water consumption of a well-managed closed system is reduced to the evapotranspiration level of the plants. The system requires water of very good quality that is difficult to find in Cyprus. In the coastal areas where greenhouse cultivation has developed due to the favourable climatic conditions, the ground water salinity ranges from 1.5 to 4 dS/m, whilst the salinity of water coming from dams is around 1 dS/m. The fresh water supplied to the closed system can be therefore rainwater collected from the greenhouses or water treated by a small reverse osmosis unit. Thus, the need for replacing the nutrient solution due to the increasing concentration of chlorides and sodium is minimized. The experiments are carried out at the ARI research station at Zygi on tomato cultivation (Polycarpou and Hadjiantonis, 2004).

In addition, an open system using a mixture of locally available organic materials with perlite or peat moss as substrate is being studied in floriculture. In this “zero loss” system, the nutrient solution is supplied to the plants, planted in big boxes (substrate volume 15 liters/plant), in such a quantity that leaching just starts. In this way the water and fertilizer loss from the system is minimal. The salts are pushed by the irrigation water away from the root zone and are accumulated in the outer volume of the substrate not affecting the growth of the plants.

In designing and operating such a closed hydroponic system, the following main parameters are to be considered:

Crop related matters such as the life span of the crop, the water and nutrient requirements (recipe) and the cultural practices needed.

Method for fertilizer mixing and supply of irrigation water (Using simple volumetric fertilizer injectors or automatic fertilizer mixing units).

Use of locally available inert substrates like perlite, coarse sand, crashed gravel vs. imported inert materials like rock wool.

Climate Control in Greenhouses, like monitoring the aerial climate requirements (temperature, relative humidity, light, CO_2, etc), the root zone requirements (root temperature and O_2 supply in the root zone) and improving the PAR transmission of covering materials and lowering their NIR transmission.

Due to the advantages of the closed hydroponic system compared to the open one, ARI is investing a lot of efforts in optimizing its parameters, simplifying its operation and training the growers in its effective management and utilization (Polycarpou and Hadjiantonis 2004).

III – Water resources assessment and water policy

1. Water supply

The maximum quantity of water, for calculating its availability for planning purposes, is the mean annual long term precipitation that is 513 mm (1987-2000) times the area that is 9250 Km2. It corresponds for the whole island to approximately 4600 million cubic meters (MCM) of water per year. More than 80% of this returns to the atmosphere through evapotranspiration. Only the remaining 20%, i.e. about 900 MCM, can be considered as the actual water available for use. From this, 600 MCM is surface water and the rest i.e., 300 MCM, flows into the aquifers. The above are estimates of 1970 and refer to the whole island. They are based on rainfall-runoff and groundwater hydrology relationships of past years. Since then, rainfall has decreased considerably, more than 13%. Consequently, there is a noticeable decline of the surface and groundwater sources. It is estimated that the reduction may be as high as 30 to 40%. A reassessment of both the surface and subsurface hydrology is urgently needed, for meaningful planning and management of the water resources of the island (Socratous, 2003).

The drastic reduction of the water supply coupled with the concurrent increase of the demand for water have brought about the full utilization and even overuse of the available traditional water sources, i.e. groundwater and surface water. Groundwater is reliable, clean and cheap when compared to other sources. The result is that all aquifers in Cyprus are today exploited beyond their safe yield, which is estimated at 230 MCM per year. The excess pumping over natural recharge is in the order of 40 MCM per year. The result is sea intrusion into most of the coastal aquifers. The Government of Cyprus embarked in 1960, the first year of its independence, into an ambitious program of tapping the surface waters that used to be lost into the sea. This program was in essence a comprehensive water resources program that was produced in 1967 to 1970 with the technical help of the United Nations Development Programme. Thanks to this program the storage capacity of surface reservoirs has reached 327,5 MCM from a mere 6,1 MCM in 1960. The yield of these reservoirs is about 130-150 MCM/year. This value is now seldom reached because of the decline in rainfall and hence of runoff (Socratous, 2003).

Now, as the conventional water sources are reaching saturation in their development, the Government is planning the use of treated sewage as the additional main source for water supply for agriculture and the use of desalination water for domestic purposes.

The first large sewage treatment plant in the Government-controlled areas started operating in Limassol in the summer of 1995. Sewage treatment plants are now under design or construction in all the major cities and sensitive mountain villages of Cyprus. All municipal sewage treatment plants have provisions for tertiary treatment. Projections estimate that the volume of reclaimed sewage effluent will increase to 25 MCM by the year 2020.

Desalination of seawater was first introduced in Cyprus on a large scale basis, on the 1st of April 1997, with the operation of 20 000 m^3/day reverse osmosis Dhekelia plant. Due to the drought prevailing at the time, the plant was soon expanded to 40 000 m^3/day. The plant operates on a Build, Own, Operate, Transfer (BOOT) basis and the desalinated water is presently sold to the Government, at source, at a varying unit price which is about £0,54/m^3. A new seawater desalination plant, of 51 667 m^3/day nominal capacity, has been constructed next to the Larnaca airport. It started normal operation in February 2001. This too, is a reverse osmosis BOOT type plant. The cost of the water from this plant is only £0,43/m^3. However, the present tragic situation demands the construction of another 30 000 to 40 000 m^3/day seawater desalination plants. In this way, the domestic water demand for water will not any more be dependent on the vagaries of the weather.

Other tertiary or exotic sources of water supply, such as, importation of water from abroad, artificial rainfall, undersea fresh water tapping, underground deep drilling and evaporation suppression from water surfaces are not economically justifiable and/or risky and unreliable (Socratous, 2003).

2. Rainwater harvesting

The government promotes the collection of rain water from the roofs of greenhouses for irrigation purposes. This is achieved by installing a simple rain harvesting system next to the greenhouse. The water falling on the greenhouses is collected and stored in a water reservoir for later use. The reservoir is dug in the soil and a UV stabilized plastic membrane is used for preventing water leakage. The good quality water harvested can be used for leaching the salts from the soil, or for irrigation of the crops. Considering the yearly rainfall in Cyprus this would mean a water supply of about 20% of the irrigation water needs of the crops in greenhouses. An area of about 4 times that of a greenhouse would be enough to cover the entire needs of a greenhouse.

3. Water demand

Domestic use and irrigation are the two main sectors of water demand. The total water consumption in the Government controlled areas in 1994, a year having no appreciable water supply restrictions was 235 MCM, of which 55 MCM was for the domestic sector. The industrial and tourist demand were 6 and 11 percent respectively of the total domestic consumption. Gross and net consumption of water was 220 l.p.c.d. and 140 l.p.c.d. respectively. This compares well with consumption in most European countries. As the tourist industry seeks new forms of recreation e.g. golf facilities, the water demand for recreation will be increasing. It is conservatively estimated that the domestic water demand will rise to 100 MCM in 2020. Irrigation water use in 2007 in the Government controlled areas totalled up to 73.9 MCM i.e., 67.5% of the total water demand. More than half of this amount was supplied from Government water works. The demand for irrigation water will increase to 225 MCM by 2015. Demand for irrigation water is expected to remain stable thereafter.

4. Water management

In making the supply meet the demand, the Government policy has encouraged and adopted such management measures as water rationing, increase of public awareness for water conservation measures and water pricing for improvements in the water use efficiencies.

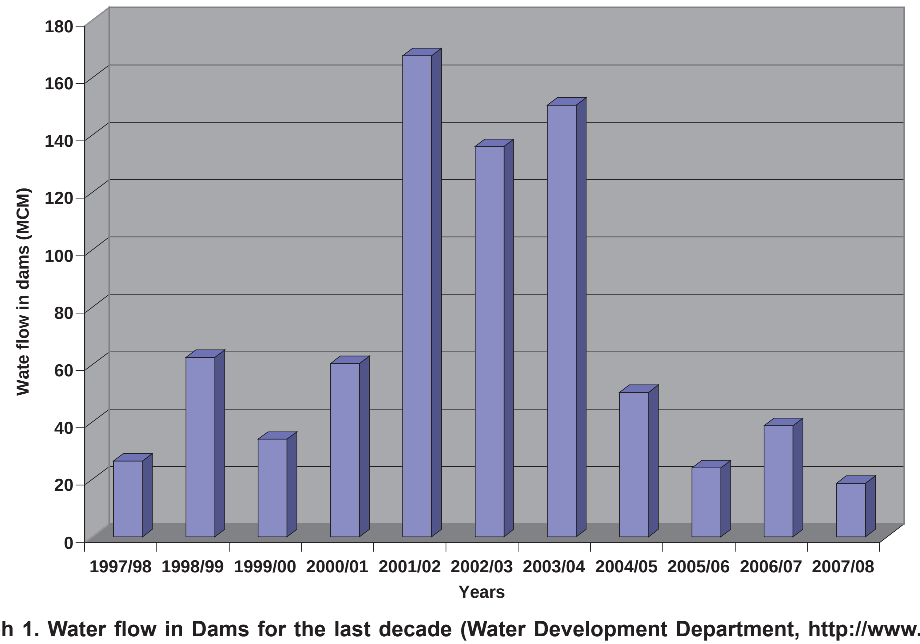
Water rationing has been extensively applied in an attempt to curtail the demand in periods of drought. This has allowed the authorities in the last year to reduce the water by 30% of the normal demand for domestic purposes and by 50 percent for irrigation purposes. Water conservation measures include subsidies for use of inferior quality groundwater or the treatment of the grey water from households for the flashing of toilets and irrigation of house gardens in the cities. Furthermore, the campaign for raising the “water awareness” of the public towards water conservation proved to be successful. Now, water pricing is an integral part of the Government policy on water. Water for municipal including industrial, commercial and tourist purposes is sold at full cost, while irrigation water is heavily subsidized by as much as 77 percent. The Governments´ policy towards agriculture is very generous and this has contributed to the selection of non-efficient cropping patterns and even to the wastage of water. It should be noted that in the last six years the water tariff for the domestic sector does not reflect the full cost as is formed with the recent introduction of the comparatively expensive desalinated water. The subsidy is as high as 34 percent. The present price of the water to agriculture and domestic sector is 6.5 c/m3 and 33,5 c/m3 respectively (Socratous, 2003).

The disruption of water supply from the governmental water works forced the greenhouse growers to use saline water from boreholes with negative impact on the soil salinity. The bad water quality led the growers to the solution of water purification through reverse osmosis. This technology utilizes about 60% of the water and the rest that is heavily loaded with salts is rejected to the environment causing pollution problems. Table 1 shows the water balance and water reserved in dams for the years 2007/08 and Graph 1: Water flow in Dams for the last decade.

In addition to the above, the Ministry of Agriculture, Natural Resources and Environment have announced measures for saving drinking water, such as periodic water supply to the households, subsidizing the excavation of private drills for irrigation and other domestic purposes, promote the installation of domestic water recycle systems and initiate campaigns for public awareness.

Table 1. Water Balance and Water Reserves in Dams for the year 2007.

	Water Sources	MCM
Water reserves in dams on 1/1/2007		60.5
Plus	Water flow in Dams	38.8
	Desalinization units	30.0
	Drills	6.7
	Recycled water	4.2
Less	Watering	-73.9
	Irrigation	-35.6
	Evaporation, losses, enrichment	-17.3
Water reserves in dams on 1/1/2008		13.4



Graph 1. Water flow in Dams for the last decade (Water Development Department, http://www.moa.gov.cy/moa/wdd).

5. New Water Policy

It is apparent, by a simple comparison of the supply and demand, that the current water situation is not sustainable. The recent droughts of 1989/91 and 1995/2006 demonstrate quite convincingly how critical the water situation may become. A new water policy is warranted that will bring about sustainability. The new water policy should include the following specific measures.

a. Secure additional sources of supply

b. Ensure efficient use of available water

c. Modify the current irrigation water allocation matrix

d. Build up strategic water reserves

e. Maintain and enhance the quality of water

f. Introduce new effective/efficient management procedures through the establishment of a Water Entity.

These measures should be holistically applied. Each measure compliments the other.

The basic water policy of the Government is the production of desalinised sea water, the use of non-conventional sources such as the use of recycled water for irrigation, recharge and amenity purposes, the desalting of brackish water, the efficient use of available water including the better use of pricing and water conservation measures, the harmonisation with the European acquis, the protection, preservation and improvement of the water quality, the introduction of new effective management procedures through the establishment of a Water Entity and the development of the remaining existing water resources with the construction of dams until 2015.

The government water policy focuses on the maximum potential exploitation of non-conventional water resources, such as recycled water, the use of which produces equal quantities of good quality water. Tertiary treated recycled water is used for irrigation of existing cropping land and for recharging aquifers. Full exploitation of recycled water is a long-term costly process, the success of which will decrease or even eliminate the necessity to build more desalination plants.

As regards the installation of sewage central collection and treatment systems, within the framework of harmonization with the European aquis, a program has been established for the installation of central sewage systems in all areas with equivalent population if over 2000 persons. The harmonization program will be completed by 2012. In parallel, the establishment of sewage systems in smaller rural communities that do not fall within the harmonization obligations (with population less than 2000 persons), is being promoted, because these communities have sewage disposal problems.

The construction of additional water works, such as new dams and expansion of irrigation networks, as provided in the Strategic Water Development Plan for the period up to 2015, is also under development.

In addition, the implementation of the Water Framework Directive constitutes an integral part of the government policy. The objective of this Directive is the conservation, improvement and safeguarding of the good condition of water bodies (surface, groundwater and coastal) until 2015 and the development of a river basin management plan at river basin level (WDD, http://www.moa.gov.cy/moa/wdd).

IV – Conclusions

Water is by far the most precious resource in Cyprus. The quality of life and almost all economic activities depend upon the presence of an economic water supply. The present water situation is not sustainable in spite of the impressive development of the conventional surface water sources in the last four decades. Much has been done but still a lot remains to be done in the realm of water resources development and management. A new approach is presented that ensures sustainability of the water sector of the island.

The targets of this new plan are summarized below:

a. The relief of the domestic sector from the vagaries of the weather;
b. The increase of water tariffs for all uses;
c. The use of recycled water for amenity purposes and irrigation;
d. The formation of underground strategic reserves;
e. The reduction of horizontal expansion of irrigation;
f. The changing of the cropping pattern to less water demanding crops;
g. The preservation and further enhancement of the water quality;
h. The formation of a Water Entity.

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Water pricing as a means to ensure water conservation: A case study from Palestine

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Abstract. Water pricing has gained widespread acceptance as a valuable and versatile tool to promote a number of goals. Borland and Whittington (2000) have identified the main goals of water pricing as follows: economic efficiency, revenue stability, equity, income redistribution, and water resource conservation. Therefore, policies should be as simple and as transparent as possible, they should also be both publicly and politically acceptable in order to reduce friction among the public and the governing bodies. In most developing countries, water management has reached its limit at the centralized level. Water supply infrastructure has been developed to serve large portions of the population in these countries including Palestine. It is now the task of local governments to provide their citizens with potable water at a price that people can afford, and at a price that will create revenue stability for the utilities in charge of supply and distribution while ensuring water use efficiency and revenue redistribution. What this demands is a pricing scheme that needs to be tailored to the social, economic, environmental and political situation of the respective country. In the West Bank, water supply management is highly scattered and is not well organized. There are many actors charged with the task of supplying water for the communities. In addition, the current situation of most of the water utilities in the West Bank reveals that the financial inefficiencies that they are faced with are partly due to the economic hardship facing people as a result of the political situation and partly ascribable to unclear pricing policies. The current paper is based on a research conducted by PHG on developing a sound pricing policy in Palestine.

Keywords. Water pricing, – Water conservation – Income redistribution – Revenue stability – Stakeholder participation – Local water supply management.

Tarification de l'eau comme moyen pour assurer la conservation de l'eau: un cas d'étude en Palestine

Résumé. *La tarification de l'eau est largement acceptée comme un outil valable et versatile pour atteindre un certain nombre d'objectifs. Borland et Whittington (2000) ont identifié les objectifs principaux de la tarification de l'eau, à savoir: l'efficience économique, la stabilité des recettes l'équité, la redistribution du revenu et la préservation de la ressource eau. Il s'ensuit que les politiques dans ce secteur devraient être aussi simples et transparentes que possible et en même temps, acceptables d'un point de vue public et politique afin de réduire la friction entre le service public et les organismes chargés de la gestion. Dans la plupart des pays en développement, la gestion de l'eau a atteint ses limites au niveau de la centralisation. Les infrastructures pour l'approvisionnement en eau ont été développées pour desservir une grande partie de la population dans ces pays, y compris la Palestine. Aujourd'hui, ce sont les gouvernements locaux qui devraient assurer aux citoyens l'eau potable à un prix abordable et capable de créer une stabilité des recettes pour les entreprises chargées de l'approvisionnement et de la distribution, tout en garantissant l'efficience d'utilisation de l'eau et la redistribution des recettes. L'enjeu est donc d'adopter un régime de tarification prenant en compte les conditions sociales, économiques, environnementales et politiques du pays concerné. En Cisjordanie, la gestion de l'approvisionnement en eau est très fragmentée et mal organisée. Il existe plusieurs acteurs chargés de fournir l'eau aux communautés. En plus, actuellement, la plupart des entreprises de l'eau sont concentrées en Cisjordanie, ce qui laisse ressortir les faiblesses financières auxquelles elles doivent faire face et qui sont imputables, d'une part, aux difficultés économiques dont souffre la population à cause de la situation politique et d'autre part, aux politiques de tarification peu transparentes. Le présent travail se base sur une recherché menée par le Palestinian Hydrology Group concernant le développement d'une politique de tarification raisonnée en Palestine.*

Mots-clés. *Tarification de l'eau – Conservation de l'eau – Redistribution du revenu – Stabilité des recettes – Participation des parties prenantes – Gestion locale de l'approvisionnement en eau.*

I – Introduction

The water sector in the West Bank and Gaza has remained undeveloped over the past three decades of occupation. Since 1967 West Bank water resources have been controlled and managed by the Israeli Military Authority through a number of Military Orders. These orders have barred Palestinians from participating in the planning and management of water resources and prevented them from developing local water resources in concert with growing water needs.

During this time, management of public resources was completely within Israeli domain; decisions were made without Palestinian participation, and with little regard for Palestinian needs and interests. As a result, the Palestinians have developed a distrustful, often antagonistic relationship with public authorities. Respect for public goods and public management decisions represented acceptance of or agreement with the Israeli occupation.

The lack of investments in improving infrastructure (physical water losses reach 50% in some areas), the scattered nature of the water supply and management utilities with the absence of adequate rules and regulations and absence of stakeholder participation has resulted in the deterioration of the entire water system.

In reality, the change in the political process in the early nineties was not merely an opportunity for greater water use, but rather a challenge to form new, responsive public institutions to govern water sector properly. It is for that the Palestinian Water Authority (PWA) was established in 1995 and was assigned the task of formulating and implementing a comprehensive water strategy and water law, which would entail setting up adequate rules and regulations including proper water pricing policy for the West Bank and Gaza. Due to the fact that Palestinians have not gained yet the full control over their water resources and the issue has been left to the final status negotiation, PWA faced with many constraints to implement the Water Law. Accordingly, no final regulation on water pricing policy has been formulated as of yet. The existing pricing schemes are those ones prior to the establishment of the water authority. They reflect mainly accounting costs of supply and allocation at each locality, while neglecting many of the economic, social and environmental costs aimed at generating a higher level of efficiency in the sector. As a result, public satisfaction with the current pricing policies hasn't been met in most of the areas in the West Bank.

In an earlier research done by Palestinian Hydrology Group (PHG), it was shown that the pricing policies used by various municipalities varied substantially, with tariffs ranging anywhere from 0.19 $\$/m^3$ (in Qalqiliya) to as high as 1.69 $\$/m^3$ (in Bethlehem). However, it may reach nearly 3 $\$/m^3$ in some localities where no proper water supply systems exist. Water obtained by Tankers may cost 5-6 $\$/ m^3$ in the areas lacking water supply services (40% of localities) in the same time the quality they get is much lower.

To further exacerbate the situation, it was shown that no local water utility in the West Bank was recovering accounting costs in excess of 85%. In some areas cost recovery was as low as 62%. It is worth noting that these recovery costs do not take into account any social, environmental, or opportunity cost.

It is with this in mind that PHG has undertaken the "pricing policy" research project, with the following main objectives :

1. Increase transparency of policy reform through the analysis of publicly collected data on affordability, willingness to pay, and water use levels in the West Bank;

2. Fostering participatory decision making mechanism in the field of Water Resources Management;

3. Formulating a water pricing policy that will meet the criteria of economic efficiency, effectiveness, affordability, democracy, legality, water conservation and revenue stability.

II – Research Problem

In recent years, water pricing has gained widespread acceptance as a valuable and versatile tool for municipalities and utilities to promote a number of goals. The most common goals associated with a sound water pricing policy, as specified by Borland and Whittington (2000), are identified as: economic efficiency, revenue stability, equity, income redistribution, and resource conservation. In addition to these five cardinal objectives, it is also important to consider the socioeconomic implications of the policy, and therefore policy makers must also strive to formulate a policy that will be both publicly and politically acceptable. In order to reduce friction from the public as well as the governing body, a policy should also be as simple and as transparent as possible, which will only lead to greater ease in the implementation of any water rate structure.

Much of the debate concerning the issue of water pricing has regarded the issue of decentralization of water management and the role local municipalities play in the process of policy formulation and implementation. In most developing countries, water management has reached its limit at the centralized level. Water supply infrastructure has been developed to serve large portions of the communities in these countries including Palestine. It is now the task of local governments to provide their citizens with potable water at a price that people can afford, and at a price that will create revenue stability for the utility in charge of supply and distribution. What this demands is a pricing scheme that needs to be tailored to the social, economic, environmental and political situation of the respective country.

In the West Bank, water supply management is highly scattered and is not well organized. There are many actors charged with the task of supplying water for the communities. The lack of cooperation between the utilities has been one of the major factors contributing to the inefficient methods of pricing, supply, and distribution. The result of this is that we find areas where a low-income household is spending 15% or more of their yearly income on household water use alone. And given the inelastic demand of water used for household consumption, little can be done to avoid these high costs of water.

In addition, the current situation of most of the water utilities in the West Bank reveals that the financial inefficiencies that they are faced with are mainly because of the people's inability to pay for the water supply services. Moreover, the water pricing policies adopted by these utilities rarely reflects the public willingness to pay and to the extreme, it is sometimes driven by political motives rather than social, economic or environmental values. For example, in areas where water prices have traditionally been low, local municipalities face pressure to keep that price (often times artificially) low, regardless of whether it is a true reflection of the total cost of water. This creates a vicious cycle that neither allows for sufficient revenue stability, nor provide sufficient incentives for the consumer to practice any type of water conservation practices. These two effects combined have a devastating impact on the water utilities themselves and on the general welfare of the public.

Accordingly, it is imperative that one of the main goals of any water pricing policy reform in the West Bank should be the socially equitable and just administration of potable water. In brief, the price of water is a major lifestyle determinant in the West Bank. Therefore, margin families will receive the greatest marginal benefit from a pricing policy that considers their socioeconomic circumstances. Conversely, they will face the greatest marginal cost if water policy fails to address their needs. This would entail to consider both environmental and social (user) costs when developing such policy. These two costs represent externalities that must be included in the final price of water in order for the local utilities to gain the public acceptability and insure full cost recovery of supplying water to the public for domestic use. Any failure to do so will only result in further deficits, decline in revenue stability and hence will lead to further deterioration of both water infrastructure and services.

The current paper is summarizing most of the concerns listed above and tried to reflect public opinion in the formulation of the basis for the future water pricing policy in Palestine.

III – Methodology

After reviewing the existing literature concerning the different economic theories, social aspects, willingness to pay models and their valuation techniques and game theories, special attention was given to the decision theory and bidding game in particular. The decision theory establishes that if people are not able to communicate about their decisions they usually have a worse outcome as when they were able to talk with each other about it. The bidding game is a tried and tested method to determine the willingness to pay for water. This is based upon the premise that the water supply is regular, clean and potable. The game allows the users to imagine that they are bidding for water in accordance with their current income levels.

The main concepts established were to define the best methods of reflecting the willingness to pay while assessing the various factors influencing it. In addition, to assess the gender aspects of water issues and to reflect on the water use practices and the level of awareness that people have. Furthermore, the relation between the water price and the quantity used as well as how a sound pricing policy might influence the rationing of water use was also studied.

These concepts were reflected in a form of questionnaire. After that a sample size has been selected using multistage stratified cluster sampling and conducted on four stages:

a) Selecting a population location using probability proportional to size sampling (PPS);

b) Selecting a cluster or census track from the population location. The cluster or the census track contains approximately 100 to 150 households;

c) Selecting 1 household from the cluster using systematic sampling;

d) Selecting an adult from the people living in the selected household using simple random sampling.

Despite the fact that cluster sampling is less efficient than simple random sampling, yet it is more cost effective. Accordingly, a margin of error of 4% was considered under simple random sampling then the effect that should be used under cluster sampling to produce the same margin of error was derived. It was concluded that the sample size would be around 1250 households, then reduced to reflect real target population to 1190 +-10%.

The questionnaires were then classified for both clusters of the communities connected to water supply and those who are not connected, and distributed to the pollsters in the different parts of the West Bank. It is good to mention that the pollsters were divided into groups of two one male and one female for the same cluster. The rationale behind sending one male and one female to the same cluster is to reflect the gender aspects properly in the survey. In addition, it is socially more acceptable to females in the team to enter houses when the head of the house is not there and the female pollster can interview the female respondent in the house.

Following to the completion of the survey, questionnaires were analyzed using one of the specialized statistical packages (SPSS), and results generated. However, it was realized that there are some aspects that could not be covered by the questionnaires. Therefore, a second track was used to capture such information using focus group meetings.

The methodology used in the meetings was the participatory rapid appraisal (PRA). The PRA method allows people to go beyond the quantitative aspects that are covered by the questionnaire. It also attempted to promote open group discussion on the value placed on water. In addition, different tools such as the matrix mapping and pie chart were used during the meetings.

The results obtained on willingness to pay and affordability, public perception, the type and efficiency of water pricing schemes in place and the gender perception of water issues in conjunction with the information collected through focus group meetings together with the findings of the theoretical background of economic theories and the actual socio-economic conditions in the West Bank were then used to propose a draft water pricing mechanism to be considered in Palestine.

IV – Discussion

It was realized that water pricing policy is not just about money and law. It is in the first place about people. What people are willing to pay and what they can afford to pay for the water? How do they value water and how do they perceive water pricing policy?

Accordingly, the challenge was how to address these issues and how to adequately value water in a way that people will endorse and deal with it. Mitchell (1984, quoted by Brooks *et al.*) presents three procedures that provide a framework for placing a value on water.

- Next best alternative: a value can be assigned to water in terms of the cost of the next best alternative. This approach reflects the cost of obtaining and delivering alternative supplies;
- Value-added: the value of water can be established with reference to the value added to the manufacturer's products or consumer's satisfaction. This concept also applies in the case of water uses that deplete or degrade the water supply for downstream users;
- Intrinsic value: an intrinsic value could be assigned to water before it is developed, as is done with other natural resources, such as oil and gas. The cost to the user would include this intrinsic value of water plus the costs of supply, treatment, and distribution. One way to determine the in-source value of water is through bargaining among interested parties. Other ways involve techniques such as willingness-to-pay and contingent valuation.

The main message adopted from conducting the valuation is that, the later is a useful process whereby it assist in safeguarding the public interest through defining the net benefits in excess of costs imposed on third parties or environment; it will also assist in monitoring and regulating water exchange; and finally will assist in developing better water pricing by addressing the people's WTP and the demand elasticity for different types of uses, purposes, quality and reliability in the different seasons of water demand.

Determining people's WTP is always a relative issue since there is often a gap between what people say and what they actually do. The challenge is how to narrow this gap and how to be as much close as possible to the real price that people is willing to pay under various conditions. Although many do not trust WTP for policy recommendation because it is hypothetical data and not market data. In theory, the Compensated Income Variation (CIV) or the Equivalent Income Variation (EIV) can measure WTP (Van Ireland, 1993). Both measure the consumer surplus, the CIV measures how much income is needed to put a consumer at his initial level of utility to prevent being at a lower indifference curve. The EIV measures how much income the consumer is willing to sacrifice (and go back to the initial utility level) in order not to face the new prices. Therefore, water pricing policy is not just one figure or one scenario, it is merely a mix of scenarios under which prices are set for water.

The issue that remains is how best to advocate for such water pricing policy. The pricing notion often creates some reaction especially at the poorer sectors of the community. Therefore, it is imperative to introduce the pricing as a regulatory mean and as an incentive to achieve water conservation within a framework of water policy. It is also imperative that such policy clearly addresses the interest of the different groups, including the most marginal part of them and adopt means that ensures social fairness among all layers of society. The principle of "the more you use the more you pay" is just a means to ensure this and also to ensure rationing of water use. In addition, people participation in developing the water pricing policy will create an ownership obligation that people may adopt.

Therefore, it was realized that the best approach to adopt in developing the water pricing policy for Palestine was the increased block tariff (IBT) approach where it ensures the basic needs at lower price, where poorer sectors can afford. In the mean time, it compensates for the cost by charging those who use more in a manner that the richer sector will subsidy the poorer sector. In this way more social cohesion and farness might be felt in the society. In addition, IBT rate structure is designed to promote the conservation of water. As the price per unit of water increases with each block, it is assumed that given water is a normal good, consumption will decrease. People will be less likely to use water in wasteful ways or in ways where its benefit is below its cost.

It is concluded that a proper water pricing policy would need three main issues: regulation, economics and information. Moreover, to ensure people participation, a good governance system needs to be in place. It is clear that good governance would entail the presence of adequate regulation which is based on proper laws. In the mean time economic means will be necessary to develop the viable pricing policy and finally the information is very crucial for both categories to be realized and for the actors to know better about their system. Numerous studies have shown that water pricing policies are most effective when they are used in conjunction with complimentary legislative mechanisms and other economic incentives such as increased options for reallocation of water among water users and public support .

V – Results

It was found that there is large spatial variation in the water use and water price across the West Bank districts. However, it can be concluded that there is an inverse relation between the price of water and the quantity used in the areas that traditionally have no abundant water while it was difficult to provide a clear relation in the areas that traditionally have water abundance such as Tulkarm, Qalqilia and Jericho in the case of connected areas. The comparison was much harder in the case of the areas not connected, as shown in Figures 1 & 2.

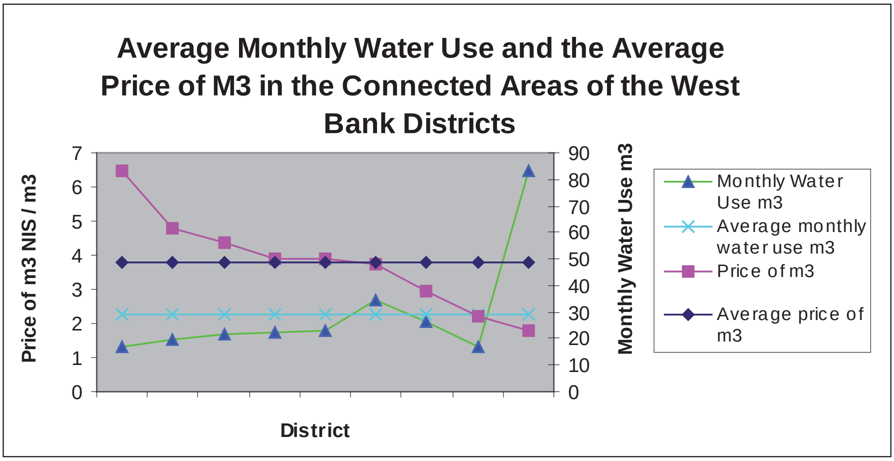

Figure 1. Water use and water price in the connected areas.

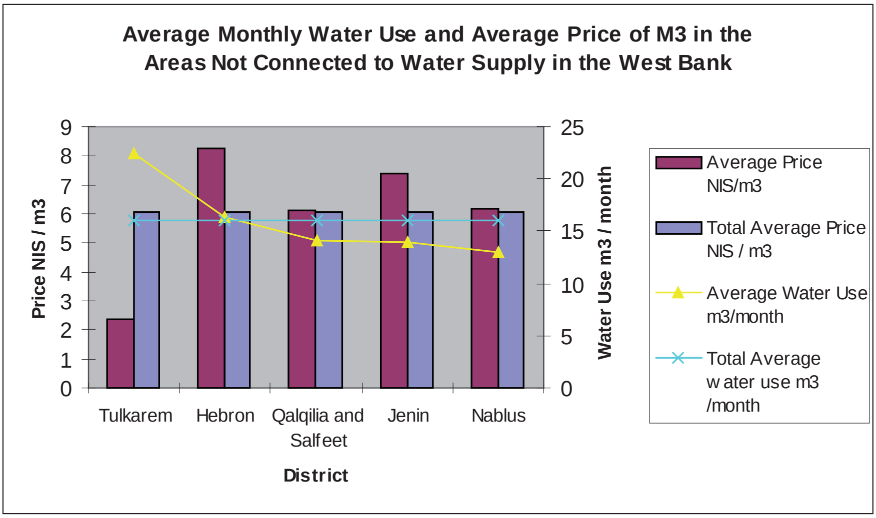

Figure 2. Water use and water price in the areas not connected.

As can also be seen from the two figures when the price of water is much below the average price, water use is much higher than the average in the two examples mentioned earlier.

In addition, it was realized that there is a big gap between the current water use levels and the quantities needed in the areas not connected with water supply in Palestine as shown in figure 3.

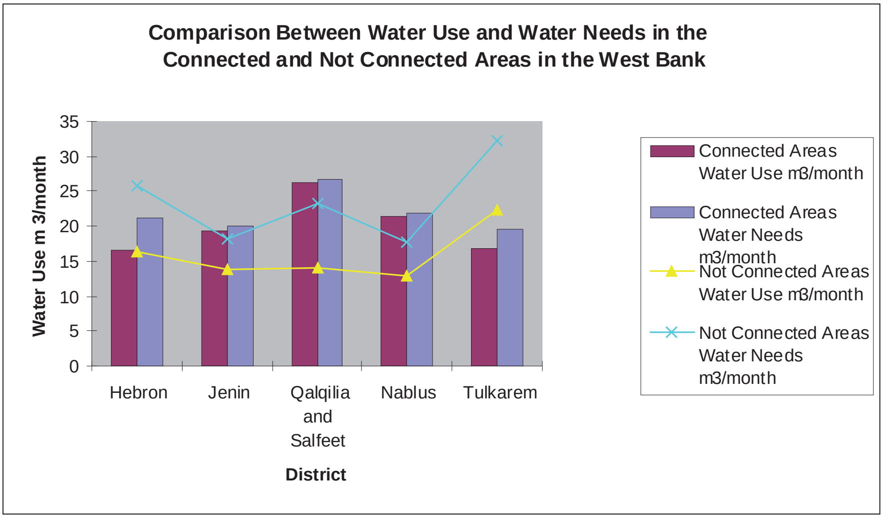

Figure 3. Water use versus water needs in both connected and not connected areas.

Generally speaking people in both connected and not connected areas are aware of the importance of rationing water use. However, they don't do much to practice such rationing. It will be important to conduct a public awareness campaign for rationing the water use in the West

Bank for both areas. Table 1shows no much difference in several features and practices in both areas. The major differences are in the areas of grey water reuse, the use of toilet flush and the cause of water problem. It is obvious that people with less water quantities available will do every possible effort to use the water as much efficient as they can. This of course is certainly done on the expense of other issues such as hygiene.

Table 1. Water conservation and water use practices in the connected and not connected areas in the West Bank.

Connected areas	Unconnected areas
85.9% open the faucet at low level during water use	88.5% open the faucet at low level during water use
96% uses water for main needs	96% uses water for main needs
79.9% use old faucets	86.4% use old faucets
27% re-use grey water	55.24% re-use grey water
88.7% are aware of importance of rationing water use	92.4% are aware of importance of rationing water use
51.3% mop the floor instead of washing it	69.7% mop the floor instead of washing it
50.4% don't irrigate gardens	58% don't irrigate gardens
46.6% don't use the hose	57% don't use the hose
78.25% don't use any mean to reduce water in toilet flushes	80.6% don't use any mean to reduce water in toilet flushes
21.6% of houses lack the flushing toilet system	56.8% of houses lack the flushing toilet system
90% support the need to pay for water	86.4% support the need to pay for water
7% disagree with the need to pay for water	10% disagree with the need to pay for water
96.9% reject illegal water connection	96.4% reject illegal water connection
33% attribute water problem to Israeli control of Water Resources	87% attribute water problem to Israeli control of Water Resources
77% support women's strong role in water resources management	80% support women's strong role in water resources management

The gender issue was one of the key issues that was also analyzed. The main issues addressed are the difference between males and females in the water use practices, the willingness to pay for water and the attitude toward women participation in managing water resources. The key results obtained from the survey are listed in Table 2.

Table 2. The gender aspects of water in the West Bank

Females	Males
86.4% support the idea of women having strong role in water resources management	74% support the idea of women having strong role in water resources management
63.9% use grey water	46% use grey water
67.5% use the hose	45.3% use the hose
87.5% indicated facing problem of high water prices	95.7% indicated facing problem of high water prices
66.7% are satisfied with the quantities and qualities obtained	46.9% are satisfied with the quantities and qualities obtained
45.6% are worried about waterborne diseases	61.5% are worried about waterborne diseases
79% perceive paying for water	95% perceive paying for water
Oppose illegal connection	Oppose illegal connection
Have strong feeling of responsibility for providing water for future generation	Have strong feeling of responsibility for providing water for future generation

It can be noticed from the table that there is a strong attitude from both males and females toward the women participation in the water management. In addition, the males have a stronger perception to pay for water than females.

VI – Conclusion

- Willingness to pay is generally higher than the level of the current water prices.
- There is a general will to pay for a good and sustainable supply.
- There is substantial variation in the willingness to pay for water between districts and within each district. This makes the development of a comprehensive water rate structure very challenging task in the West Bank.
- The type of water pricing schemes currently exists in the West Bank vary from the flat rate water pricing structures to the increased block tariff water pricing in the best cases. All of them are rarely take into consideration much more than the accounting costs of water supply and distribution.
- It was noticed that there is an inverse relation between the price of water and the quantity used in the areas that traditionally have no abundant water while it was difficult to provide a clear relation in the areas that traditionally have water abundance such as Tulkarm, Qalqilia and Jericho in the case of connected areas.
- People in both connected and not connected areas are aware of the importance of rationing water use. However, they don't do much to practice such rationing.
- It was concluded that people are spending nearly 2% of their monthly income for water, although it can reach 8% at the low income families in the connected areas while people in the areas not connected are paying 3.4% but may also reach 9.5% in the low income families.
- It was noticed that there is a strong well among the people to get connected to sewage systems (92.5%). The majority is also willing to pay for a wastewater service a fixed monthly or yearly payment (58.6%).
- It was concluded that the weighted average water price that people are willing to pay is 6.7 NIS/ m^3 while the largest percentage (nearly 62.5%) indicates that they are willing to pay 3NIS /m^3
- It was noticed that willingness to pay to cover the cost of water and to insure its sustainability is higher at the area not connected than it is in the connected areas.
- It was noticed that the willingness to pay to cover cost is mainly influenced by the geographic location of the respondent. However, this factor is interrelated with income in some districts, with gender in some other districts and with water supply reliability in some others too.
- It was noticed that people are not in favour of privatizing the water services in the West Bank since 96% of them in favour of public sector.

VII – Recommendations

- It is recommended to consider a **progressive tariff system that truly reflects the social and environmental costs of water and allocates the basic water needs for people before water is allocated to other needs in the West Bank.**
- It is recommended to establish a monitoring program that will keep an eye on the changes in water prices and how this will effect the socio-economic and health conditions of the people and assists to set adequate pricing policies for the areas not served with water yet.

- It is recommended to establish a proper mechanism of information sharing and feed back between public and water utilities; especially pertaining to the water prices and the way they have been calculated.
- It is recommended to include social and environmental costs (the major externalities) within water pricing structures in the West Bank.
- It is recommended to develop a flexible water pricing structure in which water prices need to be set at rates equivalent to the rate of natural changes in the supply (scarcity value).
- It is recommended to conduct a public awareness campaign for rationing the water use in the West Bank for both connected and not connected areas.
- It is recommended to conduct a research on willingness to pay for wastewater services (collection, treatment and reuse) in the West Bank.
- It is recommended to organize the water supply to the areas not connected with water more efficiently and to set a price for cubic meter not exceeding the limits that people are willing to pay.
- It is recommended to conduct capacity building programs targeting women to enable them from participating in the management of water resources.

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Third part

Sustainable technological solutions for water treatment, recycling and reuse

Treating emerging contaminants (pharmaceuticals) in wastewater and drinking water treatment plants

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Abstract. In this study the behaviour of several pharmaceuticals belonging to different therapeutic categories (analgesics and anti-inflammatory drugs, lipid regulators, antibiotics, etc.) was monitored during the treatment of wastewater in a laboratory-scale membrane bioreactor (MBR) and in a full-scale drinking water treatment plant (DWTP) using reverse osmosis (RO) and nanofiltration (NF). The results of MBR were compared with the removal of the target compounds in a conventional activated sludge (CAS) process in an existing wastewater treatment facility. The performance of an MBR was monitored during approximately two months in order to investigate a long-term operational stability of the system and a possible influence of solid retention time on the removal efficiencies of target compounds. The behaviour of the selected pharmaceutical residues facing an NF/RO membrane and evaluation of the performance of this kind of advanced treatment was studied under real conditions of a full-scale DWTP. Excellent overall performance of both NF and RO was noted, with high rejection percentages for almost all of the pharmaceutical residues investigated (>85%), while in wastewater treatment using an MBR the pharmaceutical compounds were generally removed to a higher extent than during CAS process.

Keywords. Pharmaceuticals – Membrane bioreactor (MBR) – Conventional activated sludge (CAS) – Nanofiltration (NF) – Reverse osmosis (RO).

Traitement des contaminants émergents (composés pharmaceutiques) dans les stations d'épuration des eaux usées et de traitement de l'eau potable

Résumé. *Le but de cette étude a été de suivre le comportement de plusieurs composés pharmaceutiques appartenant à diverses catégories thérapeutiques (médicaments analgésiques et anti-inflammatoires, régulateurs des lipides, antibiotiques, etc.) pendant le traitement des eaux usées dans un bioréacteur à membrane (BRM) à l'échelle de laboratoire et dans une station de traitement de l'eau potable (STEP) à grande échelle, utilisant le traitement par osmose inverse (OI) et par nanofiltration (NF). Les résultats du BRM ont été comparés avec ceux obtenus par l'évacuation des boues activées conventionnelles dans une usine de traitement des eaux usées. La performance du BRM a été évaluée pendant environ deux mois afin de déterminer la stabilité d'exploitation du système à long terme et l'influence possible du temps de rétention des solides sur l'efficience d'évacuation des composés cibles. Le comportement des résidus pharmaceutiques sélectionnés vis-à-vis d'une membrane de NF/OI et la performance de ce type de traitement avancé ont été étudiés dans les conditions réelles d'une station de traitement de l'eau potable à grande échelle. On a mis en évidence une performance générale excellente aussi bien dans le cas de la NF que dans le cas de l'OI, avec des pourcentages élevés de rejets pour la quasi-totalité des résidus pharmaceutiques considérés (>85%). Par ailleurs, dans le traitement des eaux usées, le BRM s'est avéré être plus performant que le système des boues activées conventionnelles pour l'élimination des composés pharmaceutiques.*

Mots-clés. *Composés pharmaceutiques – Bioréacteur à membrane (BRM) – Boues Activées Conventionnelles (CAS) – Nanofiltration (NF) – Osmose Inverse(OI).*

I – Introduction

Pharmaceuticals in their native form or as metabolites are continuously introduced to sewage waters mainly through excreta, disposal of unused or expired drugs or directly from pharmaceutical discharges. During the treatment at wastewater treatment plants (WWTP), they are either partially retained in the sludge, or metabolized to a more hydrophilic, but still persistent form that passes the wastewater treatment plant and ends up in the receiving waters. The removal of pharmaceuticals in WWTPs is variable and depending on the properties of the substance and process parameters (i.e. sludge retention time (SRT), hydraulic retention time (HRT), temperature) (Clara *et al.,* 2005; Vieno *et al.,* 2005). A large number of pharmaceuticals is hardly eliminated and therefore detected in WWTP effluents. The presence of pharmaceuticals in surface and drinking water is well documented in literature (Ternes, 1998; Heberer, 2002; Metcalfe *et al.,* 2003; Giger *et al.,* 2003; Castiglioni *et al.,* 2006; Gros *et al.,* 2007). Although present in low environmental concentrations, drugs can have adverse effects on aquatic organisms. These effects are rather chronicle than acute toxic effects, depending on the exposure factor (bioavailability), degradability and susceptibility of the compound in question (Jemba, 2006).

Therefore, in order to ensure compliance with future discharge requirements, an upgrading of existing wastewater treatment facilities and implementation of new technologies is required as a next step in the improvement of wastewater treatment. Membrane bioreactor (MBR) treatment is an emerging technology based on the use of membranes in combination with the traditional biological treatment. MBRs are considered as promising technologies to achieve further removal of micro-pollutants in comparison to conventional WWTP. This is due to two characteristics of MBRs, (a) the low sludge load in terms of biological oxygen demand (BOD) that can be expected to force bacteria to mineralize also poorly degradable organic compounds and (b) the high sludge age that gives bacteria the time to adapt to these substances (Ghyoot and Verstraete, 2000; Wei *et al.*, 2003).

Another advanced technique that has been gaining attention during the last few years is nanofiltration (NF) and reverse osmosis (RO) treatment. These two treatments seem to be able to effectively remove most organic and inorganic compounds and microorganisms from raw water (Chellam *et al.*, 1997; Gagliardo *et al.*, 1998) and have been widely applied to drinking water treatment and wastewater reclamation.

The objective of this work was twofold: (i) to assess the viability of MBR operating under anaerobic conditions in the treatment of pharmaceuticals in relatively low strength wastewaters in municipal applications and (ii) to evaluate the performance of full-scale NF and RO drinking water treatments in rejecting pharmaceutical residues from rather contaminated groundwater.

II – Methods

1. Conventional activated sludge (CAS) treatment at wastewater treatment plant (WWTP)

WWTP Rubí was designed for 125.550 equivalent inhabitants. During the sampling campaign WWTP was operating with an average daily flow of 22.000 m3 day-1. Treated wastewater is a mixture of municipal, hospital and industrial wastewater. The treatment consists of a pre-treatment, preliminary treatment, primary sedimentation unit and a secondary (biological) treatment. Pre-treated wastewater goes through a physical process of settling in a primary clarifier. Secondary treatment consists of a pre-denitrification (anaerobic) and nitrification (aerobic) tank, and two secondary clarifiers. Secondary sludge is being recirculated to a primary clarifier which improves settling characteristics of primary sludge and also increases sludge age. Mixture of primary and secondary (activated) sludge is being processed (thickening, dewatering) and anaerobically digested, and biogas produced is being used for heating of a digester. Hydraulic retention time of CAS treatment in WWTP Rubí, calculated for an average daily flow, is approximately 12 h. During the performed sampling campaign, the plant was operating with SRT of approximately 3 days. WWTP effluent is being discharged into the river Riera de Rubí, which flows into the Mediterranean sea.

2. Membrane bioreactor (MBR)

A submerged MBR of approximately 21 l of active volume and equipped with 2 flat sheet membranes (A4 size, area 0.106 m2, pore size 0.4 µm) purchased from Kubota (Osaka, Japan) was installed in a municipal WWTP in Rubí (Barcelona, Spain). Although the nominal porosity of the membranes was 0.4 µm (microfiltration) a fouling layer formed on the surface of the membranes out of proteins and microorganisms brought up the effective porosity of 0.01 µm, which put the filtration type into the range of ultrafiltration. The biocenosis of the MBR was grown from the inoculated sludge from municipal WWTP (aeration basin) and cultivated over a period of approximately 1 month to reach steady state conditions. The hydraulic retention time was set to 14 hours by regulating the effluent flow, while SRT was infinite since there was no sludge discharged from the reactor. A laboratory-scale MBR was operated dynamically in an intermittent permeation mode: cycles of 8 minutes of permeation interrupted with 2 minutes of halt. Influent and permeate flows were controlled using flow meters and computer controlled pumps. A continuous aeration was provided by a sparger pipe situated at the bottom of the reaction vessel, keeping the oxygen concentration between 1 and 2 mg L-1. The temperature inside the reactor was 20º ± 2ºC during the whole sampling campaign. For more details see Radjenovic *et al.* 2007.

3. Nanofiltration and reverse osmosis waterworks

The sampled DWTP located in NE-Spain is able to treat 200 Ls-1 and supplies drinking water to around 50,000 inhabitants. The DWTP works with three treatment lines operating in parallel, one equipped with NF, and two lines equipped with RO membrane filtration racks (see Figure 1). All three lines are fed from groundwater wells.

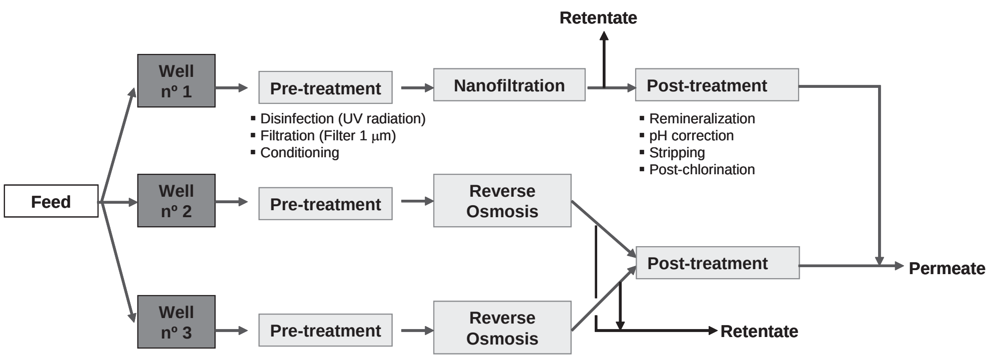

Figure 1. Scheme of nanofiltration and reverse osmosis treatment lines at the DWTP Besós.

The RO rack consists in two parallel stages, whereas the first has 40 membrane modules and the second one 20 (each one consists in 6 "loose" RO membranes type BW30LE-440, Dow-FilmTec). The NF line comprises also two stages, with 31 and 15 membrane modules, respectively, equipped with 6 "tight" NF membranes (NF90-400, Dow-FilmTec) each. The treatment consists in pre-treatment (UV radiation, filtration and conditioning), NF/RO filtration and post-treatment (remineralisation, pH correction, stripping by CO2 and post-chlorination). After the filtration stage, treated water from all three lines is being further processed before sending to water network in a joint post-treatment step. During the pre-treatment, UV radiation is used to sterilize the entering water and to eliminate present organic matter before its entrance to the membrane's rack. Next, filtration is achieved by two cartridge filters (selectivity 1 µm; each filter has 180 cartridges) which are functioning alterably: when the filter in operation gets abrupt by impurities, the other one is set to function while the first one is being cleaned. Finally, water is conditioned with sodium hydrogen sulphate that prevents bacterial growth, eliminates organic matter, reduces free chlorine content (that can damage the membranes) and also water oxygen content (that causes corrosion), and lowers its pH. Moreover, a dispersant is added in order to lower water hardness.

4. Chemical analysis

All target compounds were extracted in one single extraction step, according to the previously published analytical method (Gros *et al.*, 2006) using Oasis HLB cartridges (200 mg, 6 ml) from Waters Corporation (Milford, MA). The elution was performed two times with 4 ml of methanol at a flow of 1 ml min-1. The extracts were then evaporated under a nitrogen stream and reconstituted with 1mL of methanol-water mixture (25:75, v/v).

LC analysis was performed using a Waters 2690 HPLC system (Milford, MA, USA) coupled to a Micromass Quattro (Manchester, UK) triple quadrupole mass spectrometer, equipped with a Z-spray electrospray interface. Chromatographic separation was achieved with a Purospher Star RP-18 endcapped column (125 x 2.0 mm, particle size 5µm) and a C18 guard column, both supplied by Merck (Darmstadt, Germany). Details of specific multi-residue analytical method applied for the analysis are published elsewhere (Gros *et al.*, 2006), with the addition of hydrochlorothiazide and glibenclamide. Recoveries of the method were determined as follows: groundwater samples were spiked in triplicate with a standard mixture of selected compounds to a final concentration of 1 µg L-1. Spiked samples together with a blank sample were analysed by the above mentioned method. Method detection limits (MDL) and method quantification limits (MQL) were calculated by a signal- to-noise ratio (S/N) of 3 and 10, respectively. Recoveries of the target pharmaceuticals were in the range 43.6% (mevastatin)-112.3% (glibenclamide), whereas for most of the compounds they were very satisfactory (>75%). Method detection limits (MDLs) were in the range 0.03 (azithromycin)-16.2 ng L-1 (lansoprazole).

III – Results and discussion

1. RO and NF

The sampling campaign was done in waterwork Besós (Barcelona, Spain) during September-December, 2006. In total 70 samples were analyzed, 45 samples from reverse osmosis (RO) pilot plant, and 25 samples from nanofiltration (NF) pilot plant. Compounds that were detected in feed stream (groundwater) of all five sampling campaigns and at relatively high concentrations (>100 ng L-1) were diuretic hydrochlorothiazide, analgesics and anti-inflammatory drugs ketoprofen, diclofenac and propyphenazone, lipid regulator pravastatin and antiepileptic drug carbamazepine. Excellent overall performance of both NF and RO was noted, with high rejection percentages for almost all of the pharmaceutical residues investigated. Pharmaceutical residues detected in all five sampling campaigns were analgesics and anti-inflammatory drugs ketoprofen, diclofenac, acetaminophen and propyphenazone, β-blockers sotalol and metoprolol, antiepileptic drug carbamazepine, antibiotic sulfamethoxazole, lipid regulator gemfibrozil and a diuretic hydrochlorothiazide. Highest concentrations in feed stream (groundwater) were found for a diuretic hydrochlorothiazide, analgesics and anti-inflammatory drugs ketoprofen, diclofenac and propyphenazone, lipid regulator pravastatin and antiepileptic drug carbamazepine (>100 ng L-1). No removal in either of the investigated processes was seen for psychiatric drug paroxetine and β-blocker propranolol (<20%). However, since these two pharmaceutical residues were detected only in one or two sampling campaigns, this data cannot be taken as conclusive. Due to the high efficiency of NF and RO treatments, permeate concentrations of compounds detected in the feed water were below the limit of detection (bLOD) or below the limit of quantification (bLOQ) in most cases. The highest effluent concentrations were found for hydrochlorothiazide and gemfibrozil that had NF permeate concentrations of 73.0 and 60.0 ng L-1, whereas their RO permeate concentrations were slightly lower- 24.6 and 33.5 ng L-1, respectively (see Table 2). Removal rates of the detected pharmaceuticals were calculated and they are presented in Fig. 2.

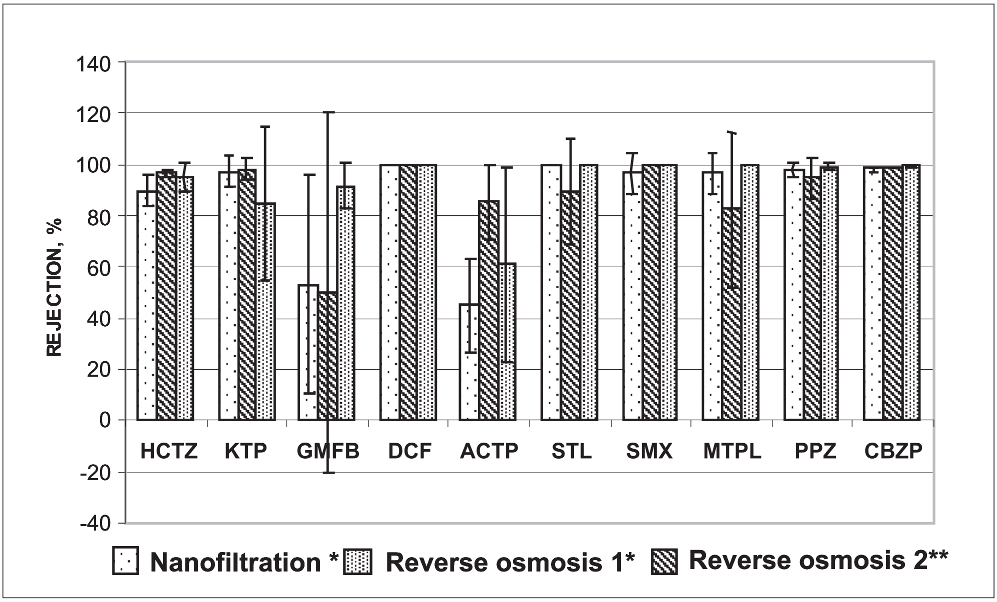

Figure 2. Rejection efficiencies in conditioning, UV, NF/RO stage of treatment are illustrated for frequently found pharmaceutical residues. Rejections are presented as mean values, with their corresponding RSDs for the NF and RO filtration stages (*N=5, **N=4). HCTZ-hydrochlorothiazide, KTP-ketoprofen, GMFB-gemfibrozil, DCF-diclofenac, ACTP-acetaminophen, STL-sotalol, SMX-sulfamethoxazole, MTPL-metoprolol, PPZ-propyphenazone, CBZP-carbamazepine.

Table 2. Concentrations ranges and frequencies of detection of compounds in permeate water of NF and two RO treatment lines of Besós waterworks.

Compounds	Frequency of detection in NF permeate (N=5)	NF permeate concentration (ng L^{-1})	Frequency of detection in RO permeate (N=9)	RO permeate Concentration (ng L^{-1})[a]
Hydrochlorothiazide	5	2.6-329.7 (73.0)	9	0.8-117 (24.6)
Ketoprofen	1	bLOD-37.3 (7.5)	2	bLOD-51.4 (8.0)
Gemfibrozil	3	bLOD-297.9 (60.0)	4	bLOD-288.3 (33.5)
Diclofenac	0	bLOD	0	bLOD
Acetaminophen	4	bLOD-9.3 (bLOQ)	5	bLOD-16.7 (bLOQ)
Sotalol	0	bLOD	1	bLOD-3.1 (bLOQ)
Sulfamethoxazole	1	bLOD-4.8 (bLOQ)	0	bLOD
Metoprolol	1	bLOD-8.1 (1.6)	2	bLOD-13.5 (2.6)
Propyphenazone	3	bLOD-7.9 (3.2)	4	bLOD-12.0 (2.4)
Carbamazepine	5	0.5-5.7 (2.3)	7	bLOD-1.8 (0.9)
Mefenamic acid	3	bLOD-19.9 (4.5)	4	bLOD-19.8 (4.7)
Glibenclamide	1	bLOD-2.9 (bLOQ)	2	bLOD-2.8 (bLOQ)
Propranolol	2	bLOD-57.8 (11.6)	2	bLOD-51.5 (10.3)
Ofloxacin	1	bLOD-7.0 (bLOD)	1	bLOD-11.5 (bLOQ)
Pravastatin	0	bLOD	0	bLOD
Erythromycin	0	bLOD	0	bLOD
Loratidine	0	bLOD	0	bLOD
Nifuroxazide	1	1.0	0	bLOD
Bezafibrate	1	bLOD-1.1 (bLOD)	2	bLOD
Atenolol	1	bLOD-0.3 (bLOD)	0	bLOD
Paroxetine	1	bLOD-3.9 (0.8)	2	bLOD-2.2 (0.8)

[a]Permeate water concentrations are presented as a range, with mean values inside the brackets.

2. MBR

The performance of an MBR was monitored during approximately two months in order to investigate a long-term operational stability of the system and a possible influence of solid retention time on the removal efficiencies of target compounds. In general pharmaceuticals were removed to a higher extent in the MBR integrated system than during CAS process. For most of the investigated compounds, MBR treatment had a better performance (removal rates>80%) and steadier effluent concentrations than the conventional system (e.g. diclofenac, ketoprofen, ranitidine, gemfibrozil, bezafibrate, pravastatin, ofloxacin) (see Table 1). In some cases the removal efficiencies were very similar and high for both treatments (e.g. ibuprofen, naproxen, acetaminophen, paroxetine, hydrochlorothiazide). The antiepileptic drug carbamazepine turned out to be the most persistent pharmaceutical as it passed both through MBR and CAS system untransformed. Since there was no washout of biomass from the reactor, high-quality effluent in terms of chemical oxygen demand (COD), ammonium content (N-NH4), total suspended solids (TSS) and total organic carbon (TOC) was obtained.

Table 1. Mean removal of selected pharmaceuticals for MBR and CAS process

Compound	Elimination in MBR, %[a]	Elimination in CAS,%[b]
Naproxen	99.3 (1.52) *	85.1 (11.4)
Ketoprofen	91.9 (6.55)	51.5 (22.9)
Ibuprofen	99.8 (0.386)	82.5 (15.8)
Diclofenac	87.4 (14.1)	50.1 (20.1)
Indomethacin	46.6 (23.2)	23.4 (22.3)
Acetaminophen	99.6 (0.299)	98.4 (1.72)
Mefenamic acid	74.8 (20.1)	29.4 (32.3)
Propyphenazone	64.6 (13.3)	42.7 (19.0)
Ranitidine	95.0 (3.74)	42.2 (47.0)
Carbamazepine	no elimination**	no elimination
Paroxetine	89.7 (6.69)	90.6 (4.74)
Ofloxacin	94.0 (6.51)	23.8 (23.5)
Sulfamethoxazole	60.5 (33.9)	55.6 (35.4)
Erythromycin	67.3 (16.1)	23.8 (29.2)
Atenolol	65.5 (36.2)	no elimination
Metoprolol	58.7 (72.8)	no elimination
Hydrochlorothiazide	66.3 (7.79)	76.3 (6.85)
Glibenclamide	47.3 (20.1)	44.5 (19.1)
Gemfibrozil	89.6 (23.3)	38.8 (16.9)
Bezafibrate	95.8 (8.66)	48.4 (33.8)
Clofibric acid	71.8 (30.9)	27.7 (46.9)
Pravastatin	90.8 (13.2)	61.8 (23.6)

* values are presented as average with relative standard deviation (%) in brackets, for [a]N=10 and [b]N=8 samples.

**as to "no elimination" all cases with elimination efficiency below 10% were considered.

IV – Conclusions

For most of the investigated pharmaceuticals MBR effluent concentrations were significantly lower than in the effluent of a conventional treatment. Hydrochlorothiazide and paroxetine had slightly higher elimination percentages in CAS. Some substances were not removed neither in MBR nor in CAS process (e.g. carbamazepine). However, no relationship was found between the structures of target compounds and their removal during wastewater treatments. Furthermore, the range of variation of the removal rates of the MBR system was small for most of the compounds, while in the conventional treatment stronger fluctuations were observed and it turned out to be a lot more sensitive to changes in operational parameters (temperature, flow rate, etc).

NF and RO membranes investigated proved to be very efficient in eliminating the pharmaceuticals encountered, having different physico-chemical properties. The removal found for NF treatment was mostly over 85%, with the exception of gemfibrozil (50.2%), bezafibrate (71.8%), atenolol (66.6%), mefenamic acid (30.2%) and acetaminophen. The average removal from two RO treatment lines were slightly higher than for NF filtration (>90%). The only compounds with lower RRs in RO treatment were mefenamic acid (57.9%) and acetaminophen. Paroxetine and propranolol were not eliminated in neither of the treatments, but since they were found only in one sampling campaign no conclusion can be drawn on their behaviour.

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Nanotechnologies and membrane engineering at the core of water and related questions in the Mediterranean and Middle-East countries

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Abstract. After a short recall on the importance of water questions for Mediterranean countries, membranes are presented as breakthrough technologies for the field of desalination. Then basic recalls are done concerning membrane materials and processes. A few examples of new very promising materials and processes operating at the nanoscale, not only for desalination but also with other water treatment applications, are presented. As a conclusion, a few ideas are proposed about the best ways to approach all these questions in the future. Undoubtedly, with cell membranes as an ultimate model, all these breakthrough bio-mimetic approaches offer a privileged direction to reach sustainable development.

Keywords. Membranes – Nanomaterials and processes – Desalination – Water treatment – Mediterranean countries.

Les nanotechnologies et les technologies à membrane au centre des questions relatives à l'eau dans les pays méditerranéens et du Moyen-Orient

Résumé. *Après avoir précisé la centralité des questions relatives à l'eau dans les pays méditerranéens, on va parcourir les technologies à membrane qui représentent une avancée significative dans le domaine du dessalement, en illustrant dans les grandes lignes les matériaux et les processus. Des exemples sont présentés concernant de nouveaux matériaux et processus très prometteurs, utilisés à l'échelle du nanomètre, non seulement pour le dessalement mais aussi dans le cas d'autres applications pour le traitement de l'eau. En conclusion, des propositions sont avancées pour aborder ces questions à l'avenir d'une manière appropriée. Sans aucun doute, avec les membranes cellulaires comme modèle ultime, ces approches biomimétiques innovantes s'avèrent être une voie importante à suivre pour atteindre un développement durable.*

Mots-clés. *Membranes – Nanomatériaux et processus– Dessalement – Traitement de l'eau – Pays méditerranéens*

I – Introduction

«Before conceiving His Creation, God was in a cloud in the sky. Then He created His Throne above water» (Hadith) - For the Koran, water is the essential element of Creation and there is really a sort of "charm" for water in the Holy Book with more than 60 mentions! The religions of the Book - Judaism, Christianity and Islam - took all birth in arid zones, where water remains invaluable -"a gift of God". It was the same with the old Egyptian (with the Nile divinity) or Mesopotamian (Gilgamesh story) civilizations. Thus it is easy to understand why water represents such a huge cultural heritage for all the religions and civilizations born in this part of the world!

Water production for human consumption, irrigation... has become today a crucial question for a lot of countries all over the world, and not only for the MENA countries. Even to a less extent, its importance is great for the south of Europe. The need for replacing this question in a "global situation", by taking into account energy considerations, new waste generation and citizen health, is a new trend. In this way, it is at the core of a huge debate on sustainable development,

preservation of natural resources and well-being of population in a quickly changing world (increase of population, new ways of life, climate changes…)
What solutions? Probably the need for:

- new technologies having the capacity to address the challenges with which we are faced,
- technical skills and expertises necessary for the implementation of these technologies,
- companies working to develop these new solutions,

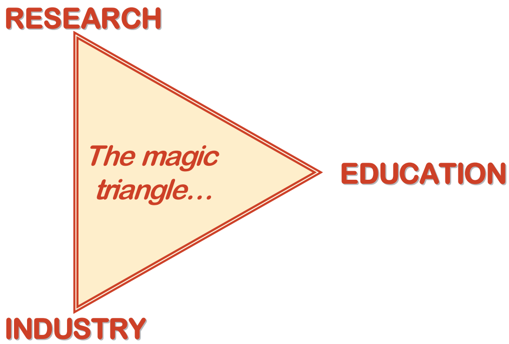

Figure 1. The magic triangle as well as rules to provide the necessary framework for these very ambitious integrated actions and their acceptance by population (information/communication).

II – Desalination and new breakthrough membrane technologies

Desalination is probably as old as human civilization. Socrates already taught students how to distil seawater to obtain fresh water…Today, two groups of technologies must be distinguished: thermal or distillation processes which involve some form of boiling or evaporation with steam generators, heat boilers (Multiple Effect –MED- and Multiple Stage Flash –MSF- distillation) and membrane / RO processes (ordinarily isothermal operations with a significant energy saving … but which produce brines).

The current situation may be quickly summarized as follows (Proceedings of the EuroMed conference, 2006): all the annual fresh water supply for the planet comes from evaporation from the seas; only about 1% of the world potable water is derived from desalination plants; only a lower % is used for industrial needs and practically zero for irrigation; the total capacity of desalination was in 2000 of about 26 million m^3 per day (60% from seawater and 40% from brackish water) and it represents a quickly growing billion-dollar business!

Among the major impetus for strategic opportunities in these fields: a fast growing population (particularly in mega cities along the sea costs), breakthroughs in the reduced energy requirement and investment costs of desalination (from 3 to 5 \$/ m^3 10 years ago to 0.4 to 0.8\$ today before distribution, particularly due to the development of Membrane/RO processes) and in parallel a cost increase of traditional water supply. The very large-scale seawater desalination installations ordered by Israel, Saudi Arabia, Jordan, Florida, Spain… may treat today up to 200,000 m^3/day. Next important challenges will be to change traditional fossil energy supply into renewable energy sources such as solar, photovoltaic, fuel cell technologies or even to set-up nuclear power plant to feed huge desalination plants.

Up to recent years, there has also been a strong and emotional opposition to desalination as too costly, too large in scale, too technical for universal solutions… and some misunderstanding with the traditional water supplier's culture. But today innovative forces and entrepreneurial creativity result from our increased awareness of a world-wide water problem!

Concerning the life cycle assessment (LCA), it appears that desalination based on RO provokes significantly lower environmental load than thermal desalination; but thermal desalination technologies have a great environmental impact reduction when integrated with other production processes as shown in table 1. Thus analysis needs to be done on a case-by-case basis. Concerning marine environment and water quality, there is a potential negative impact of brine discharge (RO) on the ocean floor and benthic environment; but according to the more recent studies conducted in Cyprus or in the USA (Electric Power Research Institute, California Coastal Commission…), it should be managed correctly with appropriate environmental regulations (reject at a depth of 10–15 m, limitations on the chemicals used in the maintenance processes…).

Table 1. LCA details.

	MSF	MED	RO
kg. CO_2 / m^3	23.41	18.05	1.78
g. dust / m^3	2.04	1.02	2.07
g. NO_x / m^3	28.3	21.41	3.87
g. NMVOC[1] / m^3	7.90	5.85	1.10
g. SO_x / m^3	27.91	26.48	10.68

1 non-methane volatile organic compounds

m^3 of desalted water

	MSF	MED
Kg. CO_2 / m^3	1.96	1.11
g. dust / m^3	2.04	1.02
g. NO_x / m^3	4.29	2.42
g. NMVOC / m^3	1.22	0.59
g. SO_x / m^3	14.80	16.11

For processes driven by residual thermal energy

Looking at the market place, it appears that membrane technologies have the main advantages over thermal solutions to be very versatile (applicable to both large- and small-scale needs), and also to be competitive not only in the desalination of seawater but also for water recycling from effluents. All that represents an enormous challenge and opens very bright perspectives for membrane technologies!

You said "artificial membranes"?

Life is based on biological membranes which basically are thin layers separating two media in order to protect one medium from the other, while allowing selective exchanges between them. All the cells of living organisms are surrounded by membranes; our skin is also a fantastic high-tech membrane… Artificial membranes are simplistic industrially-manufactured copies of these biological models. The exchanges are regulated by the external forces - as an example a transmembrane pressure as for reverse osmosis (RO) or an electrical potential for electrodialysis (ED) as shown on figure 2-, the properties of the fluids -which ordinarily circulate in a tangential way as regards the wall to limit fouling and to increase the whole process/system efficiency- and the characteristics of the thin film material – which may be polymeric, inorganic or hybrid, dense or porous, neutral or electrically charged…-. The main performance criteria are the flux (which represents the quantity of fluid crossing the layer) and the selectivity (associated to the balance between the retained and non-retained species) (Basic principles of membrane technology, 1991).

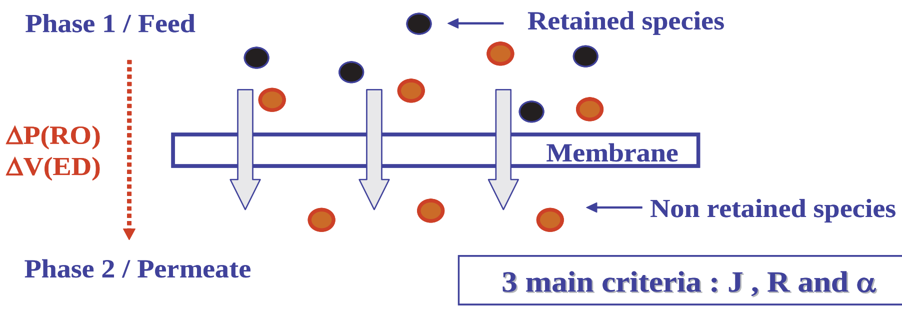

Figure 2. Schema presenting membrane technologies.

The key factor to improve the performance of a membrane operation is to keep the right balance between the limitations induced by the supporting material on the one side, and the fluid phases flowing along it on the other side. With the development of nanotechnology, new materials and concepts have emerged which seem promised to a really bright future.

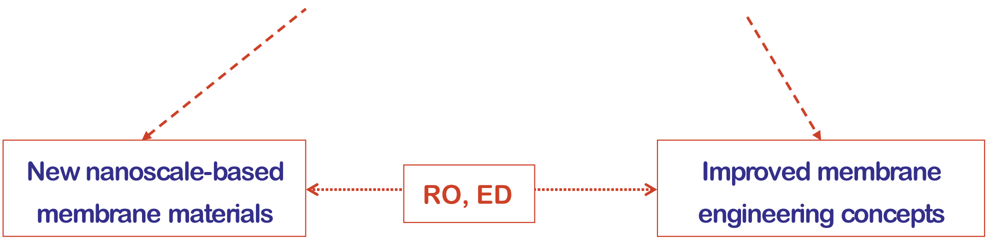

Figure 3. The ways to improve RO and ED.

Due to their intrinsic and well-known characteristics - modularity, easy control, low operating costs, isothermal working, no chemical addition…- membrane operations participate already to pre-treatment, purification and even finishing steps in water and effluents treatment processes like:

- Microfiltration for the separation of small particles and bacteria…
- Ultrafiltration for rejection of colloids, recovery of colorants in textile industries, concentration of oil-water emulsions
- Reverse osmosis for water desalting
- Electrodialysis for recovery of heavy metals from effluents, acid regeneration…

Beyond these "classical" techniques, a lot of other more recent technologies are developing such as membrane contactors and reactors.

III – A few examples of new promising membrane materials

The mixed-matrix membranes (MMMs) are merely hybrid membranes consisting of nanoparticles imbedded into polymeric matrix as represented on figure 4. The presence of nanoparticles allows getting much higher selectivity without compromising the flux. Different concepts are under investigation, which involve zeolites, carbon molecular sieves, other porous particles…or non-porous fillers. The selectivity is linked to the polymer-free volume, the particle size and surface, the presence of covalent bonding…

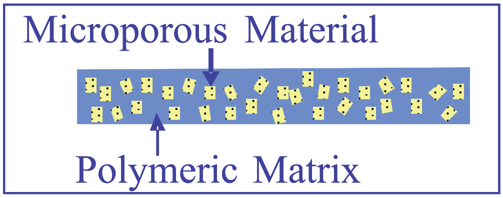

Figure 4. Scheme of an MMM.

An interesting example is provided by the new RO membrane presented by Eric Hoek (E.Hoek *et al.*, 2007) from the University of California to reduce the cost of sea-water desalination and waste-water reclamation. It is a uniquely cross-linked matrix of polymers and nanoscale engineered particles, which creates molecular tunnels through which water flows much more easily than nearly all the contaminants. The highly porous nanoparticles are soaking up water like a sponge, while repelling dissolved salts and other impurities such as organics and bacteria. As a result, driven-pressure is lower than in conventional systems. The overall cost of desalination is considerably reduced (25%), including energy demand and environmental issues. One must remember that water production and recycling is a key topic for California, the fifth largest economy in the world!

Molecular self-assembly is another way to obtain a new kind of membrane materials. Self-organization is an important building principle of biological membranes; with this concept as a guideline, efforts have been made during the last years to imitate nature, with molecules very different from the biological ones. Block copolymers represent one class of self-assembling materials attractive to fabricate well-ordered nanometer-scale structures (spheres, cylinders and lamellae…depending on the volume fractions : figure 5). With them it can be envisaged to manufacture membranes, with an extremely narrow pore size distribution, leading to superior selectivity without flux decrease.

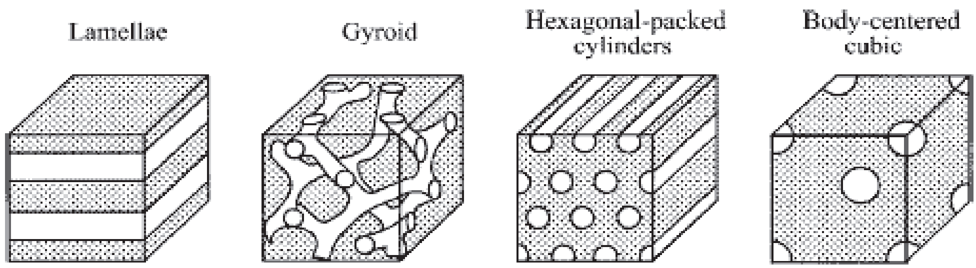

Figure 5. Ordered nanometer-scale structures obtained by self-assembly.

With such materials, a potential alternative has been recently proposed at Urbana and Cambridge in the United States which consists in coating commercial polyvinylidene fluoride membranes (PVDF) with self-assembling amphiphilic graft copolymers [poly (oxyethylene) methacrylate] to prepare new antifouling NF membranes. It is worth recalling that with traditional UF membranes employed in membrane bioreactors (MBRs), a high susceptibility to fouling by extracellular polymeric substances (EPS) is ordinarily observed.

IV – Nanofiltration (NF) a very quickly developing technology

NF is a quite new technology (Handbook of Membrane separations, 2008) which allows the removal from a liquid (see figure 6) of:

- nanoscale uncharged molecules by size exclusion and/or from differences in diffusion rates,

- ions (mainly multivalent) by electric charge effects.

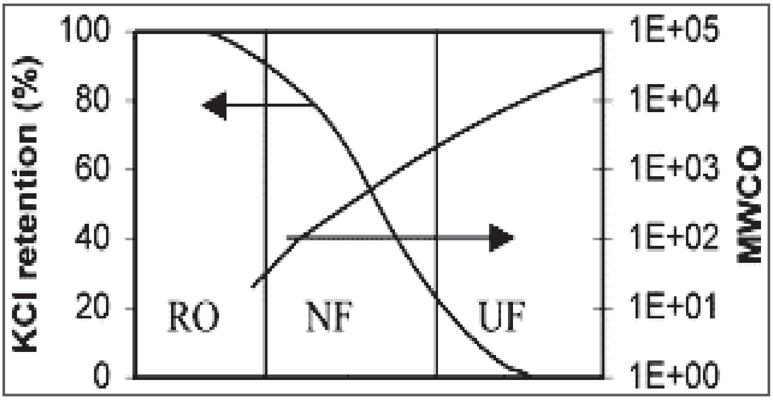

Figure 6. Classical NF performance.

For the last decade, one can mention among the main breakthroughs and more ambitious projects involving NF for improving drinking water quality:

- the reduction of hardness with softening processes; in that case NF is in competition with traditional ion-exchange systems or lime softening (regeneration, sludge and wastes…) and typical rejections of 70 to 90% are obtained through the separation of natural organic material (NOM) : today there are on the market various membranes with MWCO below 500 daltons, sufficiently low to remove the major part of humic and fulvic acids
- the high elimination of micro pollutants such as pesticides and organohalide compounds which have very negative effects on health (carcinogenic…); in that case, NF is competing with activated carbon adsorption, a very expensive method in the presence of large fractions of NOM due to competition, regeneration…

New very promising projects of technological developments are today focused on the abatement of fluoride ions to prevent fluorose disease, or the separation of arsenic, lead, aluminium and uranium. The maximum fluoride concentration in drinking water has been fixed by the World Health Organization at about 1.5-2.0 mg/l; in some sub-Saharan African countries it may be higher than 20-25 mg/l ! As (V) and As (III) are limited to 10 mg/l in France: in a lot of countries in the world concentrations higher than 50 mg/l may be found (not only in Bangladesh, India, China… but also in the USA). For such applications and large water production in rural countries, NF appeared to be more adapted than ion exchange, adsorption or biological treatment.

Other works are devoted to membrane bioreactor coupling with nanofiltration for an improved removal of toxicity in the hospital effluent. In hospital discharges, and more generally in water resources, there are numerous toxic pollutants (estrogenic hormones and other bio-products) which are responsible for cancers, allergies, fertility losses, thyroid diseases … Until now there was no clear legislation anywhere in the world about this topic; but they are being developed very quickly. With the process here proposed, by adjusting the contact time between the pollutant and the purifying biomass (MBR) it is possible to eliminate a large part of contaminants with strong biological/chemical resistance and/or low concentration; the addition of a further NF step to an MBR may eradicate the residual pollution.

V – Conclusion

Nanotechnologies and membrane technologies represent definitely a central question for the future of all our societies in terms of health, environment, energy, industrial market! This is particularly true for the Mediterranean area due to the scarcity of the water resource! Let us hope that they will be able to bring positive contributions as large as the water service roads of the Roman Empire or the Arab kingdoms of Al Andalusia…

To be as efficient as possible, research and technological developments will ask for a strong and revitalized collaboration between Europe and MENA countries based on our huge cultural heritage, our geographical proximity, our historical contacts and other complementarity reasons. Holistic approaches based on a strong integration of disciplines and expertise on a case-by-case basis will have to emerge and all kind of synergies will be welcomed.
Among others and along with more classical bilateral actions, it seems that UNESCO through the actions of its chairs and centers, as well as the European Union through its various research and structuring programs, should play a main part in this whole process.

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[1] NanoMemPro : see www.nanomempro.com
[2] EMH: a Belgian international non-profit making association : see www.euromemhouse.com
[3] SIMEV – Head : Prof. L.Cot – « Membrane technologies applied to the environment »

Life Sellustra Project: Planning and implementation of integrated methods for the restoration of the catchment in Val Sellustra

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Abstract. The “Sellustra Life” project is one of the 19 Italian projects financed in 2001 through the “Life Environment Program”. The proponent end-beneficiary of this project is the Municipality of Dozza (a town in central Italy) with the scientific collaboration of CIRF (Italian Center for River Restoration). The project appeals to the Public Administrations and offers an example of application of innovative systems at low environmental impact for the control of pollution sources and for the requalification of river environments and rural landscape. The objective of the project consists in planning and steering public and private works oriented to manage the sources of pollutants that flow in the Sellustra stream and to improve the environmental value of its banks and of the rural landscape. The purpose is to join productive activities (included farming) with environmental safeguard and sustainable development. The planting of buffer strips, to improve the landscape and to reduce pollution, will not be funded directly by Life project but will be encouraged by farmers-oriented activities that will be carried out. Other actions directly financed by the project regard the building of constructed wetland and some bioengineering works. Another objective of the project is not to demonstrate the validity of the single techniques but to highlight the opportunities of using these integrated techniques for solving different problems (pollution, environment degradation, simplification of landscape). This project wants to produce a useful “model” for planning remediation projects following a bottom-up strategy that can be reproduced in other geographical areas.

Keywords. River restoration – Buffer strips – Bioengineering – Constructed wetland.

Le Projet Life Sellustra : Planification et mise en œuvre des méthodes intégrées pour la réhabilitation du bassin hydrographique dans la région de Val Sellustra

Résumé. *Le projet “Sellustra Life” est l’un des 19 projets italiens financés en 2001 par le Programme “Life Environment”. Le bénéficiaire final et porteur de ce projet est la municipalité de Dozza (une petite ville en Italie centrale) qui a pu compter sur la collaboration scientifique du CIRF (Centre Italien pour la Réhabilitation des Rivières). Ce projet s’adresse aux administrations publiques et représente un exemple de l’application de systèmes innovants à faible impact environnemental pour la lutte contre les sources de pollution et la réhabilitation des environnements des rivières et du paysage rural. L’objectif de ce projet est donc de planifier et orienter les travaux publics et privés pour la gestion des sources de polluants qui sont déversés dans le cours du Sellustra et de promouvoir la valorisation environnementale de ses berges et du paysage rural. Les activités productives (y compris l’agriculture) seront couplées à la protection de l’environnement et au développement durable. La création de zones tampons pour améliorer le paysage et réduire la pollution ne sera pas soutenue directement par le projet Life, mais elle sera encouragée par des activités en faveur des exploitants qui les réaliseront. D’autres actions financées directement par le projet concernent les zones humides artificielles et les travaux de bioingénierie. Par ailleurs, le projet vise non seulement à démontrer la validité de chaque technique, mais surtout à mettre en évidence les opportunités qu’offrent ces techniques intégrées pour faire face à de nombreux problèmes (pollution, dégradation de l’environnement, simplification du paysage). Enfin, un “modèle” sera proposé pour contribuer à élaborer des projets d’intervention basés sur une stratégie ascendante qui pourrait être reproduite dans d’autres régions géographiques.*

Mots-clés. *Réhabilitation des rivières – Zones tampons – Bioingénierie – Zones humides artificielles.*

I – Introduction

The general methodological objective of the project "Planning and implementing integrated methods for the environmental restoration of the Val Sellustra basin" was to demonstrate the effectiveness of a new approach to the management and restoration of catchment areas based on orchestration between citizens and public organisations. From ideation up through implementation, the project strategy was intended to:

– highlight the role that a small municipal administration can assume in promoting initiatives regarding river restoration with respect to superordinate bodies;

– emphasise the importance of starting with in-depth planning at the basin level involving all parties interested in the territory to ensure the design and subsequent implementation of focused and effective measures;

– favour cultural growth and sharing of environmental subjects at local and regional level;

– successfully implement pilot measures that could act as flywheels in spreading the use of low environmental impact techniques throughout the Sellustra basin as well as in other environments.

The Sellustra Life project was intended to demonstrate that local authorities, due to their greater and more direct knowledge of the territory and its social elements, are in some cases better able to develop participatory processes to allow objectives and intervention methods to be shared with interested parties.

In this way, by understanding the needs of the territory and transferring them to the decision-making process (bottom-up strategy), local authorities can become promoters of a more consistent and farsighted policy than typical command and control policies (top-down strategy). The project strategy transpired from the fact that, although the beneficiary of the planned activities was autonomous from the onset, meetings, internal conventions and debates with institutions were promoted in order to present the initiative and stimulate new partnerships, thereby increasing the possibilities of interventions on the Sellustra basin or favouring the reproduction of the experience in different situations.

The aim of the project was also to demonstrate, through the improvement of the ecological conditions of the Sellustra river, the effectiveness of the integrated application of low-impact techniques such as bioengineering and constructed wetlands. More specifically, the measures planned as part of the Sellustra Life project were aimed at:

– improving water quality in terms of nonpoint (nitrates from agriculture) and point (outflow discharges from the sewer system) source pollution;

– resolving problems regarding bank erosion through low-impact measures and eliminating or reducing the effects of the intense use of artificial elements in the channel;

– Increasing biodiversity and improving the landscape by restoring the riparian vegetation and recreating habitats, refuges for the fauna and ecological corridors.

II – Methods

1. The measures implemented - The constructed wetland.

The system implemented is a horizontal subsurface flow (SFS-h) system. The waste passes through a gravel bed located on an impermeable basin in which vegetation is planted, and the plants provide the oxygen required for the biological process of nitrification and degradation of the organic matter.

From a functional standpoint, this type of system provides greater purification efficacy per unit area than free water systems. Since the wastewater level is lower than the surface of the gravel bed, the surface of the wetland remains dry and accessible for maintenance activities, which, moreover, are minimal. Furthermore, the absence of wastewater exposure limits nuisances such as odours or insects.

Dimensioning of the purification system was based on the characteristics of the influent and the established purification objectives, using the most diffused seizing equation available in the international scientific literature to forecast the performance of the system.

The sewage system intercepted, which was previously attached to the Sellustra pumping station, collects wastewater for a total of approximately 120 population equivalents (p.e.). The system implemented provides for primary sewage treatment in Imhoff septic tanks, to treat the gross suspended solids and avoid clogging phenomena at the wetland inlet.

The Imhoff system effluent is divided inside a sump pit and routed to 2 rectangular constructed wetland cells each with a surface area of 180 m (12 m long and 15 m wide), positioned parallel to one another. The layout of the system was chosen for reasons regarding the area morphology, to allow better inclusion in the landscape, as well as for its functionality (Figure 1).

Figure 1. The constructed wetland realized near Sellustra stream.

It allows a better distribution of influents, provides a larger crossing area and prevents clogging. In addition, maintenance can be carried out on one of the cells without interrupting the system operation.

The beds of the cells are lined in non-woven fabric made of type 250 g/m2 mineral fibre, which, being biodegradable, is of moderate environmental impact as compared to other alternatives. A continuous layer of natural, easily obtainable sand was placed on top of the non-woven fabric in order to achieve a 1% slope and to provide mechanical protection of the geomembrane from puncture.

To avoid any contact of wastewater with groundwater, black, high-density polyethylene geomembrane (2 mm thick) was used, which offers high mechanical, chemical and physical resistance while having, in this case as well, moderate environmental impact as compared to other alternatives. It also provided considerable ease in shaping during positioning.

The inlet and outlet pipes are polyethylene, easily installable, highly resistant to chemicals and electrolytes and have surfaces that prevent scale build-up. In addition, they adapt well to irregularities in the terrain and, due to their smooth surfaces, provide higher flow rates than traditional piping.

The location of the wetland allows the wastewater flow occur by gravity, avoiding the use of pumps that requires energy. The drainage system is made of perforated polyethylene piping that enables flows to be drawn from the bottom of the cells, prevents the infiltration of coarse materials and allows backwashing.

The cells were filled with round gravel with an average diameter of 8/10 mm, which was thoroughly washed and deposited in a layer of 80 cm average thickness. A level of porosity was chosen that would ensure good hydraulic conductivity, efficient removal by sedimentation and adequate support for the development of bacterial biofilms and macrophyte communities.

The species of plants used are *Phragmites australis*, which have a high capacity for survival in extreme environmental conditions and a good tolerance to influent concentrations. They are proven to be efficient, are readily and economically available and have more extensive root systems than other macrophytes. Plant density is approximately 4 plants/m2.

Lastly, an embankment was placed around the wetland with a height of 0.33 m, a width of 0.5 m and a slope of approximately 45°. Turfgrass was placed on the banks and protected with a geonet made of jute in order to mitigate the impact of the geomembrane, to allow a layer of terrain to be blocked, to protect the banks from erosion and to prevent soil runoff during heavy rains. Discharge of the effluent into the receiving body of water occurs after passage through a control sump where the water level is adjusted and samples are taken.

2. The measures implemented - Bioengineering measures

The objectives of the bioengineering measures implemented as part of the project included:

- restore natural conditions of the aquatic ecosystem;
- enhancing the landscape and ecological quality of the riparian vegetation strips;
- reducing the transport of fine sediment in the channel.

In selecting areas to act on, situations were identified that were representative of the overall conditions of the river. In this way, generalised implementation methods could be outlined, in keeping with the “pilot” character of the project. The general approach of the project aimed at reducing the restoration works to the minimum, trying to increase the natural enhancement capacity of the river itself. Despite its general state of degradation, the channel of the Sellustra presents a varied morphology useful for a rich river ecosystem. Even some areas of the riparian formations are of significant interest, with isolated specimens of arboreal species such as willow trees and poplars.

A generalised reprofiling of the banks would have led to the loss of these elements and impoverished the channel by making it monotonous. It was therefore decided to act on areas that showed true signs of instability or where the introduction of artificial elements into the channel was particularly accentuated. For measures regarding vegetation restoration, an effort was made to enhance the existing vegetation as much as possible by removing only invasive arboreal vegetation and replanting where coverage had become exceedingly sparse. The site was identified downstream from the bridge in Via Sellustra, near a pig-breeding farm.

The naturalness of the channel had been particularly damaged in this tract as a result of erosion-halting measures that had been implemented over time. In addition to the discontinuity caused by the bridge foundation, which created a weir approximately 1 metre high, the river bed is covered with a slab of reinforced concrete, also almost a metre high. The banks are protected with mesh gabions filled with rock that, if removed, would have excessively upset the equilibrium that has been established over time. The remaining banks showed excessive sloping and the presence of numerous points of active erosion. The vegetation along the banks was considerably degraded with an abundance of Robinia. The measures implemented had two distinct goals:

– reducing the artificial elements in the upstream part of the channel;

– finding more stable physical and ecological conditions for the banks along the remaining tracts.

The discontinuity created by the weir under the bridge was resolved by constructing a ramp out of rocks partially tied with steel cables, at a 10% slope. Above the cemented area, which would have been too difficult to remove and excessively risky for the area overall stability, a number of weirs were constructed using stones tied with steel cables or beams anchored to the concrete underneath. In the portion of the channel downstream from the curve, the banks were reprofiled to provide a more stable slope. In the few bank sections where riprofiling was not required only restoration of the vegetation was carried out.

The reprofiled bank was protected from erosion at the toe by horizontal or vertical live palisades and, in the lower 2 m portion, with turfgrass protected with a geonet made of jute. Small, deep-rooted, shrubby plant species were planted in the area of the bank above the protected turfgrass in the following proportions: Euonymus europaeus 20%, Cornus sanguinea 30%, Rosa sempervirens 15%, Sambucus nigra 20%, Ligustrum vulgare 15%. In the area near the river edge, Ulmus minor and Fraxinus oxycarpa varieties, ranging from 1.5 to 2.0 m in height, were planted with their rootballs.

Figure 2. The slope built with stone blocks in order to smooth the drop under the bridge.

III – The measures implemented - The wooded buffer zones

Buffer zones are typically used as best management practices along lower-order streams for the enhancement of water quality, protection of fish and wildlife habitat, etc. To meet such diverse objectives, riparian zones remove sediment from overland flow, remove and sequester nutrients and other pollutants from overland and shallow subsurface flows, and provide habitat values in the form of streamside shading, generation of coarse and fine particulate matter, and food and cover for wildlife.

The control of nitrate pollution can be realized increasing the complexity of the landscape, not necessarily all over the catchment but in specific zones, especially within the river corridor. For this reason an important part of the project was the plantation of woody buffer strips near the Sellustra stream and its tributaries.

Plantation of the wooded buffer zones was not included in the Sellustra Life project as an initiative financed by the project itself, but as the result of the activity of territorial animation primarily directed at the farms bordering the river.

It was, in fact, decided to implement measures that were in synergy with the already existing possibilities of financing provided for by the structural funds of the Regional Rural Development Plan, with strategic objectives that included involving regional authorities in the project, making private parties directly responsible for and involving them in restoration of the catchment area and generating a flow of additional resources to the territory.

From an environmental standpoint, the buffer zones contributed to the attainment of objectives regarding the improvement of water and landscape quality as well as the containment of erosion along the banks. The information counter provided farms with the technical assistance necessary for planning the wooded hedges plantation and preparing applications for financing. A total of four buffer zones were planted during the Life project, three of which were financed by independent private initiatives and one of which was publicly financed.

IV – Results and discussion

1. Evaluation by monitoring activity

Evaluation is an extremely important step in the rehabilitation procedure. With no formal check on the success of a project, it is difficult to improve the techniques we use, because we don't even know if they need improving. The monitoring involved in evaluation means that damage, or flaws in the project, can be detected and fixed, where otherwise they may have gone unnoticed. Our evaluation approach dealing with natural and spatial variability is called BACI (Before-After/ Control-Impact). This is an evaluation program with rehabilitation and control sites, with replicate samples taken through time.

Adoption of a basin-level approach imposes that the environmental monitoring activity not be limited to assessing water quality, but that it takes other important aspects into consideration as well, including the morphology of the channel, the structure and state of riparian vegetation and the functioning of selected ecological processes.

Each index used is associated with the specific environmental objectives of the project: EBI (Extended Biotic Index), chemical and bacteriological parameters (L.I.M.), SECA (Ecological State of the River), I.F.F. (Index of River Functionality), and Leaf packs. This last one is a method allowing the evaluation of the complex effect of different biochemical water parameters through the measure of decomposition rate of leaves inside water.

The improvement of water quality resulting from the implementation of the constructed wetland and buffer strips is measured using the EBI (Extended Biotic Index), macro indicators (L.I.M.) and Leaf packs. Enhancement of the quality of the landscape resulting from the naturalistic engineering measures and buffer strips is evaluated using I.F.F. (Index of River Functionality). The evaluation of the functioning of the fluvial ecosystem was performed using retention capacity and Leaf packs methods.

An integrated evaluation of the LIM and EBI data allows determination of the SECA. For the Sellustra stations, the worst results are those registered by the EBI. The chemical and bacteriological parameters (L.I.M.) have instantaneous values so they could not measure alterations either occasional or not directly caused by water quality. On the other hand, these alterations are well recorded by macroinvertebrate community.

For sure the river restoration realized is not yet adequate to improve water quality. In addition, the extraordinarily dry climatic conditions of the summer 2003 and some temporary and unknown urban and industrial wastes impacted water quality. All these natural and artificial unpredictable events hindered the normal performance of the monitoring activities, resulting in the delay of an entire data collection campaign. The post restoration monitoring shows only one improvement and some worsening of class SECA quality.

Table 1. The S.E.C.A. values before-after/control-impact

PRE

Sites	1	2	3	4	5	6	7	8	rio R.	rio S.
L.I.M.	III	III	IV	II	III	IV	III	III	III	IV
I.B.E.	III	III	V	III	IV	IV	IV	IV	IV	V
S.E.C.A.	III	III	V	III	IV	IV	IV	IV	IV	V

POST

Sites	1	2	3	4	5	6	7	8	rio R.	rio S.
L.I.M.	III	III	IV	III	IV	IV	III	III	III	V
I.B.E.	III	III	IV	IV	III	V	IV	IV	V	V
S.E.C.A.	III	III	IV	IV	IV	V	IV	IV	V	V

Table 2. Comparison between daily rates (K) of decomposition before-after/control-impact

PRE	K(d-1)	95% I.C.	R2	p	g.l.
st. 2	0,020	0,015-0,026	0,774	< 0,0001	19
st. 3	0,024	0,017-0,032	0,745	< 0,0001	18
st. 4	0,017	0,011-0,023	0,744	< 0,0001	16
st. 6	0,021	0,017-0,024	0,933	< 0,0001	16
st. 8	0,028	0,016-0,040	0,745	< 0,0001	11
POST	**K(d-1)**	**95% I.C.**	**R2**	**p**	**g.l.**
st. 2	0,012	0,008-0,015	0,809	< 0,0001	14
st. 3	0,016	0,012-0,020	0,854	< 0,0001	14
st. 4	0,046	0,040-0,051	0,957	< 0,0001	15
st. 6	0,022	0,018-0,026	0,967	< 0,0001	13
st. 8	0,009	0,006-0,011	0,744	< 0,0001	17

The rate of decomposition of the leaves is surprisingly fast. The macroinvertebrate functional feeding group of shredders was limited, indicating that the fast rate of decomposition is attributable to the elevated concentrations of nitrogen and phosphorous. These concentrations are important in regulating the process of decomposition in that they cause an increase in the activity of hyphomycete fungi.

As regards the catchment area as a whole and the strong impact of nonpoint pollution on the Sellustra river, it appears that the first pilot buffer zone is insufficient for reducing the river strong nitrogen and phosphorus concentrations. More significant results would have been achieved if the project's aim, which entailed covering at least 75% of the banks with buffer zones, including near the drainage ditches in intensely cultivated areas or where manure spreading is practiced.

The naturalistic engineering measures have already begun to show some positive effects, both in terms of increased self-purifying capacity of the stream and, more important, as regards improved overall functioning of the ecosystem. These aspects can be effectively measured using the I.F.F. index. Although a period of at least two years will be required before the ecosystem reached stability and the results can be consolidated, initial analyses of the I.F.F. performed before and after the implementation of measures show significant improvements in all three reaches concerned. The promotion to a higher class is attributable to the improvement of vegetation conditions, better functioning of the banks and increased diversification of the channel morphology.

Table 3. Comparison between I.F.F. classes before-after/control-impact.

	sites	**3/A**		**3/B**		**4**	
	Banks	**L**	**R**	**L**	**R**	**L**	**R**
	SCORE	82	39	69	74	132	156
PRE	CQ	IV	V	IV	IV	III	III
	referring colours						
	SCORE	139	139	124	109	166	181
POST	CQ	III	III	III	III-IV	III	II-III
	referring colours						

V – Conclusions

The experience of the project "Sellustra life" cannot be considered concluded until actions carried out are completely developed, express definitively the foreseen environmental effects and these are measurable. Biological rate of growth of trees and shrubs must be respected and the requested time exceed the end of the project. Nevertheless, it is possible and appropriate to produce a first report into the results obtained by the work method adopted within the project:

– It contributed to developing the idea to treat locally wastewater and meteoric urban waters, adopting natural systems when possible, and return them as soon as possible to water course after cleaning

– It promoted the principles that the more natural the conditions of a river are, with a prosperous riparian vegetation, the safer and the more convenient its management is; and if important values are threatened it is better to adopt low-impact techniques.

– It showed a correct interpretation of the role of farmers as managers of the environment as established by common and national policies, especially suitably supported by financial subsides and also by information activities, training and technical assistance.

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Autonomous desalination units for fresh water supply in remote rural areas

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Abstract. Two autonomous desalination units were installed in two different villages to provide drinking water to the populations. These autonomous desalination units were installed in the framework of the ADIRA project. They both consist of a reverse osmosis unit (production capacity of 1m^3/h) which is powered by a photovoltaic plant (3.9 and 4.8 kWp). The systems are described, their water production and energy consumption are presented and their potential as an alternative water supply in remote areas is discussed.

Keywords. Desalination – Brackish water – Reverse osmosis – Photovoltaic energy – Autonomous systems – Rural areas.

Unités autonomes de dessalement pour l'approvisionnement en eau douce des zones rurales éloignées

Résumé. *Deux unités autonomes de dessalement ont été installées dans deux différents villages afin de fournir l'eau potable aux populations locales. Ces unités autonomes de dessalement ont été mises en place dans le cadre du projet ADIRA. Elles consistent en une unité d'osmose inverse (capacité de production de 1m^3/h) qui est alimentée par une installation photovoltaïque (3.9 et 4.8 kWp). Les systèmes sont décrits en présentant la production d'eau et d'énergie et en mettant l'accent sur leur potentiel comme alternative pour l'approvisionnement en eau des régions éloignées.*

Mots-clés. *Dessalement – Eaux saumâtres – Osmose inverse – Énergie photovoltaïque – Systèmes autonomes – Zones rurales.*

I – Introduction

The supply of drinking water to rural areas is a challenging problem especially when brackish or sea water is the only available resource within reasonable distances. The provision of drinking water is usually carried out by children and women at the expense of schooling and other income generating activities. In addition, in some cases, the available brackish water is used for human consumption which further results in health problems.\

On the other hand, fresh water resources in Morocco and other countries are characterized by their large regional variability and increasing scarcity. The situation is worsening in recent years due to climate changes, re-occurring droughts and increasing demand. The exploitation of brackish and seawater resources is therefore becoming increasingly necessary especially in remote rural areas where these are the only available resources. Furthermore, some of these remote rural areas are not /or are weakly electrified. In such cases, desalination systems powered by renewable energies (referred to as autonomous desalination systems, ADS) may offer an attractive alternative to provide drinking water for such villages, especially when electricity grid access is not economically possible (Karagiannis *et al.*, 2007; Outzourhit and Mokhlisse, 2008; Manolakosa *et al.*, 2008; Mohameda Essam *et al.*, 2008)

As a part of its activities in rural areas, Fondation Marrakech 21 (FM21) has recently installed two reverse osmosis (RO) desalination units powered by photovoltaic energy to provide drinking water for the populations of two villages (**Outzourhit and Mokhlisse, 2008**). This task was carried out in the frame work of the ADIRA project (Autonomous Desalination system concepts for seawater and brackish water In Rural Areas with renewable energies- Potentials, Technologies, Field experience, Socio-technical and Socioeconomic impacts), which is co-funded by the European Union Karagiannis *et al.*, 2007. Through the implementation of pilot autonomous desalination units with different technologies and under different boundary conditions, the ADIRA project has intended to demonstrate that this technology may offer an interesting alternative for decentralized drinking water supply in such zones, by using in particular, distillation and membrane techniques powered by renewable energy sources such as solar thermal, photovoltaic and small wind turbines.

In this work, a description of the various parts of the desalination units installed by FM21 is given. Some results obtained from the monitoring the desalination plants are also presented.

II – Characteristics of the two rural villages

Following a survey of different villages in the Alhouz and Essaouira provinces, and a set of pre-selection criteria, two villages were selected by FM21 for the implementation of the ADIRA project:

– The first, Benssaine village, rural commune Tamaguerte in the Alhaouz province;

– The second, the Msaim village, Had Dra Commune, in the Essaouira province.

The PV-powered reverse osmosis units are designed to provide drinking water for the population of each village using the existing brackish water points. The main characteristics of the two villages are given in table 1.

Table 1. Main characteristics of the two sites.

	Benhssaine	Msaim
Location	Rural commune Tamguerte, Province of Alhaouez	Rural commune Had Draa, province of Essaouria
Water point	Borehole, 160 m	Well, 20 m
Salinity (g/l)	6	4.5
Pumping system	Electrical pump/ Diesel Genset (Lombardini, 20 KVA)	Vertical axis Pump* Diesel motor
Water reservoir	25 m^3	25 m^3
Water distribution	Distribution Network	Fountains
Number of households	40 (1 agglomeration)	60 (6 agglomerations)

Chemical and bacteriological analysis of the water of both sites was carried out. The results are given in table 2. Given the high salinity of the water of the two sites, we opted for reverse osmosis. In addition, for the two sites, PV-powered RO unit was installed to provide drinking water for each village given the high solar energy potential of the two sites (> 5kWh/m^2/day). The chemical analysis revealed also the need for anti-scaling agents for both sites.

Table 2. Chemical Analysis of the water for the two sites.

	Benhssaine	Msaim
pH	7,67	7,2
Conductivity (mS/cm)	11,38	7,34
Temperature (°C)	25,5	22,8
Dissolved oxygen (mg/l)	8,2	3,7
TDS (g/l)	6,6	4,1
TH (meq/l) (Ca/ Mg)	24	52,8
Ca^{2+} (mg/l)	204	430
Mg^{2+} (mg/l)	133	324
Na^{+} (mg/l)	2102	821
K^{+} (mg/l)	17	<0,3
Ba^{2+} (mg/l)	0,06	0,05
Sr^{2+} (mg/l)	1,9	1,8
Cl^{-} (mg/l)	3684,09	2499,43
SO_4^{2-} (mg/l)	132	288

III – Description of the PV-powered Reverse Osmosis Units

1. PV plant

A bloc Diagram of the PV plant is shown in figure 1.The main characteristics of the PV plant are summarized in table 2. Two PV panels (150 Wp, 24 V) are mounted in series to provide the nominal DC voltage of 48 volts. The panels are used to charge the batteries (24 flooded 2 V batteries) through two charge regulators. The battery bank is used to power the RO unit and the various equipment through the inverters.

Table 3. Characteristics of the PV plants of the two sites.

	Benhssaine	Msaim
Installed PV Power (kWp)	4.8	3.9
Battery Capacity (Ah)	900	700
Nominal System DC voltage (V)	48	48
Charge regulators	2x60 A	2x40 A
Inverters	3x3 kW	2x3 kW

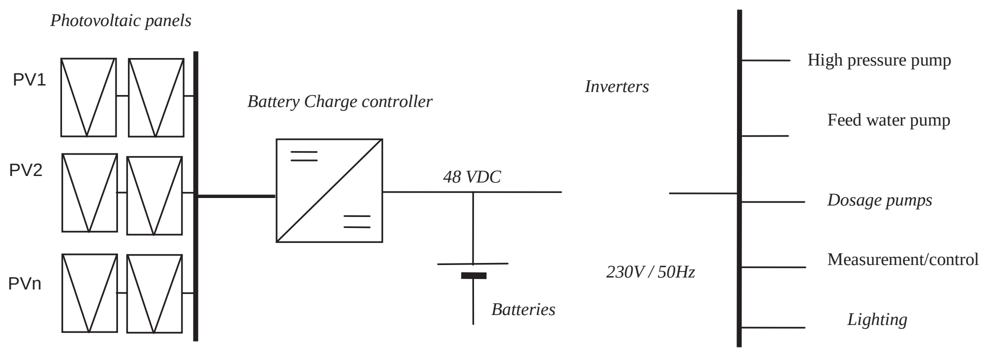

Figure 1. Schematic diagram of the PV plant.

2. Reverse Osmosis units

A bloc diagram of the RO unit is shown in figure 2 .The feed water from the storage reservoir is filtered by the multimedia filter to remove suspended solid particles. Water is then pre-treated using an anti-scaling agent (HYDREX from Veolia) to prevent fouling of the membrane. The pre-treated water is subsequently filtered by two 5 micron cartridge filters; before, it is forced through the RO modules by the high pressure pump (14 to18 bars). Each RO module contains 3 membranes (BW30 series from Filmtec). The concentrate of the first tube is fed to the second tube (3 spiral-wound membranes BW30LE-4040 for Benhssaine and BW30-4040 for MSAIM). Part of the brine is re-circulated so that only 0.5 m^3/h is rejected. The permeate of the two tubes are then mixed using a manual valve which also provides back pressure of 0.8 bars on the first tube.

The permeate fills first the flushing reservoir mounted above the unit. Then the pH of the permeate is adjusted with potash (NaOH) and it is post-treated with hypochlorite using the dosage pumps of the post treatment stage. A check valve prevents post treated water to flow back into the flushing reservoir. The flushing is performed by gravity and direct osmosis. A membrane cleaning system has been designed and tested.

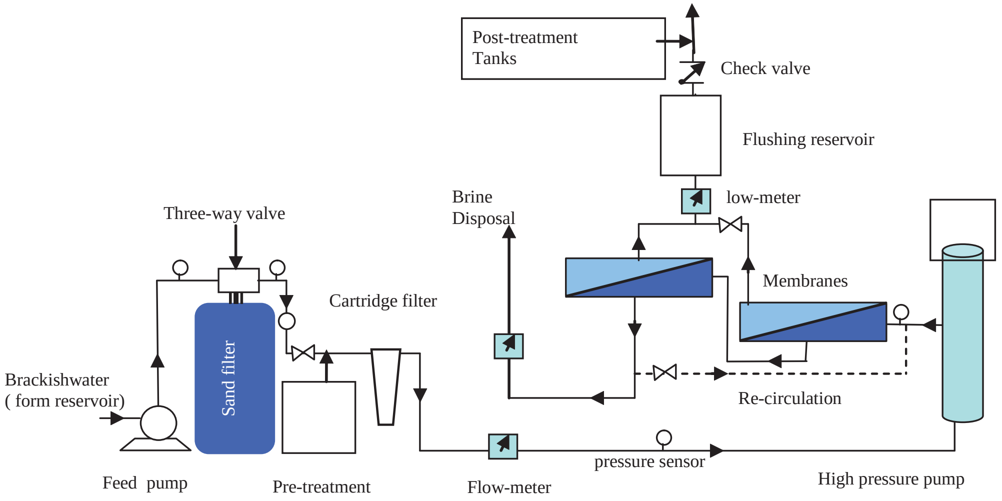

Figure 2. Schematic diagram of the RO plant.

Figure 3. Photographs of the RO unit and the PV panels for the Benhassine site.

Table 4. Characteristics of the reverse osmosis units.

	Benhsssaine	Msaim
Production Capacity (m^3/h)	1	1
Number of vessels/modules	2	2
Number of membranes /module	3	3
Pre-treatment	Antiscalant metabisulfate	Antiscalant Metabisulfate
Post-treatment	Hypochlorite pH adjustment	Hypochlorite pH adjustment
HP pump nominal power	5.5 kW	2.2 kW
Brine disposal	Evaporation ponds	Evaporation ponds

3. Monitoring System

The RO unit is continuously monitored by a Siemens S7-200 family PLC (S7-224) through the different sensors installed in the unit (conductivity, flow rates, pressures, salinity..). The RO unit is automatically stopped when a given parameter is outside specified range and the corresponding alarm is set.

For both sites, the RO units are automatically operated for a preset time fixed by a timer mounted in the control panel. The operation time starts at 12:00 in the winter time and 11 am in the summer time to produce more water. This corresponds to about a 22% depth of discharge of the batteries (when the system is operated only with batteries). This leaves enough time for the batteries to be charged by the PV panels. A remote monitoring system is also installed which enables to remotely monitor the operation of the units and sends alarms by SMS. This way, the source of faults can be known beforehand and the local operator can be guided through the phone to remedy to the fault if its origin is not serious.

IV – Water production and energy consumption

The operation parameters of the two desalination stations are shown in table 4. The overall recovery rate for the two desalination units was chosen as high as possible (65% to 70%) in order to reduce the quantity of brine rejected. This is done for two reasons: the first is that this will not please to the population as they also pay for this rejected water; the second is to limit the surface needed for the evaporation ponds and to reduce the environmental impacts of the brine. The conductivity of the produced water is on the average equal to 540µS/cm so that it doesn't require any additional re-mineralization. The specific energy consumption is lower for the case of the unit installed in Msaim (about 2 kWh/m^3 compared to 3.3 kWh/m^3) as a result of the lower salinity and permeate flow rate (0.8 m^3/h).

Table 5. Typical operational parameters recorded for the desalination units.

	Benhssaine	Msaim
Feed water pressure (bar)	3.5	3.4
High pressure (bar)	18	13.5
Brine pressure (bar)	17.5	10,5
Feed water flow rate (l/min)	26.6	22
Permeate flow rate (l/min)	18	14.5
Brine flow rate (l/h)	500	500
Permeate conductivity (µS/cm)	520 to 534	540 to 570
Recovery rate	70	65
Power requirements (kW)	3.3	2.5

The evolution of these parameters with time allows to take preventive maintenance actions (membrane chemical washing, filter changes,..).

The unit cost of the desalted water, taking into account the investment and operation and maintenance cost over the life time of the unit (fixed at 20 years), was calculated using the decision support tool (AUDESSY) developed by the ADIRA project and the actual costs of the system. The unit cost of the produced water is estimated to be on the order of 5 Euros/m^3 (55 DH/m^3). A large part of this cost is due to the renewable energy supply (PV plant) and the associated maintenance and replacement costs (batteries). This high unit cost is, however, compensated by the externalities of providing a safe drinking water supply to the populations such as improving the living conditions and the health of the population by reducing water-borne diseases. In addition, children and women will save time for other activities (schooling, income generating activities..).

In order to promote the sustainability of the units, the following tasks were also carried out:

– Training for basic operation and maintenance of a group of students, local people and technicians from the province;
– Remote monitoring of the units in addition to the regular monitoring carried out by the provider of the equipment;
– Dissemination of the technology and the results of the experience (workshops, conferences, meetings). An after installation workshop was organized on April 26 attended by high level personalities and decision makers, (Ministry in charge of water and environment, the governor of the province), president of rural communes suffering from salinity problems, private sector;
– Awareness raising.

V – Conclusions

Two PV-powered RO desalination units were installed in two rural villages to provide drinking water for their populations. The units are now operating and are being continuously monitored. The lessons learned from these two experiences are valuable for further promoting these technologies as alternative drinking water supplies in remote areas.

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Experimental plant of Carrión de Los Céspedes (Seville): model of technological transfer in international cooperation about sustainable solutions for wastewater treatment

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Abstract. The access to drinking water, proper sanitation and treatment of urban wastewater provide the backbone of development in a country. When we analyse the situation worldwide, we can state that the problem in this field is more or less solved in large and medium cities and in those areas with adequate social, economic and technological development. On the contrary, the population most affected in terms of lack of water basic services is concentrated in rural and scattered areas, as well as in the marginal zones of the large cities in underprivileged countries. In this context, where the main economic and technical limitations occur, it is necessary to have solid and adjusted solutions that guarantee the elimination and adequate treatment of wastewater with minimum implementation costs and affordable service costs for the benefited population. The non-conventional or extensive treatment technologies are a solution to this problem, given their resemblance with natural treatment process and the fact that their simplicity regarding their management and exploitation considerably reduce infrastructure and service costs. In Seville, Spain, since 1990 the Experimental Plant of wastewater treatment of Carrión de los Céspedes (EPCC) has been working on the development, implementation and diffusion of non-conventional and conventional technologies for the wastewater treatment which are generated by small communities. Nowadays, with a surface of 35,000 m^2 and a wide range of technologies, this experimental Plant is a model of technological transfer and a point of reference in the framework of wastewater depuration in small agglomerations. The high experience in the field of wastewater treatments in small agglomerations in the EPCC has been extrapolated to other countries as Morocco and Uruguay. In the North of Morocco, Tetouan, the Technological Transfer Centre is a single area covering 30,000 m^2, with different non conventional treatment systems; in the South of Uruguay the Experimental Plant of Canelones has been planned which covers all Latin America and allows the exchange of experiences and transfer of successful technologies in this area. The present document intends to illustrate these Experimental Plants and their contribution to development in small communities.

Keywords. Wastewater treatment – Small communities – International cooperation – Experimental plants.

Installation expérimentale de Carrión de Los Céspedes (Séville): un modèle de transfert technologique dans la coopération internationale de solutions durables pour le traitement des eaux usées

Résumé. *L'accès à l'eau potable, des mesures d'hygiène appropriées et le traitement des eaux usées urbaines représentent l'ossature du développement d'un pays. Si on analyse la situation mondiale, il est possible d'affirmer que les problèmes dans ce domaine sont plus ou moins maîtrisés dans les grandes et moyennes villes et dans les zones qui se caractérisent par un niveau suffisant de développement social, économique et technologique. En revanche, les populations les plus touchées par les insuffisances des services de l'eau fondamentaux sont concentrées dans les zones rurales et dispersées, et dans les zones marginales des grandes villes dans les pays les plus démunis. Dans ce cadre, là où des limitations techniques et économiques importantes interviennent, il est nécessaire de mettre au point des solutions solides et ciblées, capables d'assurer l'évacuation et le traitement appropriés des eaux usées avec des coûts de réalisation minimaux et des coûts des services abordables pour la population qui en bénéficie. Les technologies de traitement non conventionnelles ou extensives constituent une solution à ces problèmes en raison de leur proximité des processus de traitement naturels et de leur simplicité sur le plan de la gestion et de l'exploitation, qui réduit considérablement les coûts des infrastructures et des services. A Séville, en*

Espagne, à partir de 1990, l'Installation expérimentale pour le traitement des eaux usées de Carrión de los Céspedes (EPCC) s'est engagée dans le développement, la mise en œuvre et la diffusion des technologies conventionnelles et non conventionnelles pour le traitement des eaux usées qui sont générées par les petites communautés. A l'heure actuelle, avec une superficie de 35.000 m² et une vaste gamme de technologies, cette installation expérimentale représente un modèle de transfert technologique et un point de repère pour l'épuration des eaux usées dans les petites agglomérations. L'expérience considérable acquise par l'EPCC dans le domaine du traitement des eaux usées dans les petites agglomérations a été transférée à d'autres pays tels le Maroc et l'Uruguay. Dans le nord du Maroc, à Tetouan, le Centre pour le Transfert Technologique couvre une étendue de 30.000 m² et maîtrise différents systèmes de traitement non conventionnels, alors que dans le sud de l'Uruguay, l'Installation expérimentale de Canelones, qui couvre l'Amérique latine dans son ensemble, favorise un échange d'expériences et le transfert des technologies les plus performantes dans la région. Dans le présent travail, on va illustrer ces installations expérimentales, en mettant en évidence leur apport au développement des petites communautés.

Mots-clés. *Traitement des eaux usées – Petites communautés – Coopération internationale – Installations expérimentales.*

I – Introduction

Although water has always been considered as a good to be consumed, we currently talk about water as a scarce resource not accessible to everyone in the same way. There is an important imbalance between developed and developing countries regarding the access and purification of water.

In the World Summit on Sustainable Development in Johannesburg (2002), the need was acknowledged for specific actions at a global level to solve water problems, due to the strategic role that this resource plays in order to achieve the Millennium Development Goals (MDG) (2000) related to water.

Currently, more than one billion people are deprived of their right to clean water, most of them from the poorest countries, while **2.6 billions** do not have access to adequate sanitation. The differences between rich and poor communities and urban and rural ones, make this situation even worse, whilst the lack of basic sanitation negatively affects health and social development.

The access to adequate sanitation and wastewater treatment has a double benefit: it improves the life conditions of the affected population (poverty, hygiene, healthiness, etc), and it is a conservation strategy of the good ecological status of water resources.

The problem is more or less solved in large and medium cities and in those areas with adequate social, economic and technological development. On the contrary, the most affected population in terms of lack of basic services (drinking water and sanitation) is concentrated in rural and scattered areas, as well as in the marginal zones of the large cities in underprivileged countries.

It is in this context where the main economic and technical limitations occur, where it is necessary to have solid and adjusted solutions that guarantee the elimination and adequate treatment of wastewater with minimum implementation costs and affordable service costs for the benefited population. The decentralized systems at small scale, as well as the non-conventional or extensive wastewater treatments, are a solution to this situation, given their similarity with natural purification processes and the fact that their simplicity regarding their management and exploitation considerably reduce infrastructure and service costs.

During the last years, we have been able to observe a remarkable scientific progress concerning the development of sanitation and purification technologies, especially extensive technologies, which have been the object of numerous and important research studies by the scientific community. Nonetheless, such progress has not turned into a solution for this problem. In this context, it is necessary to rely on resources that contribute to improving basic sanitation and purification, and to achieving the MDGs related to water.

In this context, some international platforms for the wastewater treatment, as the Experimental Plant of Carrión de los Céspedes (EPCC) (www.plantacarrion-pecc.com), South of Spain, the Technological Transfer Centre (TTC), North of Morocco, and the Experimental Plant of Canelones (EPC), South of Uruguay, where extensive technologies are implanted at small scale, are unique places that allow managers and researchers involved in purification to assess on the ground the different options offered by these technologies, and to apply them in their own management settings.

II – Area of study

Experimental Plant for wastewater treatment of Carrión de los Céspedes (EPCC), Spain.

Andalusia has a great amount of experience in research and development regarding water purification in small towns, with its main point of reference in the EPCC, in Seville.

This Experimental Plant, belonging to the Andalusian Department of the Environment and run by the Centre for New Water Technologies (CENTA) as agreed upon with the Water General Secretariat, is part of the Andalusian Strategy for Research, Development and Innovation on wastewater purification, mainly extensive technologies, launched about 20 years ago with the main characteristic of combining purely scientific studies with an extensive knowledge of purification adjusted to specific areas. The EPCC has been working on the development, implementation and diffusion of extensive technologies for the treatment of wastewater generated by small towns. In a single area covering 35,000 m^2, both extensive and intensive technologies have been studied. The extensive ones are: green filter planted with *Populus euroamericana* and *Eucalyptus camaldulensis*, stabilisation ponds (two anaerobic, one facultative and two maturation ponds), peat filters, constructed wetlands (3 horizontal, 3 vertical and 1 free flow constructed wetland, with different substrate, planted and without plants working as secondary or tertiary treatments in combination and with an Inmhoff Tank as a primary treatment), trickling filters in combination with peat filters and anaerobic ponds and rotating biological contactors. The intensive technologies are: extended aeration, Sequential Batch Reactor (SBR), bio-catalysis, Membrane Biological Reactor (MBR), multistage reactor, etc. The EPCC has also 1,900 m^2 plot for testing the treated effluents from stabilisation ponds and constructed wetlands for agricultural irrigation purposes. On the other hand, there are six fibreglass reinforced plastic tanks where plant and animal biomasses are cultivated and a meteorological station from the State Meteorological Agency. The treated water for the irrigation of green zones comes from different points: (1) combination between vertical flow constructed wetland without plants with free flow constructed wetland planted with *Typha* sp., *Iris* sp., *Cladium mariscus* and *Cyperus* sp., (2) second maturation pond, and (3) extended aeration with sand filter and coloration system. All systems are monitored and measurements are made of some physicochemical and biological parameters, related to wastewater treatment and reuse, as well as to biodiversity in the systems. The EPCC receives numerous visits from different national and international organizations and institutions, and many activities related to training and knowledge dissemination on wastewater treatment are carried out. Figure 1 shows a view of EPCC with different installed systems. In the near future, the Experimental Plant is to be enlarged in order to create two different zones, one devoted to extensive technologies and the other for intensive technologies, and also to improve the sludge treatment line.

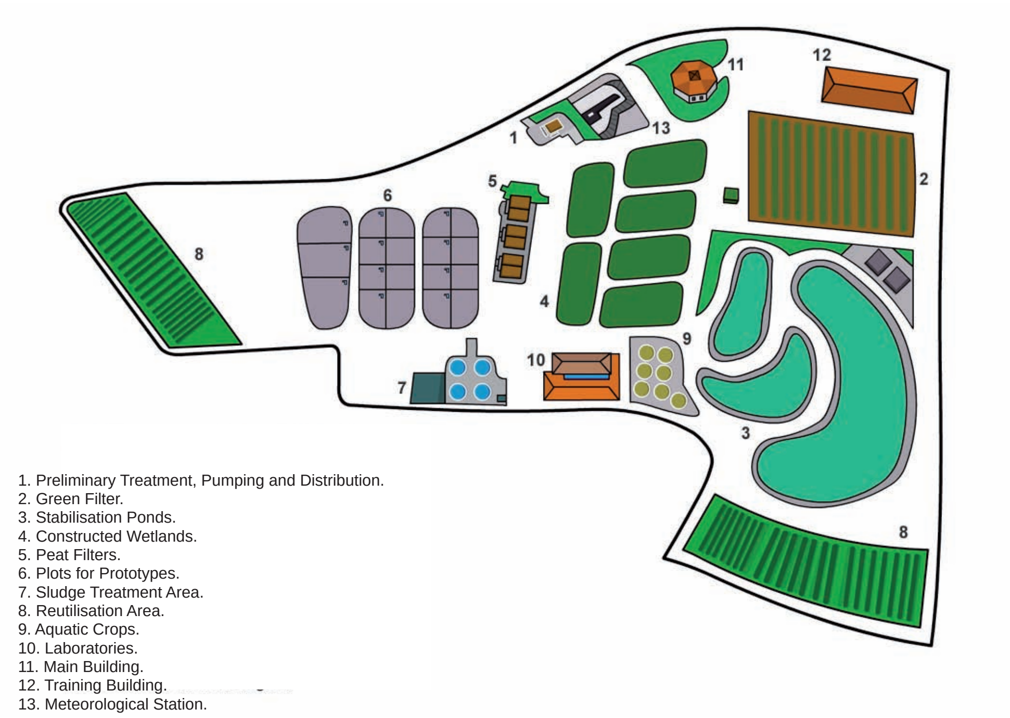

Figure 1. The Carrión de los Céspedes Experimental Plant. Spain. (Fahd *et al.*, 2007).

1. Technological Transfer Centre (TTC), Morocco

The experience and the knowledge acquired in EPCC were transferred to Morocco. Within the framework of the Interreg II Program Spain-Morocco, the TTC came up between the Moroccan Ministry of Urban Planning, Water and Environment, and Andalusia Government of the Environment.

Since 2000, the TTC has been working on the development, implementation and diffusion of extensive technologies for the treatment of wastewater generated by small towns in the North of Morocco. In an area covering 30,000 m^2, there are six extensive technologies: green filter, planted with *Populus sp*., stabilisation ponds (one anaerobic, two facultative and two maturation ponds), constructed wetland with an Inmhoff Tank as a primary treatment and planted with *Typha sp*., peat filters, rotating biological contactor and a combination of anaerobic pond and trickling filter. There are three experimental ponds of 17.5 m^2 each, aimed to perform tertiary treatment experiences.

The facilities of the Centre include also a fully-equipped laboratory (to complete the physico-chemical and biological analysis), cooperation headquarters, meeting halls and students' rooms, conference hall, meteorological station and a permanent exhibition. Figure 2 shows the flow diagram of the different systems installed in the TTC.

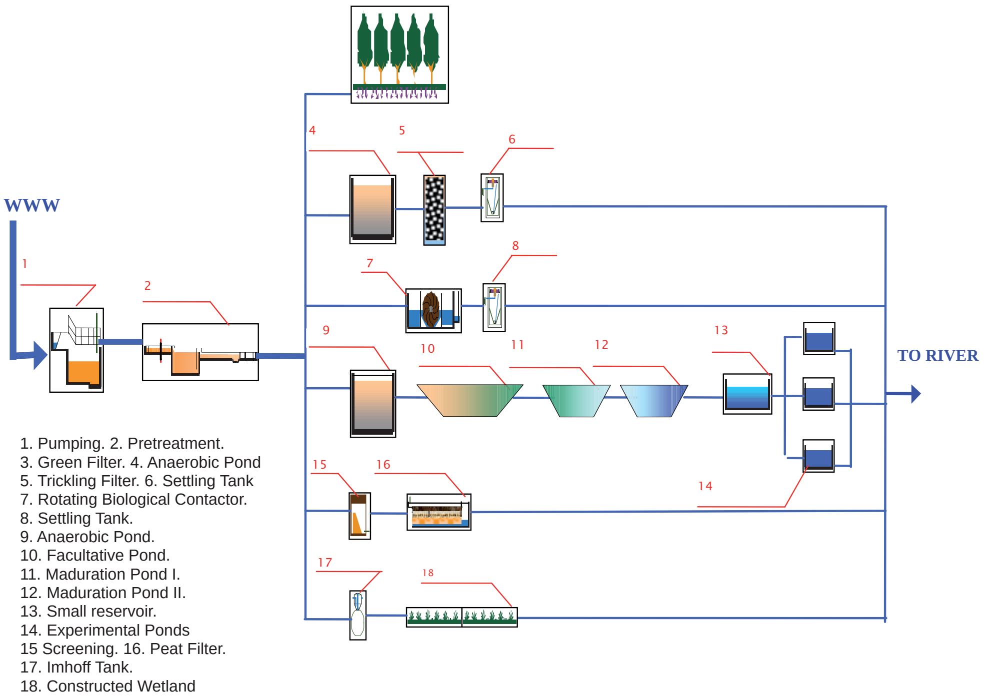

Figure 2. Flow diagram of the Technological Transfer Centre, Morocco. (Fahd *et al.,* 2007).

2. Experimental Plant for wastewater treatment of Canelones (EPC), Uruguay

In Uruguay, like in Morocco and Spain, the main problem is sanitation and wastewater treatment in small communities. In this context, during the XVII Summit of the Heads of State and Government held in Chile in 2007 the Initiative of the Latin America Cooperation was approved for the training and technological transfer in integrated management of water resources, supported by Chile, Peru, Uruguay and Spain. This initiative will be mainly supported in the Experimental Plant of Canelones, Uruguay.

This Plant will rely on different extensive and intensive urban wastewater technologies, as well as an area for industrial wastewater treatments, principally from agro-feeding sector and fundamentally dairy. The extensive systems that will be installed are: stabilisation ponds (one anaerobic pond, one facultative pond and two maturation ponds), constructed wetlands (3 vertical flow, 5 horizontal flow and one free flow), with an Inmhoff Tank as a primary treatment. The intensive systems are: Upflow Anaerobic Sludge Blanket (UASB) reactor. There will be six aquatic crops for phytoplankton and zooplankton cultures as well as a meteorological station and an area for commercial prototypes, administrative activities and a laboratory.

Finally, the EPC will include a combination of septic tanks and horizontal flow constructed wetlands, treating the effluents from the administrative area, laboratory and class for training. This system is based on that used in MEVIR system (Movement for the poverty eradication of rural and unhealthy housing). Figure 3 shows the systems that will be built in the EPC.

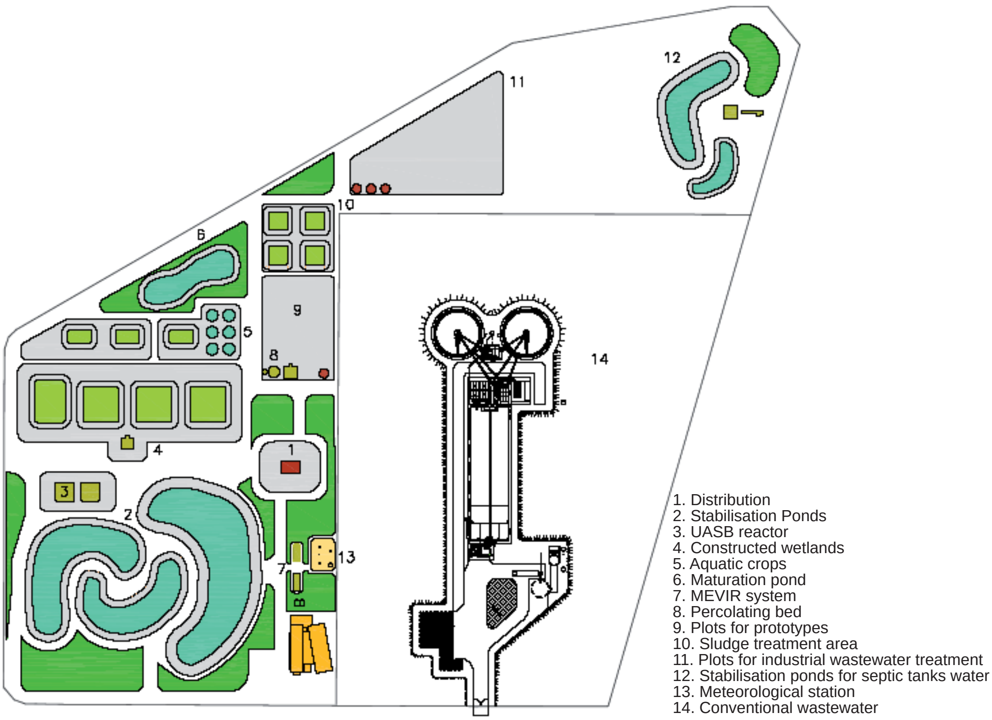

Figure 3. Experimental Plant of Canelones, Uruguay.

III – Results and discussions

Over 18 years of operations at the EPCC and 8 years at the TTC, many studies have been made on the treatment of urban wastewater using extensive technologies. The results obtained have been published in different journals, books, memories and guidelines. Conferences, Meetings and Seminars have been organised and attended, both in Spain, Morocco and abroad. The experiments performed have allowed the training of highly-qualified personnel who are able to transfer their knowledge and provide technical assistance in the field to individuals, organisations and institutions with an interest in the subject.

These two platforms achieved concrete results in the optimisation of the design and operation of these kinds of technologies, adapting them to the climatic and socio-economic conditions in many towns in Andalusia, Morocco and further areas, where the geo-climatic conditions are very similar to those of the Mediterranean area.

In the specific case of Andalusia, the direct results of the work performed by the EPCC show that more than 50% of the existing treatment plants use extensive technologies and today, a large proportion of plants currently under construction in small towns, are of this type (Centre for New Water Technologies, 2008).

On the other hand, the numerous visits made to the EPCC and TTC and the training of the technical staff and students in the wastewater treatments are part of the results of the dissemination activities undertaken at both centres.

It must be mentioned that, under the auspices of the United Nations Office, the EPCC has been assigned the task of supporting the International Decade for Action "Water for Life, 2005-2015"; it is recognized that the activities carried out in this centre may help both developed and developing countries improving their basic services of water sanitation and purification and reaching the Millennium Development Goals (2000).

Regarding Morocco, it must be mentioned that TTC has been a springboard to promote other activities related to water and sanitation in the North of Morocco. Special mention must be made of: (i) drinking water supply to douars, small settlements in the mountain, in the North of Morocco (Rif), within the PAGER Program (1995) on "Drinking Water Supply Program in the Rural Environment" established by the Moroccan Administration in the 90s, and managed by the Moroccan Ministry of Equipment; (ii) plumbing in rural schools, in the framework of "Improvement of Life Conditions in Rural Schools Program" (2005), established by the Moroccan Ministries of Education and Urban Planning, Water and the Environment.

On the other hand, this Centre has allowed the merging between the laboratory of the Quality Service of the Hydraulic Agency of the Loukos Basin and the laboratory of TCC.

IV – Conclusions

The work of EPCC has been and is emblematic. Its aim has been to promote and diversify extensive technologies for small communities so that they can be efficiently applied. The strategy of this Centre and the diversity of technologies it uses have made it a unique reference point in Europe and in the Mediterranean basin. At present, under the auspices of the United Nations Office, it has been assigned the task to support the International Decade for Action "Water for Life, 2005-2015"; it is also recognized that the activities carried out in this centre help both developed and developing countries improving their basic services of water sanitation and purification and reaching the Millennium Development Goals.

Both EPCC and TTC are meeting points and an interface between the public administrations, private enterprises, Universities and Centres; they catalyse the growing demand for demonstrations, training, dissemination and environmental awareness in society in the framework of water.

From the technical point of view, EPCC, TCC and EPC are experimental platforms, oriented towards a series of actions mainly aimed at creating an important connection between them, so that the different research lines in the wastewater treatments in one of the Centres can be investigated in the others. They present similar technical characteristics, with the possibility of varying the water level, modifying the volume and retention times of systems and the working conditions, allowing for different combinations between them. On the other hand, they have got their own laboratories, where all physicochemical and biological parameters are analysed together with their own meteorological stations. These working conditions make it easier the exchange of results and conclusions and the possibility to transfer the knowledge to other countries.

Acknowledgements

This work has been possible thanks to the help of the Andalusian Regional Ministry of the Environment (Water Andalusian Agency) in Spain. For the Kingdom of Morocco, Loukkos Hydraulic Basin Agency and Ministry of Urban Planning, Water and Environment. For Uruguay, the Spanish Ministry of the Environment, Latin American General Secretary, National Direction of Water and Sanitation in Uruguay and to Sanitary Works of Uruguayan State.

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Treated wastewater reuse for a seawater intrusion hydraulic barrier implementation in the Llobregat delta aquifer (Barcelona, Spain). First phase.

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Abstract. Sampling results of a wells network to monitor a hydraulic barrier for seawater intrusion control at the Llobregat delta deep aquifer (Barcelona, Spain) are presented here for the period March 2007-2008. The monitoring programme consisted in periodical water sampling and piezometric level control in wells, local network and wastewater treatment plant. The first-phase results of the sampling campaign show a decrease in electric conductivity in the wells closer to the injection points. Also a cation exchange index decrease is observed, indicating a continuous increase in the water mixing process in the wells. Regarding emerging contaminants, enhanced wastewater treatment removed the majority of contaminants before injection. The preliminary field results of hydrogeological control of injected water indicate that improved pre-treatment of wastewater has been appropriate for contaminants removal.

Keywords. Hydraulic barrier – Seawater intrusion – Treated wastewater – Llobregat aquifer – Microcontaminants.

Recyclage des eaux usées traitées pour la mise en place d'une barrière hydraulique à l'intrusion de l'eau de mer dans l'aquifère du delta du Llobregat (Barcelone, Espagne). Première phase

Résumé. *Dans le présent travail, on passe en revue les résultats de l'échantillonnage d'un réseau de puits mis en place afin de suivre une barrière hydraulique pour le contrôle de l'intrusion marine dans l'aquifère du delta du Llobregat (Barcelone, Espagne), dans la période mars 2007-2008. Le programme de suivi est basé sur le prélèvement périodique d'échantillons d'eau et le contrôle du niveau piézométrique dans les puits, le réseau local et la station de traitement des eaux usées. Les résultats de la première phase d'échantillonnage montrent une réduction de la conductivité électrique dans les puits les plus proches des points d'injection. Parallèlement, on observe une diminution de l'indice d'échange cationique, qui indique un accroissement continu du processus de mélange des eaux dans les puits. Quant aux contaminants émergents, l'amélioration du traitement des eaux usées permet d'éliminer la plupart des contaminants avant l'injection. Les résultats préliminaires du contrôle hydrogéologique des eaux injectées confirment l'importance d'améliorer le pré-traitement des eaux usées   pour éliminer les contaminants.*

Mots-clés. *Barrière hydraulique – Intrusion de l'eau de mer – Eaux usées traitées – Aquifère de Llobregat – Micro-contaminants.*

I – Introduction

The reuse of water originating from sewage treatment plants for environmental applications (generally focussing on clogging processes) assumes that the possible polluting agents are eliminated through conventional treatment. However, not all polluting agents are eliminated through standard treatments (Ternes *et al.*, 2002). Between these "persistent" compounds is the emergent polluting agent group, constituted by chemical compounds of a highly diverse origin, characterised by its high production and consumption entailing its continuous presence in the environment. Currently, a great interest has been taken in studying the presence of these compounds (Sedlak *et al.*, 2000), whose effects on the environment and human health still remain unknown. Among them drugs (antibiotics, painkillers, etc.) are included, diagnosis products, steroids and hormones, antiseptics, personal care products (sun creams, perfumes, etc.), petrol additives, etc. Although in the literature a great number of studies dealing with the application of recycled waters exist, the quality criteria used (Levine and Asano, 2004) do not contemplate the presence of these polluting agents.

Spain is one of the countries that employs a great amount of recycled water although in insignificant total amounts; no more than 5% of collected wastewaters is recycled nowadays. For 2015, and following the new instruments for the integrated water management implementation, the reuse up to 1200 hm^3 is foreseen. In such respect, the new Royal Decree (1620/2007, BOE 294, 8 December 2007) establishes the legal regulations for water reuse plans, reclaimed water definition and treatments to achieve the sanitary and environmental quality for its further use.

In Barcelona metropolitan area, water is a limited resource and of great importance due to the presence of an extended industrial activity and water supply demand. In order to reduce this deficit, wastewater reuse from the Depurbaix sewage treatment plant (Cazurra, 2006), located in the Baix Llobregat, is intended, thus contributing to the sustainable management of water. The volume of water to be reused is destined to satisfy different demands such as the contribution to ecological flow, agricultural irrigation, maintenance of wetlands and the construction of a hydraulic barrier against the existing sea water intrusion in the Llobregat river delta deep aquifer.

The objective of this paper is to present the preliminary results from the first phase implementation of the hydraulic barrier against seawater intrusion in the Llobregat delta. Besides, the quality assessment of the applied wastewater treatment for emerging contaminants is a secondary objective of this research.

II – Geology of the Llobregat delta

The Llobregat river delta (Barcelona, Spain) (Figure 1) is a delta formation covering 97 km^2 formed by Quaternary material deposits of a detritic nature over materials of a Pliocene age, with the exception of the margins, which overly materials of an older age.

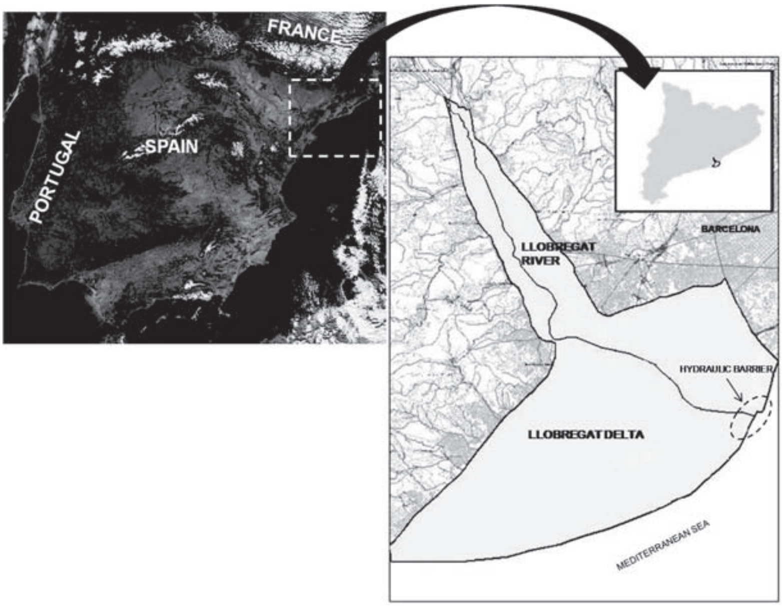

Figure 1. Situation of the study area.

This delta is characterised by two aquifers, the upper and lower aquifer which are separated by a silt wedge confining the lower aquifer, except at the borders of the delta, where this silt package disappears and the upper and lower aquifers are connected by fine sands. The lower aquifer, with an average thickness of 6 m constituted by fine sands and gravels, occupies almost the entire delta surface, extending under the sea below the silt wedge. This aquifer formation has been highly exploited and has produced a general lowering of the water table since the 1970's. This has led to the presence of sea water intrusion in different parts of the aquifer, which has been enhanced by excavations of the impermeable layer, the contact between aquifer and the sea. As a result, a progressive deterioration in the groundwater quality has been observed, which reduces the possibilities of exploiting the aquifer.

With the objective of controlling the sea water intrusion wedge produced in the lower aquifer, studies of different nature have been carried out. Among the numerous articles published, it is possible to mention, for example, Iríbar *et al.* (1997) and Abarca *et al.* (2006) focussing on the hydrogeological aspects, or those describing the construction of a hydraulic barrier by means of the injection of recycled water originating from the Depurbaix sewage treatment plant (Cazurra, 2006; Ortuño *et al.*, 2008).

III – Methodology

The hydraulic barrier consists of injecting treated recycled water to conform a pressure ridge along the coast, therefore stopping the sea water from entering the aquifer. Sampling is currently carried out by the Comunitat d'Usuaris d'Aigües del Delta del Llobregat (CUADLL), Agéncia Catalana del Aigua (ACA) and UPC. The analysis of the components is accomplished by different organisations: detection of major elements (ACA), polluting agents, priority substances and heavy metals (University of Almería and University of Jaén), microbiological analyses (Autonomous University of Barcelona) and analysis of toxicity (Department of the Environment, INIA).

IV– Injection wells

For the first stage, four injection wells were constructed (P1 to P4) at a depth of 70 m, that totally penetrate the lower aquifer (59-65 m). These wells are located 1500 m inland, aligned parallel to the coastline, separated by a distance of 300 m between them (Figure 2). The wells have a diameter of 610 mm, lined with stainless steel to 350 mm. After drilling, pump tests were carried out to define the hydraulic characteristics of the lower aquifer. Results obtained demonstrate that wells P1 and P3 show the highest transmissivity values (700 to 2000 m^2/day), whereas P2 and P4 present smaller transmissivity values (100 to 200 m^2/day).

The injection in wells P3 and P4 commenced in March, 2007. Later, injection began in P2, and in July, 2007, the injection in P4 ceased, leaving only P2 and P3 operative which is the current situation. The initial injected volume was 620 m^3/day during 8 hours per day, until November, 2007, when the volume was increased to 2500 m^3/day during 24 hours.

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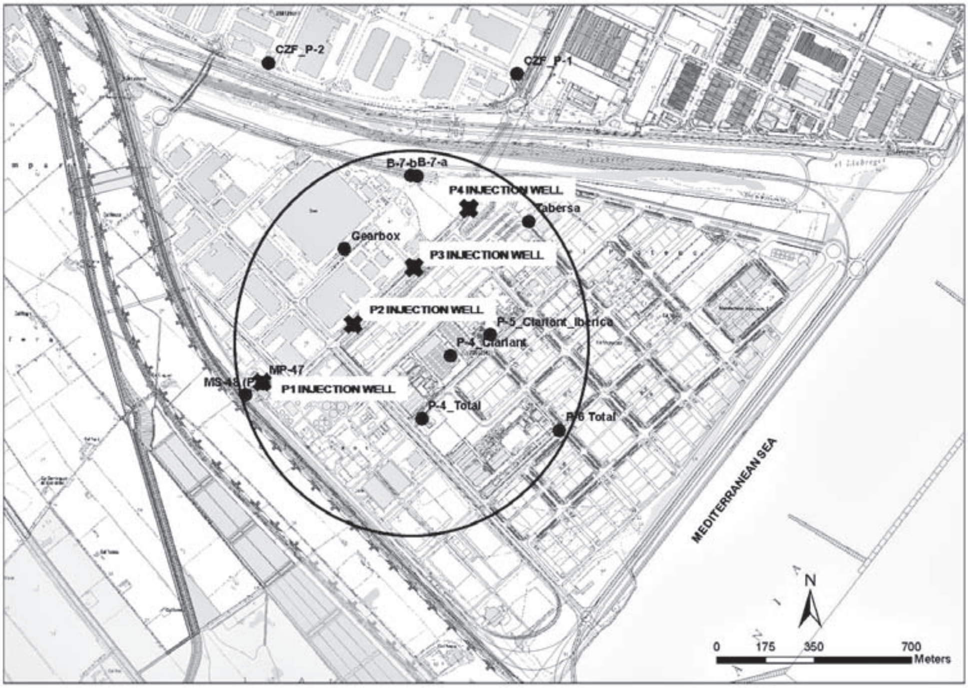

Figure 2. Situation of the injection wells and the local wells network.

V – Injected water

The injected water for the hydraulic barrier initially consisted of an equal mixture between treated wastewater and tap water, following a similar model of the Orange County Water District barrier (California). The water mixture was replaced by recycled water in March, 2008.

The injected treated wastewater consists of outflow water from the Depurbaix tertiary sewage treatment plant that receives an additional treatment. After the conventional tertiary treatment (coagulation-flocculation processes, lamellar clarification, filtration and UV disinfection), water is additionally treated by ultra-filtration, reverse osmosis and UV disinfection before being stored in a deposit for further injection in wells.

VI – Monitoring

In order to control and monitor the hydraulic barrier performance, samples of the influent and effluent of the tertiary treatment were taken, along with the injection water storage deposit and groundwater from the local network (located within a 1 km radius around injection wells). Monitoring started in March 2007.

On a fortnight basis, *in situ* measurements of temperature, dissolved oxygen, Eh, pH, conductivity and piezometric level are taken from wells in the local network and in the water tank for injection. Water samples of the local network and water to be injected are carried out every second month, while influent and effluent samples of the tertiary treatment water were carried out on a monthly basis since April 2007 until May 2008.

For the emerging contaminants and priority substances, 105 substances between which drugs, personal hygiene products, volatile metals, priority polluting agents, polycyclic aromatic hydrocarbons and other priority polluting agents have been selected (Table 1).

Before the injection period commenced on the 26th of March, 2007, samples were taken from injection and local network wells with the objective to determine the background level of the aquifer in respect to its contents of micropollutants. Until the present day 10 sampling events have taken place; however, not all the analytical data is currently available yet.

Table 1. Emerging contaminants and priority substances selected.

Pharmaceuticals	N-acetyl-4-amino-antipiryne (4-AAA) *	Hexachlorobenzene
4-amino-antipiryne (4-AA) *	Naproxen *	Pentachlorobenzene
4-dimethylaminoantipiryne (4-DAA) *	N-formyl-4-amino-antipiryne (4-FAA) *	Alfa-hexachlorocyclohexane
4MAA	Nicotine *	Beta-hexachlorocyclohexane
Acetaminophen	Ofloxacin *	Gamma-hexachlorocyclohexane (lindane)
Antipyrine	Omeprazole	Delta-hexachlorohexane
Atenolol *	Paraxanthine *	Alachlor
Benzafibrate *	Paroxethine	Tetra-brominated diphenyl ether
Biphenylol *	Propanolol hydrochloride	Penta-brominated diphenyl ether 2
Caffeine *	Ranitidine *	Penta-brominated diphenyl ether 3
Carbamazepine *	Salbutamol	**PAHs**
Carb,Epoxide	Sotalol	Acenaphthene
Cefotaxime	Sulfamethoxazole *	Acenaphthylene
Chlorophene	Terbutaline	Anthracene
Ciprofloxacin *	Triclosan *	Benzo (b) fluoranthene
Clofibric acid	Trimethoprim *	Benzo (a) anthracene
Codeine *	**Personal care products**	Benzo (a) fluoranthene
Diatrizoate	3-(4-methylbenzylidene) camphor	Benzo (a) pyrene
Diazepan *	Benzophenone-3	Benzo (k) fluoranthene
Diclofenac *	Celestolide	Chrysene
Erythromycin *	Ethylhexyl methoxycinnamate	Fluoranthene
Fenofibrate	Galaxolide *	Fluorene
Fenofibric Acid	Octocrylene	Naphthalene
Fenoprofen	Octyl-triazone	Phenanthrene
Fluoxethine	Phantolide	Pyrene
Furosemide *	Tonalide *	**Other priority pollutants**
Gemfibrozil *	Traseolide	2,3,7,8-tetrachloro-dibenzo-p-dioxin
Hydrochlorothiazide *	**Metals**	2,7/2,8-dichloro-dibenzo-p-dioxin
Ibuprofen	Ni *	Alpha-Endosulfan
Indomethacine *	Cd	Atrazine
Ketoprofen	Hg *	Beta-endosulfan
Ketorolac	Pb *	Chlorfenvinphos
Mefenamic Acid	**Volatile prioritary pollutants**	Chlorpyriphos-Methyl
Mepivacaine	1,2,3-trichlorobenzene	Diuron *
Methylprednisolone 6-alpha sodium succinate (Urbason)	1,2,4-trichlorobenzene	Endosulfan sulphate
Metoprolol	1,3,5-trichlorobenzene	Isoproturon
Metronidazole *	Hexachloro 1,3-butadiene	Simazine

*: Compounds with concentration higher than 0.1μg/l present in the tertiary treatment effluent.

VII – Results and discussion

The distribution of water volumes injected in the different wells was based on transmissivity data collected from pump tests once drilling had ceased, where more volume is injected in the higher transmissivity wells and the more saline ones. In July, 2007, P4 was abandoned due to malfunctioning, and since then P2 and P3 remain operative, through which an approximated proportion of 15% to 85% of the total volume is injected.

According to the records from September 2007, a volume of 286837 m^3 has been injected up until January 2008.

1. Piezometric evolution at the injection points

In the wells under operation, the dynamic water level is currently located at around -4.7 masl (P2) and -3.5 masl (P3), which represents an increase in the absolute level of 0.58 m and 1.68 m respectively. In agreement with the observed values, and considering the volume of water injected in each well, the flow rate/piezometric uplift relation seems to stay more or less constant, which indicates no evidence of possible clogging until now. Due to problems related to the data acquisition system and to the calibration of the wells pressure sensors, data were not available before September 2007, making piezometric level monitoring more difficult.

2. Evolution of the salinity

In spite of the reduced volume of water injected in the aquifer, a slight reduction of the electric conductivity has been detected in some points of the local network such as at Gearbox Prat (where the conductivity has decreased from 15,723 to 9,770 µS/cm), and in MP-47 and Clariant P4, where the reduction is smaller (around 200 µS/cm in both points). Both wells are located at 640 m and 327 m of distance from the injection wells (Figure 2).

3. Presence of emerging contaminants

From the analytical data available from samples taken from the tertiary treatment plant corresponding to the months of April, May and July (2007), it is observed that some compounds are not totally eliminated by the treatment process. A total of 33 out of the 105 micropollutants analysed were found in concentrations above 0.1 µg/l (accepted maximum value for micropollutants) (Table 1).

In regards to the samples taken from the injecting water deposit, it has been observed that micropollutants that were present in the tertiary treatment effluent tend to disappear after undergoing the further treatment of ultrafiltration, reverse osmosis and UV disinfection. Only one compound, Galaxolide, was found in a concentration greater than 0.1 µg/l.

Finally, for the local network points and injection wells, data is available for the months of March, June and July, 2007. The March sampling was carried out previous to the commencement of the injection with the objective to define the emerging compounds background state of the aquifer. In this initial sampling event, caffeine was detected at concentrations superior to 0.1 µg/l. In the following sampling events at the beginning of the injection period in June and July, concentrations superior to 0.1 µg/l were found for caffeine along with three other compounds: Paraxantine, Nicotine and Galaxolide. Caffeine, which has been detected in concentrations superior to 0.5 µg/l, is an alkaloid compound present in many common drinks; Paraxantine is a metabolite or degradation product of Caffeine. Nicotine, also a composed alkaloid, originates from the tobacco plant and is used in insecticides commonly employed in greenhouses. Galaxolide, found in concentrations that reach 0.35 µg/l, is a fragrance used to manufacture detergents, deodorants, cosmetics, etc.

VIII – Conclusions

The analysis of monitoring records from the first phase of the injection hydraulic barrier along a year has shown a decrease in electric conductivity in wells in the mixing front of groundwater and injected water.

The treated water quality has been one of the most important issues in order to avoid further aquifer impacts. In the case of the treated wastewater destined to the delta deep aquifer injection, the water employed is of the highest quality. The results obtained show that having undergone additional water treatment, the quality of the recycled water is improved to the point where it complies with the criteria required for optimum water reuse in aquifer recharge regimes. Moreover, the additional treatment impairs possible clogging effects of wells due to physico-chemical and biochemical reactions.

Regarding the presence of caffeine, Paraxantine, Galaxolide and Nicotine, given that these compounds were not found in samples taken from the injection water deposit, it seems probable that their presence is related to natural aquifer recharge.

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Low cost bio-sorbent for the removal of phenolic compounds from olive mill wastewater

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Abstract. The adsorption of phenolic compounds from olive mill wastewater (OMW) has been investigated as a function of adsorbent dose, pH and contact time. The results showed that the increase in the banana peel dosage from 10 to 30 g/L significantly increased the phenolic compound adsorption rates from 60 to 88%. Increase in the pH above neutrality resulted in the increase in the phenolic compound adsorption capacity. The adsorption process was fast, and it reached equilibrium in 3h contact time. The equilibrium process was described well by the Langmuir and Freundlich isotherm models with maximum sorption capacity of 688.9 mg/g of phenolic compounds on banana peel at 30°C. Banana peel, an inexpensive and easily available material, can be an alternative to more costly adsorbents used for the removal of phenolic compounds from olive mill wastewater (OMW).

Keywords. Banana peel – Adsorption – Phenolic compounds – Olive mill wastewaters.

Les biosorbants à faible coût pour l'élimination des composés phénoliques des eaux usées d'huile d'olive

Résumé. *L'adsorption des composés phénoliques des eaux usées d'huile d'olive (OMW) a fait l'objet d'une étude visant à évaluer la dose adsorbante, le pH et la durée du contact. Les résultats ont montré que si on accroît le dosage des pelures de banane de 10 à 30 g/L, le taux d'adsorption des composés phénoliques augmente significativement, en passant de 60 à 88%. L'élévation du pH jusqu'à atteindre la neutralité a eu comme résultat l'augmentation de la capacité d'adsorption des composés phénoliques. Le processus d'adsorption s'est avéré rapide et il a atteint l'équilibre après un temps de contact de 3 heures. Le processus d'équilibre a été décrit d'une manière appropriée par les isothermes de Langmuir et Freundlich avec une capacité d'adsorption maximale de 688.9 mg/g de composés phénoliques sur les pelures de banane à 30°C. Les pelures de banane, un matériel économique et facilement disponible, peuvent représenter une alternative aux adsorbants plus coûteux utilisés pour l'élimination des composés phénoliques des eaux usées d'huile d'olive (OMW).*

Mots-clés. *Pelures de banane – Adsorption – Composés phénoliques – Eaux usées d'huile d'olive.*

I – Introduction

Olive mill wastewaters (OMW) are a significant source of environmental pollution related to olive oil production industries. Olive oil extraction processes generate three phases: olive oil, solid residue and aqueous liquor (OMW) which averagely represent 20, 30 and 50% respectively of the total weight of the processed olives. OMWs cause serious environmental deteriorations such as colouring of natural waters, alteration of soil quality, phytotoxicity and odour nuisance.

Conventional methods for the removal of phenolic compounds from OMW can be divided into three main categories: biological(Dias *et al.*, 2004, Mantzavinos and Kalogerakis, 2005, Balice *et al.*, 1990), chemical (Jaouani *et al.,* 2005, Achak *et al.*, 2008, Khoufi *et al.,* 2008) and physical treatment (Aktas *et al.,* 2001, Canepa *et al.,* 1988, Dhaouadi and Marrot, 2008).

Adsorption has been found to be superior to other techniques for water reuse in terms of initial cost, flexibility and simplicity of design, ease of operation and insensitivity to toxic pollutants (Aksu and Yener, 2001). Adsorption also does not result in the formation of harmful substances and the organic sorbents can be used as fuel for power generation or as ferment substrate.

Many sorbents based on low cost agricultural by-products had been used for dye sorption from wastewater, which included banana pith (Namasivayam and Kanchana, 1992), orange peel (Namasivayam *et al.,* 1996), wheat straw (Robinson *et al.,* 2002), sawdust (Garg *et al.,* 2004), powdered waste sludge (Serpil and Fikret, 2006), wheat shells (Bulut *et al.,* 2007), wheat bran (Sulak *et al.,* 2006) and hen feathers (Mittal *et al.,* 2007). However, at the best of our knowledge, the adsorption and removal of specific organics from OMW by banana peel has not been reported.

The aim of this work is to investigate the efficiency of banana peel as a biosorbent for the removal of phenolic compounds from OMW. The effects of various operating parameters on biosorption such as sorbent dosage, initial pH and contact time were monitored and optimal experimental conditions were determined. Different adsorption isotherms (Langmuir and Freundlich isotherms) were used to find out the most suitable models describing our experimental findings.

II – Experiment

1. OMW origin

OMW were obtained from a three-phase continuous extraction unit from Marrakech, southern Morocco. The OMW were first stored in a plastic can (120L-capacity) at ambient temperature.

2. Preparation of the adsorbent

Banana peel was from a local market. The collected biomaterial was extensively washed under tap water to remove soil and dust, sprayed with distilled water. This biosorbent was cut into small pieces, dried in sunlight, crushed and sieved through a 1mm size before its use in adsorption experiments without any further treatment.

A. Physical-chemical analysis of OMW

pH was determined with a pH meter (716 DMS Titrino). Electrical conductivity (EC) was measured with a conductivimeter (Tacussel) (Rodier, 1984). Total suspended solids (TSS) were determined after filtering a sample through a GF/C filter (0.45 μm) and drying the retained residue at 105°C for 60 min (Rodier, 1984). Total and dissolved chemical oxygen demand (COD) was determined by a colorimetric method (APHA, 1992). The biochemical oxygen demand (BOD_5) was assessed by measuring the oxygen uptake in a sample over a period of 5 days at 20°C, in the dark using the BOD Track apparatus (AFNOR, 1983). Kjeldhal N (Kj-N), ammoniacal nitrogen (NH_4) and nitrite (NO_2) were determined by AFNOR method (AFNOR, 1983). Nitrate (NO_3) was determined like nitrite after its reduction by passage in a cadmium-copper column (Rodier, 1984). The phosphorus content (expressed as phosphate equivalents) was determined colorimetrically using the AFNOR method (AFNOR, 1983). Phenolic compounds were quantified by means of the Folin-Ciocalteu colorimetric method (Box, 1983) using caffeic acid as a standard.

B. Adsorption experiments

Batch adsorption experiments were carried out using a rotary shaker (rotatest 74581) at 200 rpm.min^{-1} at 30°C ± 2°C in a 250 mL shaking flasks containing 100 mL of OMW with a known concentration of phenol (13.45 g/L). Different doses (1-5 g) were tested at various pHs (2-11). The pH of the suspension was adjusted by 0.1 N HCl or NaOH. The changes in the adsorption rates of phenols were monitored at different time intervals (1; 1.5; 2; 2.5; 3; 4; 18; 24h). Samples were taken out from flasks and the solutions were separated from the adsorbent by filtration with a 0.6 mesh stainless steel sieve and centrifuged for 20 min at 5100 rpm min^{-1}. Phenolic compounds concentration in the supernatant solutions was determined.

The amount of adsorption at equilibrium, q_e (mg/g), and the percent adsorption (%) were computed as follows:

$$q_e = [(C_0 - Ceq)\ V]/\ X \qquad (1)$$

$$\text{Percent adsorption (\%)} = (C_0 - C) * 100 / C_0 \qquad (2)$$

Where C_0 and Ceq are the initial and equilibrium concentration of phenolic compounds (g/L), V volume of solution (L), X the weight of banana peel (g) and C the phenolic concentration at the end of adsorption.

III – Results and discussion

1. OMW characterization

Table 1 shows the main properties of OMW after one week decantation to remove the total suspended solids. As depicted in table 1, the sample shows an acidic pH value (5.06), the electrical conductivity was very low (6.9 mS/cm) compared to that reported by Zenjari *et al.* which varies between 25.3 and 36.6 mS/cm (Zenjari *et al.,* 1999). OMWs contain also a high level of organic matter (70.2 g O_2/L of total COD, 48.7 g O_2/L of dissolved COD) and high amounts of total phenolic compounds (13.4 g/L) which are toxic. The OMWs contain some valuable nutrients such as nitrogen and potassium, which would be useful in agriculture after effluent treatment.

Table 1. Physical-chemical determination of the raw OMWs (mean values of 3 separate analyses ± standard deviation).

Parameters	Data
pH (25°C)	5.06
Electrical conductivity (mS/cm) à 20°C	6.85
Total suspended solids (TSS) (g/L)	2.07±0.02
TKN (g/L)	1.96 ± 0.01
NH_4^+ (mg/L)	0.64 ± 0.04
NO_3^- (mg/L)	0.4 0 ± 0.07
NO_2^- (mg/L)	4.00 ± 0.03
Total phenols (g/L)	13.45 ± 0.01
Total COD (gO_2/L)	70.22 ± 1.22
Dissolved COD (g O_2/L)	48.69 ± 3.18
BOD_5 (g O_2/L)	16.74 ± 0.19
PO_4^- (g/L)	0.36 ± 1.43
Total P (g/L)	0.42 ± 0.003

2. Effect of adsorbent rates

The equilibrium uptake for the adsorption of phenolic compounds on banana peel was determined with 100 mL of OMW containing 13.45 g/L total phenolic compounds. The system was agitated for 24h (200 rpm) at a constant temperature (30°C ± 2°C) at the origin pH 5.

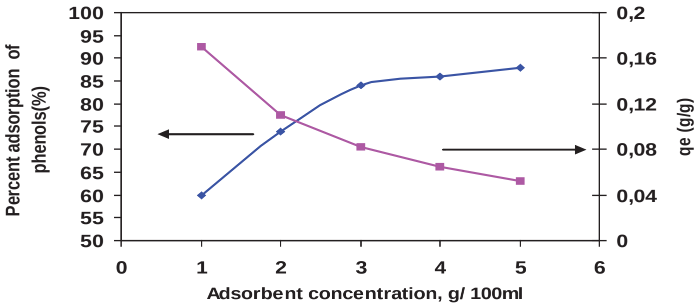

Figure 1. Influence of adsorbent concentration on adsorption rates of phenolic compounds and the equilibrium uptake (Conditions: 100 mL of OMW, temperature: 30°C, contact time: 24h and initial pH 5).

Figure 1 shows that the increase in adsorbent dosage from 10 to 50 g/L resulted in a decrease from 60 to 88% in phenolic compounds of the OMW. It is readily understood that the number of available adsorption sites increases with the increase in the adsorbent dosage and it, therefore, results in the increase in the amount of adsorbed phenolic compound.

A. Effect of pH on phenolic compounds biosorption

The most important parameter influencing the adsorption capacity is the pH of adsorption medium (Goyal *et al.,* 2003). The final pH of an adsorption medium affects the adsorption mechanisms on the adsorbent surface and influences the nature of the physico-chemical interactions of the species in solution and the adsorptive sites of adsorbents (Aksu *et al.,* 2002).

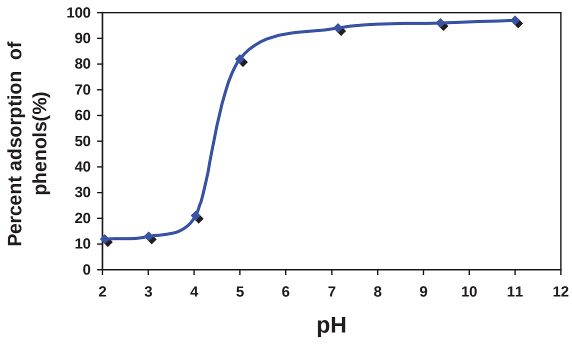

Figure 2. Effect of pH on adsorption of phenolic compounds by banana peel (Conditions: 100mL of OMW, Temperature: 30°C, contact time: 24h and sorbent dose: 30 g/L).

The effect of pH on the adsorption of phenolic compounds by banana peel at pH ranging between 2 and 11 is shown in figure 2. The adsorption efficiency increased from 12 to 97% when the solution pH varied from 2 to 11.

As shown in figure 2, at low pH values, the rate of the sorbed phenolic compounds was very low. At higher pH, the adsorption increased and stabilized from pH 7 to pH 11. Thus, the high elimination (97%) of natural phenolic compounds in OMW is achieved in a large pH zone above neutrality. From a practical point of view, this will be of great interest, since it will not necessitate very accurate adjustment of the medium pH.

The mechanisms of action of pH cannot be reduced to a surface charge modification and the adsorption of phenolic compounds and other compounds must not be seen only as the result of electric interactions. Many other interactions can lead to the adsorption of molecules on adsorbent surfaces especially in the case of bioadsorbants. Adsorption can result from weak forces interactions, ionic strength and chemical reactions leading to irreversible bindings.

B. Effect of contact time

The effect of contact time on adsorption of phenolic compounds by banana peel is presented in figure 3. The adsorption equilibrium of phenolic compounds was obtained after 3 h and no remarkable changes were observed for longer contact time.

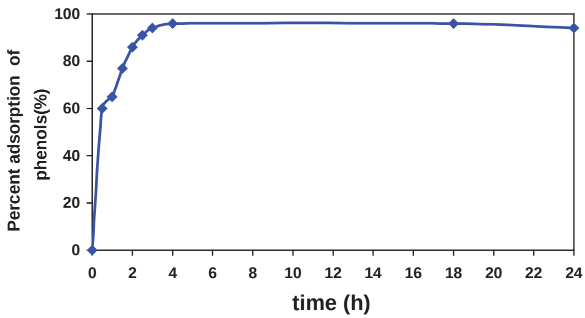

Figure 3. Effect of contact time on the adsorption of phenols by banana peel (Conditions: 100 ml of OMW, temperature: 30°C, sorbent dose: 30g/l and pH 7).

Adsorption rate of phenolic compounds on banana peel was found to be relatively much faster than those reported for some other normal adsorbents (Xiaolo and Youcai, 2006, Thawornchaisit and Pakulanon, 2007, Bhatnagar, 2007). Initially, a large number of vacant surface sites is available for adsorption; the adsorption rate is very fast, thus it rapidly increases the amount of adsorbates accumulated on the banana peel surface mainly within the first hour of adsorption. As a result, the remaining vacant surface sites are difficult to be occupied due to the formation of repulsive forces between the phenolic compounds on the solid surface and the bulk phase (**Srivastava *et al.,* 2006**).

C. Adsorption isotherms

Equilibrium relationships between sorbent and sorbate are described by sorption isotherms, usually the ration between the quantity sorbed and that remaining in the solution at a fixed temperature at equilibrium.

In order to optimize the design of a sorption system to remove phenolic compounds from OMW, it is important to establish the most appropriate correlation for the equilibrium curve. Many theories which described adsorption equilibrium were applied. Several isotherm equations are available, and two important isotherms are selected for this study: the Langmuir and Freundlich isotherms (Chan *et al.*, 2008, Lata *et al.*, 2008). The linearised Langmuir equation is represented as follows:

$Ce/qe = 1/bQm + Ce/Qm$ (3)

Where qe (mg/g) and Ce (g/L) are the amount of adsorbed phenolic compounds per unit weight of adsorbent and the unadsorbed phenolic compounds concentration in solution at equilibrium. *b* is the equilibrium constant or Langmuir constant related to the affinity of binding sites (L/g) and *Q*m represents a particle limiting adsorption capacity when the surface is fully covered with phenolic compounds and assists in the comparison of adsorption performance.

The essential characteristic of the Langmuir isotherm can be expressed by the dimensionless constant called the equilibrium parameter, R_L, defined as:

$R_L = 1 / (1 + b\ C_0)$ (4)

Where b is the Langmuir constant, C_0 is the initial phenolic compounds concentration (g/L) and R_L values indicate the type of isotherm to be irreversible (R_L =0), favourable (0< R_L <1), linear (R_L =1), or unfavourable (R_L >1) (HO *et al.*, 2002). Our results show that the adsorption for phenolic compounds on the banana peel is favourable and has an R_L value between 0 and 1 (table 2).

Also, data were studied with the Freundlich isotherm, which can be expressed by logarithmic form as:

$\ln qe = \ln K_F + 1/n \ln Ce$ (5)

Where K_F is a Freundlich constant that shows adsorption capacity of adsorbent, n is a constant which shows greatness of relationship between adsorbate and adsorbent.

The Freundlich describes reversible adsorption and is not restricted to the formation of monolayer. It has been found that the adsorption for phenolic compounds on the banana peel is favourable and has an n value between 1 and 10 (table 2). The Qm, b, R_L, R_1^2 (correlation coefficient for Langmuir isotherm), K_F, n, and R_2^2 (correlation coefficient for Freundlich isotherm) are given in table 2.

Table 2. Isotherm constants and the correlation coefficients of Langmuir and Freundlich isotherms.

	Langmuir isotherm				Freundlich isotherm		
Effluent	Qm (mg/g)	b (L/g)	R_1^2	R_L	K_F	n	R_2^2
OMW	688.9	0.24	0.94	0.57	0.13	1.13	0.99

The $R_1^2$and R_2^2 values shown in table 2 are evidence that the phenolic compounds adsorption in this study is well fitted to both Langmuir and Freundlich models; a possibility of mono and heterolayer phenolic compounds formation on the adsorbent surface. This observation is not rare as similar findings have been reported before (Mohd Din *et al.*, 2008, Vazquez *et al.*, 2007, Annadurai *et al.*, 2002). This phenomenon can be further explained by understanding the surface chemistry of banana peel used in this study. The presence of active functional groups with different intensity and non-uniform distribution may cause differences in the energy level of the active sites available on the banana peel surface thus affecting its adsorption power. Active sites with higher energy level tend to form heterolayer phenolic compounds coverage with robust support from strong chemical bonding whilst active sites with lower energy level will induce monolayer coverage due to electrostatic forces.

IV – Conclusion

Banana peel has proven to be a promising material for the removal of contaminants from olive mill wastewaters. Not only banana peel is an abundant cheap adsorbent, but it is also highly efficient for removing phenolic compounds from OMW. All those add more credits to banana peel for removing pollutants from wastewaters. The main characteristics of the adsorption process of the natural phenolics from OMW on banana peel can be summarized as follows:

- The banana peel showed a high adsorption capacity of phenolic compounds (688.9 mg/g), revealing that banana peel could be employed as a promising adsorbent for phenolic compounds adsorption.
- The adsorption process was very fast, and it reached equilibrium in 3h of contact. The equilibrium of the solid-phase concentration of phenols (qe, w/w) decreased with increasing adsorbent (banana peel) concentration. This is mainly attributed to the unsaturation of the adsorption sites through the adsorption process. The equilibrium was reached at 82.33 (mg/g) (3 g/100mL) of banana peel.
- The pH played an obvious effect on the phenolic compounds adsorption capacity onto banana peel. An increase in the solution pH leads to a significant increase in the adsorption capacities of phenolic compounds on the banana peel, maximum adsorption capacity occurred at alkaline pH.
- Both Langmuir and Freundlich isotherms provide good correlations for the adsorption of phenolic compounds onto banana peel.

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Valorization of a mining effluent by selective recovery of Zn using solvent extraction

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Abstract. Zn is a typical metal component of acidic mining waters. Its selective recovery is a goal to valorize such effluents and also to minimize the cost for the mandatory treatment of such effluents. To this purpose, a solvent extraction process was developed successfully in our laboratories after comparing the results of applying different organophosphorous acids such as di-2(-ethylhexyl)-phosphoric acid (D2EHPA) and bis-(2,4,4-trimethylpentyl)-phosphinic acid (CYANEX 272 and IONQUEST 290) to a specific acidic mine effluent of South Spain (Aznalcollar Mine). Results showed that kinetics is faster with CYANEX 272 (CY) and IONQUEST 290 (IQ) than with DEHPA, reaching a 95% of the Zn recovery at less than 5 minutes for CY and IQ and 10 min for DEHPA. Regarding the selectivity, DEHPA extracts more efficiently Al and Ca than Zn. Ca is re-extracted from the organic phase to the stripping phase, providing an effluent almost saturated with gypsum, that will interfere in the EW process. In addition, Al is not re-extracted from the organic phase causing poisoning of DEHPA and avoiding their future reutilizations. On the other hand, neither IQ nor CY indicates Al, Cu, Mn or Ca enrichment in the stripping solution thus there is no need for scrubbing the organic phase. IQ recovery of Zn is 5-10% higher than for CY. Taking into account all these results, the best solvent considered for the extraction of Zn was IONQUEST 290.

Keywords. Mining effluent – Solvent extraction – Zinc –DEHPA - IONQUEST 290 – CYANEX 272.

Valorisation des effluents miniers par récupération sélective du Zn utilisant l'extraction par solvant

Résumé. *Le zinc est un composant métallique typique des eaux acides minières. Sa récupération sélective est une étape fondamentale pour valoriser ces effluents et minimiser les coûts de leur traitement obligatoire. A cette fin, un processus d'extraction par solvant a été mis au point avec succès dans nos laboratoires après avoir comparé les résultats de l'application des différents composés organophosphorés tels l'acide phosphorique di(2-éthylhexyl) (D2EHPA) et l'acide bis-(2,4,4-triméthylpentyl)-phosphinique (CYANEX 272 et IONQUEST 290) à des effluents acides miniers dans le sud de l'Espagne (mine d'Aznalcollar). Les résultats ont montré que la cinétique est plus rapide avec le CYANEX 272 (CY) et l' IONQUEST 290 (IQ) qu'avec le DEHPA, permettant de récupérer 95% de Zn en moins de 5 minutes dans le cas du CY et de l'IQ et de 10 minutes dans le cas du DEHPA. S'agissant de la sélectivité, le DEHPA extrait plus efficacement l'Al et le Ca que le Zn. Le Ca est ré-extrait de la phase organique à la phase d'extraction, produisant ainsi des effluents presque saturés en gypse, qui vont interférer dans le processus d'EW. En plus, l'Al n'est pas ré-extrait de la phase organique provoquant une contamination du DEHPA et évitant une réutilisation future. Par ailleurs, ni l'IQ, ni le CY n'indiquent un enrichissement en Al, Cu, Mn ou Ca dans la solution d'extraction pas plus que dans la solution organique rendant ainsi nécessaire le scrubbing de la phase organique. La récupération du zinc avec l'IQ est 5 à 10% plus élevée qu'avec le CY. A la lumière de ces résultats, l'IONQUEST 290 s'avère être le meilleur solvant pour l'extraction du zinc.*

Mots-clés. *Effluent minier – Extraction par solvant – Zinc – DEHPA – IONQUEST 290 – CYANEX 272.*

I – Introduction

Developing viable ways of recycling industrial waters such as mining effluents rather than the simple disposal of the effluents and their derivate sludge as a hazardous waste in specially controlled landfills is extremely important from an environmental and economical point of view. In a currently abandoned mine in Andalusia, Spain, huge streams of effluents, containing about 1 g/l Zn and significant amount of calcium, copper, aluminium and manganese cations were treated in order to obtain pure Zn. Zinc is the fourth most commonly used metal in the world trailing only iron, aluminum and copper in annual production. Over 7 million tons of zinc are produced annually worldwide. Nearly 50% of the amount is used for galvanizing to protect steel from corrosion, approximately 19% is used to produce brass and 16% goes into the production of zinc base alloys to supply the die casting industry. Significant amounts are also utilized for compounds such as zinc oxide and zinc sulfate and semi-manufactures including roofing, gutters and down-pipes. These first-use suppliers then convert zinc into a broad range of products such as rubber in tyres, ointments to prevent bacteria and fungi from reproducing, in sunscreen, TV screens and luminous dials amongst others. These broad types of uses give zinc high economic value (Adriano, 2000).

Conventional treatment methods for zinc extraction and purification included precipitation, ion exchange, adsorption, electrochemical recovery, membrane separation and solvent extraction. Amongst those, solvent extraction (SX) has been widely proposed as one of the best ways to extract Zn from waters containing Zn and other impurities for being one of the most economical and practical processes (Devi, 1997). This is a very-well established process in hydrometallurgy used for the recovery of a large number of metals from aqueous sources. This process involves the use of a extractant usually diluted in an organic solvent. In this process, the solution containing the metal/s of interest is contacted with the extractant solution where the target elements are extracted from the initial solution. Once the extraction process has taken place, a re-extraction process or strip from the organic phase that contains the extractants "bonded" with the metals is necessary to get a clean solution with the target metals. Usually this re-extraction step is carried out with some acidic solution (strip solution) with higher affinity with the target metals than the extractant. Sometimes, when the organic phase has higher affinity for some metal/s than the strip solution, further steps may be necessary, i.e, scrubbing of the solvent, previous to the strip of the target elements or regeneration of the extractant after the stripping phase for further applications. The latter steps involve an increase in the cost due to spent in reactants as well as in time. These steps are summarized in Nowadays, a wide number of extractants are available for use in solvent extraction for the recovery of metals. Some of them are suitable for a specific metal; others must be used at certain conditions to avoid extraction of impurities. The most widely used extractants for Zn recovery are those corresponding to the organophosphorous acids group, i.e, DEHPA and CYANEX, commonly used in SX. In this study, a new commercial extractant never tested before, IONQUEST 290, is compared with the results of DEHPA and CYANEX in samples obtained from the mentioned Zn rich mine effluent in order to get a Zn sulphate rich liquor to be used later in an electrowinning plant..

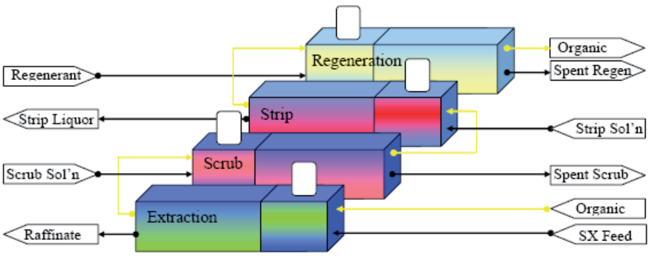


Figure 1. Typical solvent extraction process steps.

Nowadays, a wide number of extractants are available for use in solvent extraction for the recovery of metals. Some of them are suitable for a specific metal; others must be used at certain conditions to avoid extraction of impurities. The most widely used extractants for Zn recovery are those corresponding to the organophosphorous acids group, i.e, DEHPA and CYANEX, commonly used in SX. In this study, a new commercial extractant never tested before, IONQUEST 290, is compared with the results of DEHPA and CYANEX in samples obtained from the mentioned Zn rich mine effluent in order to get a Zn sulphate rich liquor to be used later in an electrowinning plant.

Di-(2-ethylhexyl)phosphoric acid (DEHPA) has been successfully used as an extractant for many metal ions, including zinc (Ritcey, 1971; Kunzmann, 1992; Sastre, 1984) due to its great extraction capacity and low cost. It has been used to extract zinc more efficiently than other bivalent metal ions (Grimm, 1974) such as copper, nickel, cobalt and cadmium. The order of extraction of eight metal ions from a sulphate solution using DEHPA has been reported as a function of pH (Ritcey and Ashbrook, 1984) to be $Fe^{3+}>Zn^{2+}>Cu^{2+}>Co^{2+}>Ni^{2+}>Mn^{2+}>Mg^{2+}>Ca^{2+}$ where zinc is extracted much earlier than manganese. In a more recent study of the separation of divalent metal ions from a synthetic laterite leach solution (Cheng, 2000), the extraction of metal ions was in the order $Zn^{2+}>Ca^{2+}>Mn^{2+}>Cu^{2+}>Co^{2+}>Ni^{2+}>Mg^{2+}$. By varying the acidic conditions and the temperature as main parameters, the target metal can be separate from the bulk solution or even different metals can be extracted separately by varying in various steps the conditions to get pure solutions of the target metals.

CYANEX 272, which is a commercial dialkylphosphinic acid produced by Cytec, has been used as well as its thiosubstituted derivatives (CYANEX 302 and CYANEX 301) in the extraction of several metal ions. Various studies report the adequacy of Cyanex 272 to extract, for instance, Fe, Zn, Cr, Cu and Ni from sulphuric and/or sulphate solutions (Rickelton, 1990; Lanagan, 2003; Rickelton, 1984; Reddy, 2001).

In the present study, to achieve greater recoveries of improved selectivity, another commercial extractant, IONQUEST 290, was selected, having the same active ingredient of CYANEX 272, Bis(2,4,4-TriMethylPentyl) Phosphinic Acid. However, IONQUEST 290, provides an average a 5-10% higher activity than in Cyanex 272. Two kerosene types with different flash point were employed as a solvent for this extractant, Ketrul D80 and Ketrul D100, with a flash point of 72 ºC and 100ºC or superior (ISO 2719), respectively. It must be pointed out that the higher the flash point, the lesser the flammability of the kerosene, and, therefore the higher the security of the solvent extraction process, specially when it is applied at outside warm climate conditions.

Thus, the aim of this work is to investigate the solvent extraction/striping processes for the recovery of zinc from a mine effluent using either DEHPA, CYANEX 272 or IONQUEST 290 as extractants to identify the best extractant regarding the efficiency as well as the process selectivity. In addition, we want to determine the best type of kerosene to be used as a solvent for the mentioned extraction/stripping process.

II – Methods

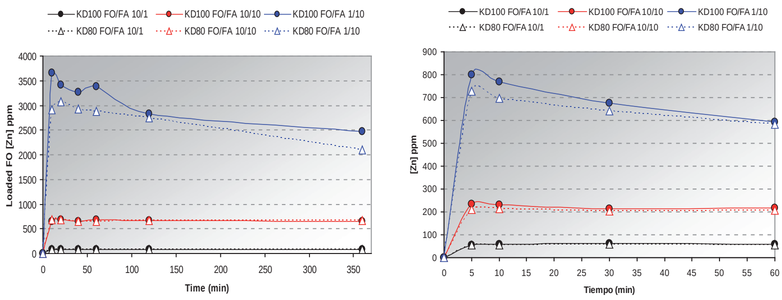
Sample description. The initial solution from the mine tailing was previously treated in order to remove the Fe content since no extractants capable to extract Zn selectively from a solution containing Fe are commercially available. Thus, a previous step involving the Fe precipitation by a bioxidation process using *Thiobacillus ferrooxidans* (Mazuelos, 2000; Carranza, 1993) was mandatory. This process was implemented in the pilot plant on a specific reactor developed by Prof. F. Carranza, from the Seville University. After iron removal, a representative sample of Aznalcollar Corta effluent was received from EGMASA at our laboratories. The solution was colourless and with a pH value of 3.7. The Zn concentration and other metal impurities were determined by ICP-OES analysis, having a content of 210 ppm of Al, 580 ppm of Ca, 45 ppm of Cu, 1.2 ppm of Fe, 195 ppm of Mn and 881 ppm of Zn amongst other elements.

R*eagents.* DEHPA (Batch ref. 0063829) was purchased form Rhodia INC, Crandbury, NJ, USA. Kerosene solvent with Flash Point 80 and 100 (Bath ref. 20062016 and 20061560, respectively) was purchased from TOTAL FLUIDES, Oudalle, France. IONQUEST 290 (Batch Ref. G05A1) was supplied by Rhodia Ltd, Oldbury, United Kingdom. The stripping of the organic enriched phase was performed using 2.0 M sulphuric acid solution. Sulphuric acid was purchased from J.T. Baker, Phillipsburg, NJ, USA. The two phases contact experiments were carried out in 50 mL stoppered glass tubes agitated by a rotating rack. The experiments to obtain the isotherms of the solvent extraction procedure were carried out varying the Vorg/Vaq ratio from 0.1 to 10 using stoppered glass tubes on a rotary rack. No centrifugation of the dual phase system was needed because of the clear phase separation obtained. Selectivity of Zn extraction is determined by metal impurities in the recovered liquor by means of ICP-OES analysis using a ThermoElemental ICP-OES (model Intrepid II XLS, Franklyn, MA, USA) on the obtained 2.0 M sulfuric acid stripping, considering the metals concentration in the initial effluent. All of them were used as it is without any further purification.

Procedure. Batch experiments were carried out by equilibrating equal volumes of CYANEX 272 or IONQUEST 290 at 5% v/v and DEHPA at 40% in each type of kerosene with the liquor containing the metals in stoppered glass tubes and were agitated using an end-over-end shaker. The different DEHPA concentration is due to reasons of efficiency (extraction yield vs extractant cost). For the kinetic experiments, the time of agitation was varied ranging from 5 to 30 minutes. For the experiments varying the equilibrium pH, the time of agitation was 30 minutes. After the extraction and phase separation, the stripping of the organic solution loaded with the metals was carried out during 30 minutes with an equal volume of H_2SO_4 2.0 M. The concentration of the metals in the re-extracted phase and in the aqueous phase after separation were analysed using a Thermo ICP-OES Intrepid II. The experiments to obtain the isotherms of the solvent extraction procedure were carried out varying the Vorg/Vaq ratio from 0.1 to 10 using stoppered glass tubes on a rotary rack. No centrifugation of the dual phase system was needed because of the clear phase separation obtained. Selectivity of Zn extraction is determined by metal impurities in the recovered liquor by means of ICP-OES analysis using a ThermoElemental ICP-OES (model Intrepid II XLS, Franklyn, MA, USA) on the obtained 2.0 M sulfuric acid stripping, considering the metals concentration in the initial effluent. % Remaining OP was found by difference of the % Remaining AP of the metal and the % Recovery found in the strip solutio

III – Results and discussion

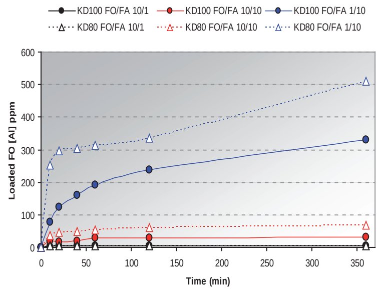
Kinetics experiments. Extraction kinetics data are given below for Zn and metal impurities such as Ca, Al, Cu, Fe and Mn for the extractants DEHPA and CYANEX 272, the latter having a behaviour similar to that of IONQUEST 290.

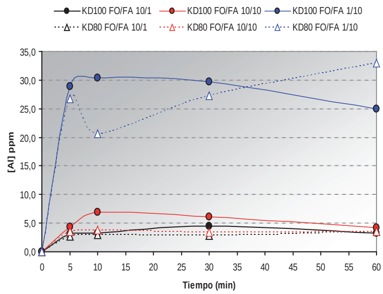


Figures 2 and 3. Comparison of Zn (organic phase) extraction kinetics when using kerosene flash point 80 and 100 at different organic/aqueous (FO/FA) ratio with DEHPA 40% (left) and CYANEX 272 5% (right).

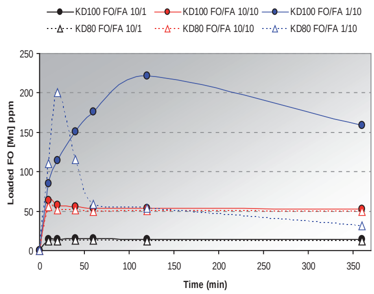
It is observed for both extractants, DEHPA and CYANEX, that less than 10 min are enough to reach the equilibrium for Zn extraction. No significant differences for Zn extraction were observed for the two flash point kerosene.

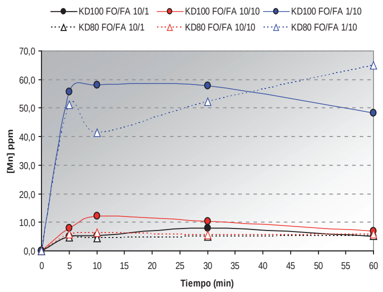
The higher recoveries obtained for kerosene with a flash point of 80 can be attributed to the higher solubility of the corresponding Al-DEHPA complex in this media. More than 10 minutes are necessary to reach the extraction equilibrium for both extractants. Comparing these data with those obtained for Zn, it is observed a higher extraction and a faster kinetics for Zn, independently of the employed kerosene. The highest differences in terms of extracted amounts are observed for a Vorg/Vaq 1/10 phase ratio. Almost an order of magnitude is observed between the extracted amounts of Zn and Al, and those differences are exacerbated in kerosene with flash point 100.





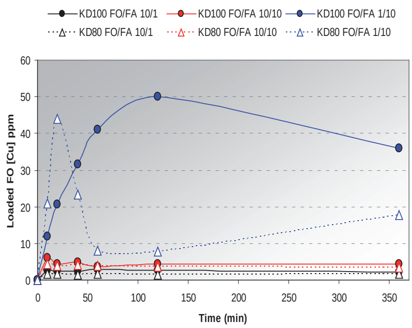
Figures 4 and 5. Comparison of Al (organic phase) extraction kinetics when using kerosene flash point 80 and 100 at different organic/aqueous (FO/FA) ratio with DEHPA 40% (left) and CYANEX 272 5% (right).

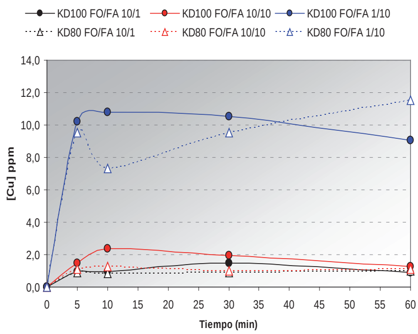




Figures 6 and 7. Comparison of Mn (FO) extraction kinetics when using kerosene flash point 80 and 100 at different organic/aqueous (FO/FA) ratio DEHPA 40% (left) and CYANEX 272 5% (right).

The comparison of Mn extraction kinetic with that of Zn shows a similar behaviour in terms of time needed to reach the equilibrium independently of the considered kerosene. Higher differences between the enrichment of the organic phase are observed for kerosene flash point 80 when comparing Zn and Mn rather than when using kerosene flash point 100.





Figures 8 and 9. Comparison of Cu (FO) extraction kinetics when using kerosene flash point 80 and 100 at different organic/aqueous (FO/FA) ratio DEHPA 40% (left) and CYANEX 272 5% (right).

As an impurity, the enrichment of Cu in the stripping indicates that the highest amounts are observed for the 1/10 ratio, especially for the kerosene flash point 100. The extraction equilibrium was reached at 120 minutes. No differences between both kerosene were observed, except for the Vorg/Vaq 1/10 phase ratio where kerosene with a flash point of 80 released higher amounts of Fe.

For Ca, the main difference is observed again for the 1/10 ratio phase, the organic phase being more enriched for kerosene FP 100 once the equilibrium is reached. When dealing with Ca, the comparison against Zn, indicates that almost no differences are observed from the kinetic point of view. However, it is interesting to highlight the higher difference on the organic phase enrichment ratio between Zn and Ca when considering kerosene flash point 80, on the 1/10 phase ratio.

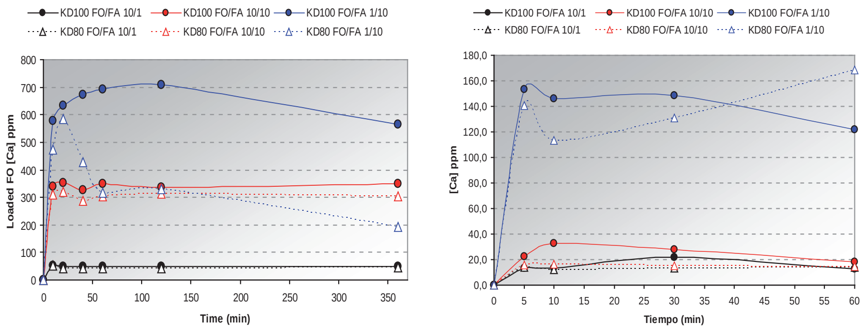


Figure 10 and 11. Comparison of Ca (FO) extraction kinetics when using kerosene flash point 80 and 100 at different organic/aqueous (FO/FA) ratio DEHPA 40% (left) and CYANEX 272 5% (right). FO=Organic Phase.

As a conclusion, kinetics of Zn extraction for both extractants employed, DEHPA and CYANEX 272, report no big differences. In terms of the other metals present, DEHPA followed the next trend: Zn> Ca> Al> Mn > Cu, being all the extractions of the interfering metals slower than for CYANEX that presents similar kinetics for all the metals in the solution. Thus, when using DEHPA short equilibrium times must be considered although for CYANEX 272 no differences will be found. Considering both solvents, Ketrul D80 and Ketrul D100, no big differences were found.

Selectivity. From the point of view of the selectivity, experiments varying the aqueous phase volume against a constant volume of the organic phase containing DEHPA and vice versa were realised. Recoveries achieved and percentage of the elements remaining in the aqueous phase after extraction process (FA) and percentage of metal remaining in the organic phase after stripping process (OP or FO) are shown in TablTable 1. Percentage of recoveries, element remaining in the aqueous phase(AP) and element remaining in the organic phase (OP) achieved using DEHPA for kerosenes Ketrul D80 and Ketrul D100 when varying the aqueous phase volume.d Table 2.

Table 1. Percentage of recoveries, element remaining in the aqueous phase(AP) and element remaining in the organic phase (OP) achieved using DEHPA for kerosenes Ketrul D80 and Ketrul D100 when varying the aqueous phase volume.

FAP	FOP	Ketrul D80			FAP	FOP	Ketrul D100		
		% Recovery	% Remaining AP	%Remaining OP			%Recovery	% Remaining AP	% Remaining OP
					Zn				
10	**10**	72,75	17,41	9,84	**10**	**10**	74,77	17,80	7,43
7	**10**	77,81	13,95	8,24	**7**	**10**	75,53	14,10	10,37
5	**10**	77,99	11,05	10,97	**5**	**10**	78,61	11,47	9,91
3	**10**	81,48	7,97	10,56	**3**	**10**	83,98	8,38	7,64
1	**10**	86,69	4,96	8,35	**1**	**10**	92,46	5,05	2,49
					Ca				
10	**10**	54,34	30,35	15,31	**10**	**10**	59,01	25,14	15,84
8	**10**	60,43	27,34	12,23	**8**	**10**	63,46	21,74	14,80
5	**10**	65,43	19,56	15,01	**5**	**10**	67,07	15,42	17,51
3	**10**	68,14	15,21	16,65	**3**	**10**	69,35	11,26	19,40
1	**10**	76,66	11,11	12,23	**1**	**10**	79,72	7,47	12,81
					Al				
10	**10**	18,89	3,55	77,56	**10**	**10**	12,92	9,19	77,88
8	**10**	20,95	3,41	75,64	**8**	**10**	18,17	4,45	77,38
5	**10**	27,80	0,65	71,55	**5**	**10**	21,91	1,76	76,33
3	**10**	22,39	0,00	77,61	**3**	**10**	17,60	0,80	81,60
1	**10**	25,06	0,00	74,94	**1**	**10**	25,78	0,00	74,22
					Mn				
10	**10**	23,97	71,61	4,42	**10**	**10**	29,34	72,95	0,00
8	**10**	28,16	66,63	5,21	**8**	**10**	34,10	68,76	0,00
5	**10**	35,61	56,32	8,08	**5**	**10**	43,05	58,16	0,00
2	**10**	48,47	40,45	11,08	**2**	**10**	59,13	39,97	0,89
1	**10**	56,45	34,76	8,79	**1**	**10**	67,24	33,45	0,00
					Cu				
10	**10**	5,77	98,45	0,00	**10**	**10**	9,70	97,53	0,00
8	**10**	6,90	95,13	0,00	**8**	**10**	11,60	97,13	0,00
5	**10**	9,85	89,89	0,26	**5**	**10**	18,11	91,57	0,00
3	**10**	13,33	87,45	0,00	**3**	**10**	22,45	86,55	0,00
1	**10**	21,81	79,45	0,00	**1**	**10**	34,79	77,49	0,00

Table 2. Percentage of recoveries, element remaining in the aqueous phase and element remaining in the organic phase achieved using DEHPA for kerosenes Ketrul D80 and Ketrul D100 when varying the organic phase volume.

AP	OP	Ketrul D80			AP	OP	Ketrul D100		
		%Recovery	% Remaining AP	% Remaining OP			%Recovery	% Remaining AP	%Remaining OP
					Zn				
10	**8**	73,83	21,44	4,72	**10**	**8**	74,40	17,70	7,90
10	**5**	64,31	27,61	8,08	**10**	**5**	62,14	25,85	12,01
10	**1**	31,40	66,10	2,50	**10**	**1**	36,83	59,22	3,95
					Ca				
10	**8**	56,91	29,08	14,01	**10**	**8**	58,25	28,66	13,09
10	**5**	49,57	41,08	9,35	**10**	**5**	49,49	37,97	12,54
10	**1**	9,37	85,31	5,32	**10**	**1**	11,60	84,69	3,71
					Al				
10	**8**	21,76	2,29	75,95	**10**	**8**	15,74	0,44	83,82
10	**5**	17,70	1,36	80,94	**10**	**5**	13,30	15,44	71,26
10	**1**	6,56	65,66	27,79	**10**	**1**	5,26	75,16	19,58
					Mn				
10	**8**	21,49	77,92	0,59	**10**	**8**	25,08	75,84	-0,92
10	**5**	14,16	83,50	2,34	**10**	**5**	18,59	84,71	-3,30
10	**1**	2,44	104,45	-6,89	**10**	**1**	4,70	103,08	-7,78
					Cu				
10	**8**	5,33	-4,63	99,30	**10**	**8**	6,90	98,26	-5,16
10	**5**	4,19	-3,45	99,26	**10**	**5**	7,87	100,47	-8,34
10	**1**	1,57	-6,02	104,45	**10**	**1**	3,21	102,98	-6,19

As observed, metal extraction follow the sequence Zn>Ca>Mn>Al>Cu. Under these conditions Cu is practically non extracted from the solution. Elements with high %Remaining OP, are extracted by the extractant but were poorly released to the stripping solution (H_2SO_4 solution). This will cause fouling of the extracting phase because the saturation of the extractant, hindering its possible reuse. This behaviour is specially shown by Al. In general, using Ketrul D100 slight higher recoveries are achieved than using Ketrul D80. The variation of the OP/AP values resulted on the expected variation of the metal extraction. The poor selectivity of Zn extraction against Ca resulted on a gypsum precipitate in the stripping solution. To solve this drawback, CYANEX 272 and IONQUEST 290, two extractants with the same active ingredient that can selectively extract Zn from a solution containing Ca and other metals, were tested.

A comparison between 5% CYANEX 272 and 5% IONQUEST 290 is shown in Figure 12. The results obtained indicate a higher performance of IONQUEST 290 regarding Zn extraction efficiency, while Cu, Mn and Al show a similar behaviour with no practical differences and an extraction recovery always below 15%, meanwhile Ca illustrates a slightly different extraction recovery, being higher for IONQUEST 290 rather than for CYANEX 272. Neither IONQUEST 290, nor CYANEX 272 at the end of the stripping show Al, Cu, Mn or Ca enrichment, thus there is no need for scrubbing the solvent. Considering the different employed kerosene, no differences are observed for Zn independently of the employed extractant while the rest of interferences show higher extraction efficiency for kerosene F.P. 100, more pronounced in CYANEX 272 than in IONQUEST 290. Thus, Ionquest seems to be a more effective extractant for Zn, also indicating lower concentration of interfering elements in the stripped solution.

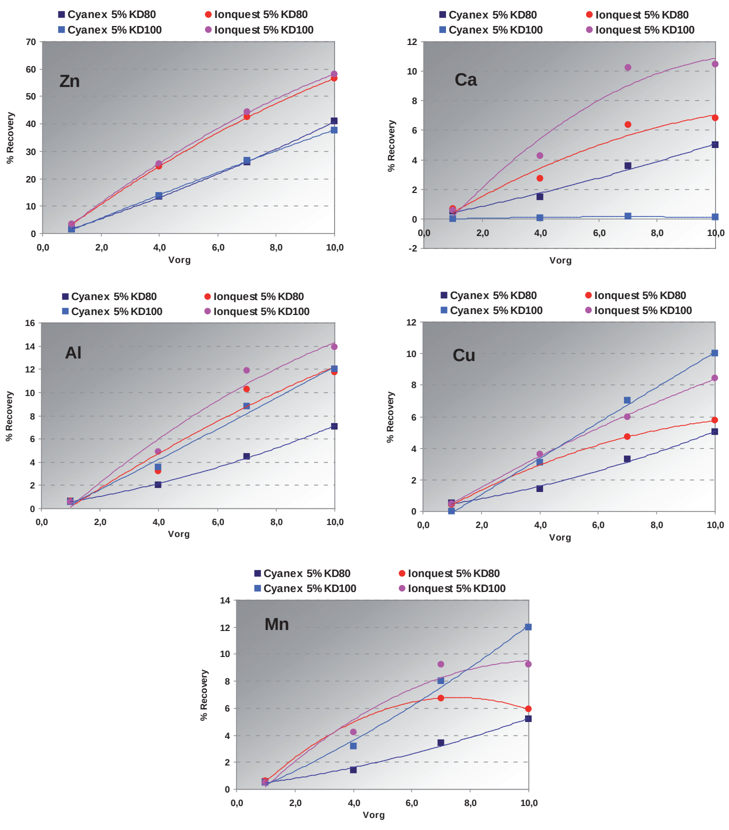


Figure 12. IONQUEST 290 5 % vs CYANEX 272 5% extraction efficiency using Kerosene F.P. 80 and 100.

Metal extraction increases when IONQUEST concentration increases. On the other hand, the observed extraction using 40% DEHPA is similar than that obtained by 20%IONQUEST and is not proportionally higher than the obtained by 5%IONQUEST (see Figure 13). No differences are observed between both employed kerosene. The most important difference when comparing IONQUEST 290 against DEHPA, is related to the Al and Ca extractability, mainly because IONQUEST 290 can greatly and selectively extract Zn without Al and Ca stripping enrichment, as Figure 13 clearly show. Despite, the low values in Ca extraction, this should be taken into account in the pilot plant when the process will be done several times with the same reactants. Taking into account this results, due to his higher recoveries achieved, IONQUEST 290 is found the most suitable extractant for the process.

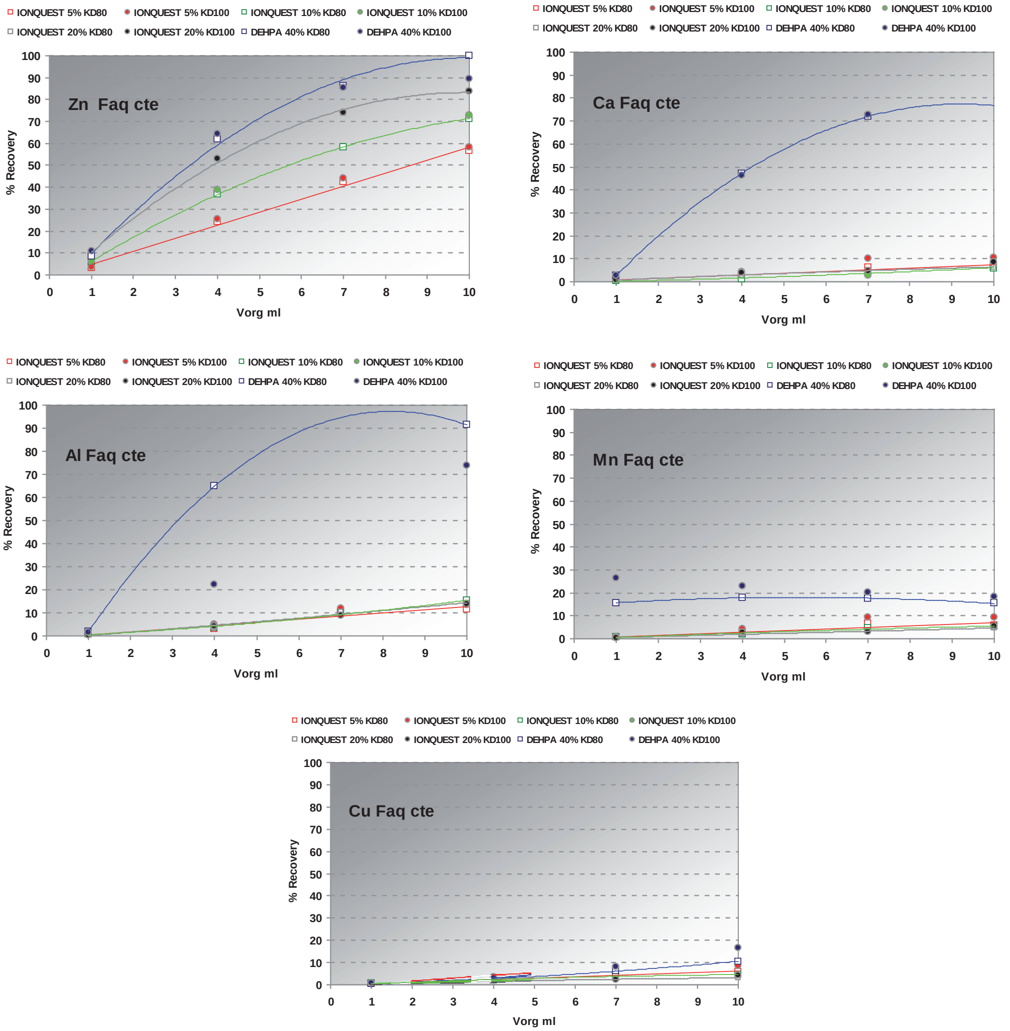


Figure 13. Recoveries obtained using IONQUEST 5% (red), IONQUEST 10% (green), IONQUEST 20% (black) and DEHPA 40% (blue) using Ketrul D80 (continuos lines) or Ketrul D100 (dashed lines).

Results from Figure 13 indicates a significantly higher recovery of Ca for DEHPA 40% than for Cyanex 5% or Ionquest 5% Also, Cyanex 5% provides up to four times higher recovery of Ca than Ionquest 5%. These results indicate that the most selective extractant to minimize calcium extraction is Ionquest at a concentration of 5%. In addition, due to their higher price, five-seven times more than DEHPA, CYANEX 272 or IONQUEST 290 concentration should be as low as possible. Furthermore, is important to determine the amount of metals remaining in the organic phase to predict the design of the overall recovery process, i.e, additional scrubbing, washing steps. This parameter was determined by applying the metals mass balance to the extraction and recovery process. The average percentage of metals remaining in the extractant phase is given in the Table 3.

Table 3. Percentage of metals remaining in the organic phase after the extraction process.

Extractant	Ca	Cu	Mn	Al	Zn
DEHPA	30 ± 4 %	0 ± 3 %	3 ± 5 %	73 ± 4 %	7 ± 3 %
CYANEX	0 ± 4 %	0 ± 2 %	0 ± 4 %	0 ± 2 %	1,4 ± 0,6 %
IONQUEST	0 ± 6 %	0 ± 6 %	0 ± 5 %	0 ± 3 %	0 ± 2 %

From the results given in Table 3Table 3. Percentage of metals remaining in the organic phase after the extraction process.n be said that both IONQUEST and CYANEX are the extractants that have less capability of fouling because none of the metals analysed remained in the organic phase after the extraction process. In the case of DEHPA, high concentrations of Ca and Al were found.

VI – Conclusions

The most relevant conclusions of the study can be summarized as follows:

- DEHPA reagent was unable to extract Zn selectively from the solution at the target pH and temperature conditions. Moreover, high amounts of Ca were extracted creating a gypsum precipitate in the strip solution avoiding their possible use for electrowinning. Furthermore, Al was extracted from the leachate but not stripped out causing fouling of the extractant and avoiding their reuse.
- Using 5% extractant solutions, IONQUEST 290 presents the highest Zn extraction yield of the studied extractants. Comparable concentrations of Ca ,Al, Cu and Mn in the stripping solution were obtained against those for CYANEX 272.
- As both solvents, Ketrul D80 and Ketrul D100 showed similar behaviour, Ketrul D100 is the solvent recommended due to its lower volatility and flammability.

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Depuration of tannery effluent by phytoremediation and infiltration percolation under arid climate

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Abstract. The specific aims of this work were to investigate the potential of *Phragmites australis* to remove chromium from diluted tannery wastewater (50%) in comparison to unplanted soil, under arid climate conditions. Dilution is made by well water. The other aim was to study the treatment of raw tannery effluent by infiltration percolation system. The results indicated that during 13 months of experiment, total chromium undergoes an overall removal of 99% for the two plots, which provides limpid purified water. The results of the distribution of total chromium in the various strata of constructed reed bed indicated a significant accumulation of total Cr reaching 80% in the surface strata for two systems. Furthermore, the results showed that Cr could migrate also towards deeper levels of the soil. After 13 months of experiment, the soil accumulated high content of chromium: 94% and 98% for the planted and unplanted systems, respectively. However, 5% of Cr accumulated in Phragmites australis. The results also showed that Phragmites australis accumulated 1690 mg/kg dry matter of chromium in the roots. The study of the treatment of raw tannery wastewater by infiltration percolation system showed that, over seven months of experiment, the mean elimination rate for total chromium was 98%. The treatment of tannery effluent by reed bed combined with infiltration percolation system is a clean approach from an ecological point of view and constitutes a viable economic alternative in comparison to the purely chemical approaches for the treatment of tannery effluents.

Keywords. Tannery – Chromium – *Phragmites australis* – Infiltration – Percolation – Treatment – Arid climate.

Epuration des effluents de tannerie par phytoremédiation et infiltration-percolation en climat aride

Résumé. Le but spécifique de ce travail est d'évaluer la capacité potentielle de *Phragmites australis* à éliminer le chrome des eaux usées de tannerie diluées (50%) par rapport au sol nu en climat aride. La dilution est réalisée en utilisant de l'eau de puits. Parallèlement, on illustre le traitement des effluents de tannerie bruts par infiltration-percolation. Les résultats indiquent que, sur les 13 mois d'expérimentation, le chrome total est éliminé à 99% dans les deux parcelles, ce qui permet de produire de l'eau épurée et limpide. A partir des données sur la distribution du chrome total dans les différentes strates de la roselière artificielle, on met en évidence une accumulation totale de Cr égale à 80% dans les strates superficielles des deux systèmes. En plus, les résultats montrent que le chrome pourrait migrer vers des couches plus profondes du sol. Au bout de 13 mois, le sol affiche une teneur élevée en chrome : 94% et 98% pour les systèmes avec ou sans lit de *phragmites*, respectivement. Toutefois, 5% de Cr est accumulé dans *Phragmites australis*. Egalement, les résultats indiquent que *Phragmites australis* accumule 1690 mg/kg de matière sèche de chrome dans les racines. L'étude du traitement des eaux usées de tannerie brutes par infiltration-percolation confirme que sur sept mois d'expérience, le taux moyen d'élimination pour le chrome total s'élève à 98%. Le traitement des effluents de tannerie en utilisant la phragmite associée à l'infiltration-percolation représente une approche propre sur le plan écologique et une alternative économiquement viable par rapport aux approches purement chimiques pour les effluents de tannerie.

Mots-clés. *Tannerie – Chrome – Phragmites australis – Infiltration – Percolation – Traitement – Climat aride.*

I – Introduction

The term phytoremediation (phyto = plant and remediation = correct evil) is relatively new, coined in 1991. Basic information for what is now called phytoremediation comes from a variety of research areas including constructed wetlands, oil spills, and agricultural plant accumulation of heavy metals (Mulligan *et al.,* 2001; EPA, 2000 ; Lutts *et al.,* 2004). Phytoremediation applications can be classified based on the mechanisms involved. Such mechanisms include extraction of contaminants from soil or groundwater; concentration of contaminants in plant tissue; degradation of contaminants by various biotic or abiotic processes; volatilization or transpiration of volatile contaminants from plants to the air; immobilization of contaminants in the root zone; hydraulic control of contaminated groundwater and control of runoff, erosion, and infiltration by vegetative covers (Ralinda and Miller, 1996 ; Schwartz *et al.,* 1999 ; EPA, 2000).

The leather tannery industry is well known for having a severe negative impact on the environment. In this industry animal hides are transformed into leather in a succession of various complex stages, consuming high quantities of water and using large amounts of such chemicals as lime, sodium chloride and chromium salts. The most dangerous problem of the pollution generated by the tannery industries in Marrakech is the discharge of heavy metal into the environment, mainly the chromium (≈40 tons/year) which is able to disturb the biological breakdown of the effluents (Scandiaconsult International, 1999). Tannery wastewater flows directly into the receiving medium without any preliminary treatment.

The objective of this study is to investigate the potential of a helophytic plant *Phragmites australis* (Cav.) Trin ex Steudel to remove chromium from concentrated tannery effluent in comparison to unplanted soil, under arid climate conditions on the one hand. On the other hand, to study the treatment of raw tannery effluent by infiltration percolation system.

II – Methods

The experiment was conducted from August 2002 to August 2003. Six plots were filled to 15 cm in depth and 60 cm with respectively gravel and soil. Three plots were planted with young shoots of *Phragmites australis* (36 stems/m^2) taken from local and natural reed stand. Three unplanted plots served for checking (figure 1).

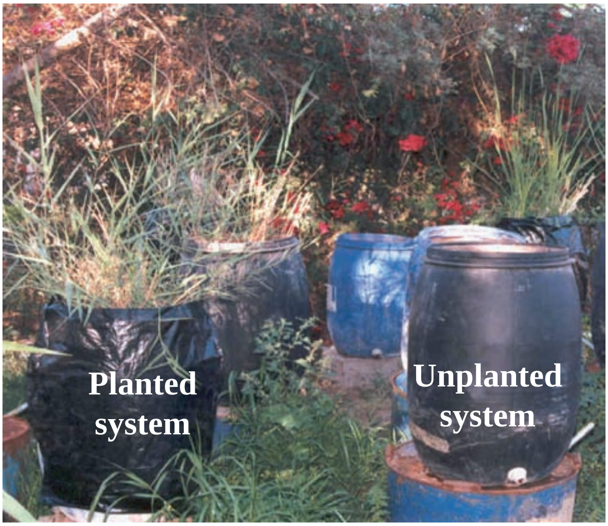

Figure 1. Experimental setup.

The soil (88% sand) used for the study is coming from the Tensift river (Marrakech). Wastewater used originates from an industrial tannery in the Marrakech region. The experimental plots were alimented by tannery wastewater, 3 times a week (10 litres per day). The water flowed vertically through substratum. The measure of the hydrogen potential (pH) is determined with a pH-meter type ORION. Electrical conductivity (EC) is measured using a standard conductimeter Tacussel (AFNOR, 1983). The total chromium is measured by spectrophotometer of atomic absorption (RODIER, 1984).

1. Physico-chemical characteristics of soil

The analysis in table 1 shows that the substrate used is rich in organic matter. Its electrical conductivity is high. It is an alkaline basic soil (table 1).

Table 1. Physico-chemical characteristics of soil.

Parameters	Contents
pH	8.63
% O.M	4.7
Cl (mg/g)	71
Zn (mg/kg)	12.11
Pb (mg/kg)	1.2
Cr (mg/kg)	0.6

2. Physico-chemical characteristics of the influent

Table 2 summarizes the mean characteristics of tannery effluent. This latter has an acid pH due to the utilization of H_2SO_4 in the operation of preparation for tanning. The effluent has a very high electrical conductivity (EC), reflecting the wealth in salts of these waters and the high concentration of chloride (20.6±4.3 g/l). This chloride concentration largely exceeds the maximum limits recommended by WHO (1989) guidelines (700 mg/l).

Table 2. Physico-chemical characteristics of the influent (number of samples: 20).

pH	3.08±1.16
EC (ms/cm)	118±50
BOD_5 (mg/l)	45±2.45
COD (mg/l)	2500±13
Cl^- (g/l)	20,6±1.3
Cr (mg/l)	1230.5±123.2

The tanning wastewater contained an important amount of total chromium (1230.5 mg/l) exceeding by far the maximum limit recommended by WHO (1989) guidelines (2 mg/l).

III – Results and discussion

1. Treatment of tannery effluent by phytoremediation

-Temporal changes in total chromium at the inlet and outlet of the two systems

Figure (2) represents the temporal evolution of the total chromium concentration at the inflow and outflow of (PP) and (NPP) systems. The total chromium concentration at the inflow varies from 534 mg/l to 1000 mg/l with an average concentration of 780±196 mg/l.

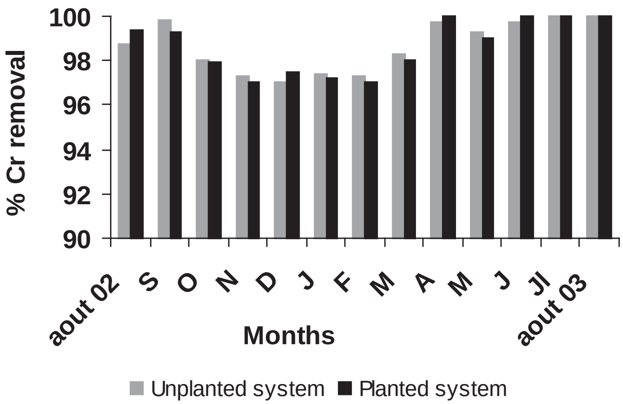

Figure 2. Total chromium percent removal of the planted and unplanted systems.

At the outflow, the total Cr concentration varies from 2.2 mg/l to 3 mg/l with an average concentration of 2±0.5 mg/l for (PP) system and from 2.5 mg/l to 4 mg/l with an average value of 2.4±1.3 mg/l for (NPP) system.

The total chromium contents at the outflow of the two systems are lower than the maximum limit recommended by WHO guidelines (2mg/l). The total chromium undergoes an overall removal of 99 % for the two plots, which provides limpid purified water (Tiglyene *et al.*, 2005). In the systems of treatment by macrophytes, several processes are responsible for the elimination of chromium. They include a mixture of physicochemical, biological and microbiological reactions with an aerobic and anaerobic procedure for wetland sites (Eger, 1994).

-Total chromium in different soil horizons of the planted system

The analytical results revealed that there is a significant total Cr 80% accumulation in the surface horizon (0-5 cm) for planted (figure 3a) and unplanted systems (figure 3b) (Tiglyene *et al.,* 2008a). Results also show that Cr could migrate also towards deeper levels of the soil. Moreover, several authors have reported these results (Legret *et al.,* 1988 ; Selim *et al.,* 1989 ; Kafka and Kuras, 1994).

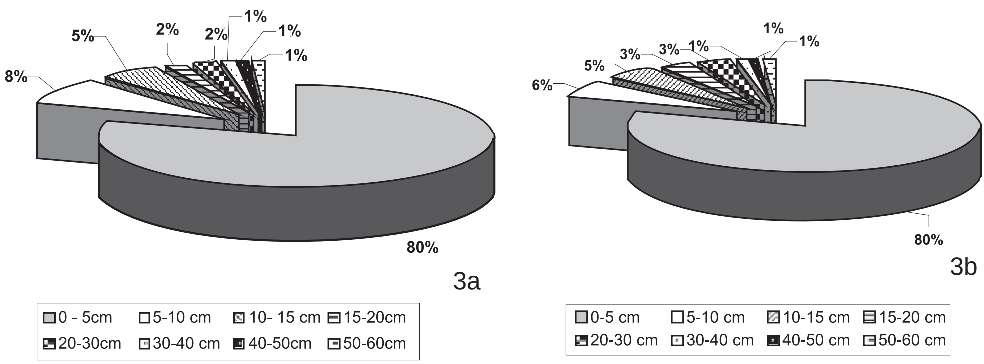

Figure 3. Total chromium percent in different soil horizons of the planted and unplanted system

-Total chromium content in Phragmites australis

Table (3) summarizes that all parts of *Phragmites australis* contain chromium. Indeed, the Cr content presents a statistically significant difference ($p<0.01$) between leaves and roots of the plant. This result was to be expected because of the close contact between the root surface and the sediment-water interface. On the other hand, *Phragmites australis* released from the root exudates, which can involve to complex the chromium. Indeed, many authors confirmed this observation (Aldrich *et al.,* 2003; Howe *et al.,* 2003).

Table 3. Total chromium content in Phragmites australis

	Leaves	Rhizomes	Roots
[Cr] g/Kg(dry weight)	0.25±0.5	0.35±1.5	6±0.5

-Mass balance of Cr for the planted system

Furthermore, after 13 months of experiment, the soil accumulates high content of chromium (94%) and 5% of Cr accumulated in *Phragmites australis.* The presence of plant ensures a sufficient porosity for the percolation of water for treatment, which makes it possible to treat a more important volume of wastewater and to reduce the required surface area by treated capita.

2. Treatment of tannery effluent by infiltration percolation

Figure 4 represents the temporal evolution of the total chromium concentration at the inflow and outflow of system. The total chromium concentration at the inflow varies from 1009 mg/l to 1345 mg/l with an average concentration of 1230.5±123.2 mg/l. At the outflow, the total chromium concentration varies from 3.4 mg/l to 5 mg/l with an average concentration of 3±0.5 mg/l.

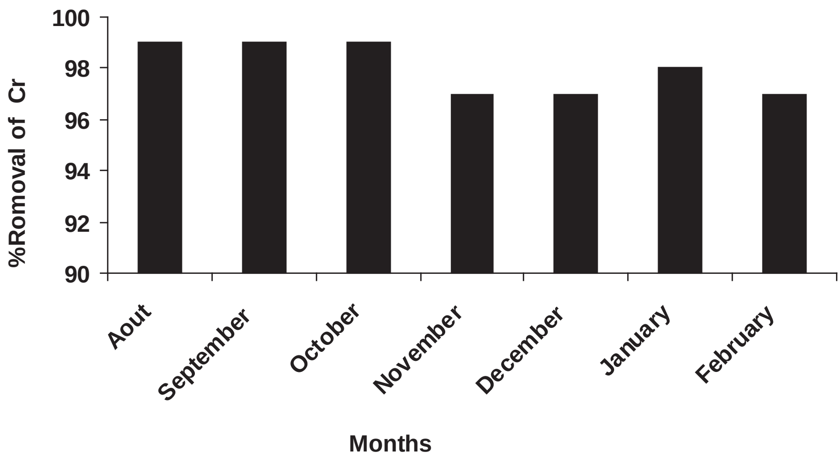

Figure 4. Temporal changes in total chromium at the inlet and outlet of the system.

The total chromium contents at the outflow of the two systems are lower than the maximum limit recommended by WHO guidelines (2 mg/l). The total chromium undergoes an overall removal of 98% for the pilot, which provides limpid purified water (Tiglyene *et al.*, 2008b). In the system of treatment by infiltration-percolation, chromium was retained by immobilization on the level of the soil via mechanisms such as adsorption on the level of the sites of exchange, fixing to the organic matter, incorporation in the structure of the ground and by precipitation in the form of insoluble compounds (Comber and Gardner, 2003).

IV – Conclusions

The objective of this study was, on the one hand, to evaluate the potentialities of a helophytic plant, *Phragmites australis,* to purify the diluted tannery wastewater (50%), and to compare them to those of an unplanted soil, under arid climate conditions; on the other hand, to study the treatment of raw tannery effluent by infiltration percolation system.

The results indicated that the total chromium undergoes an overall removal of about 99% for the two plots, which provide purified water. The results indicated that there was a significant accumulation of total Cr reaching 80% in the surface strata for the planted system. *Phragmites australis* accumulated significantly high amount of Cr in the roots.

After 13 months of experiment, the soil accumulates high content of chromium, 94% and 5% of Cr accumulated in *Phragmites australis.* Furthermore, the presence of plant ensures a porosity sufficient for the percolation of water in the treatment. Over seven months of experiment, the study of the treatment of raw tannery wastewater by infiltration percolation system showed that the mean elimination rate for total chromium was 98%.

This work shows clearly that the treatment of tannery effluent by reed bed combined with infiltration percolation system could be the depuration system alternative for raw tannery wastewater in comparison to the purely chemical approaches for the treatment of tannery effluents.

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Fourth part

Efficiency and equity in water policies

Mainstreaming Agricultural and Water Polices for Social Equity and Economic Efficiency

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Abstract. The world population, especially those living in developing countries, are faced with two major challenges represented by increasing water scarcity and looming food crises. In order to solve food shortage and secure a high degree of self-sufficiency, many of these countries have considerably expanded irrigated agriculture and this has resulted in over-exploitation and deterioration of water resources. In spite of all investments, the contribution of the agriculture sector to the national economy is declining while food imports are on the increase. In order to solve these problems an integrated approach has to be adopted by mainstreaming water and agricultural policies aimed at social equity and economic efficiency. These policies should also take into account resources conservation and environmental sustainability without compromising the rights of the future generations. Achieving food security with limited water resources is an approach that appears too ambitious but applicable where political will may rely upon strategic planning and scientific support. During the last two decades, scientific and technological advances made it possible to solve many problems in the field of agricultural development. High-tech applications in agriculture e.g. high-tech irrigation systems, soil-less culture, high-yielding varieties, and biotechnology have allowed to increase production by five to ten times. These technologies are becoming feasible with increasing food price and limited water supply. Under these conditions water productivity will be significantly enhanced compared to traditional or protected agriculture.

Keywords. Water policy – Social equity – Economic efficiency – Water resources – Jordan.

Intégration des politiques agricole et de l'eau pour l'équité sociale et l'efficience économique

Résumé. *La population mondiale, en particulier dans les pays en développement, se trouve confrontée à deux défis majeurs représentés par la croissante rareté de l'eau et des crises alimentaires menaçantes. Afin de résoudre le problème de la pénurie alimentaire et d'assurer un niveau élevé d'autosuffisance, dans plusieurs pays on a assisté à une expansion considérable de l'agriculture irriguée, ce qui a déterminé une surexploitation et une détérioration des ressources en eau. Malgré tous les investissements, la contribution du secteur agricole à l'économie nationale va en se réduisant, alors que les importations d'aliments s'accroissent. Pour faire face à ces problèmes, il est nécessaire d'adopter une approche intégrée, en prenant en compte les politiques de l'eau et agricoles qui visent l'équité sociale et l'efficience économique. Ces politiques devraient également considérer la conservation des ressources et la durabilité de l'environnement sans pour autant compromettre les droits des générations futures. Atteindre la sécurité alimentaire avec des ressources en eau limitées représente une approche qui semble être trop ambitieuse, mais applicable, à condition que la volonté politique soit soutenue par une planification stratégique et l'apport scientifique. Ces deux dernières décennies, les progrès scientifiques ont permis de résoudre de nombreux problèmes dans le domaine du développement agricole. Les applications de haute technologie en agriculture, à savoir des systèmes d'irrigation très avancés, la culture hors-sol, des variétés de haut rapport et les biotechnologies ont permis d'augmenter la production de cinq à dix fois. Ces technologies deviennent de plus en plus applicables vu la hausse des prix des aliments et la disponibilité limités de l'eau. Dans ces conditions, la productivité de l'eau pourra augment considérablement par rapport aux systèmes de culture traditionnels ou sous couverture.*

Mots-clés. *Politique de l'eau - Équité sociale - Efficience économique- Ressources en eau – Jordanie.*

I – Introduction

Water is one of the five largest markets in the world. It is estimated that over $350 billion are spent annually on generating and delivering water for human consumption, industry and agriculture.

Expenditure is growing by seven percent yearly because of population growth, a higher standard of living, a decline in available groundwater sources and climate change leading to drought conditions worldwide.

As water demand grows and resources shrink, new technologies are needed to increase the supply. In the year 2006, over $50 billion were invested in infrastructure and technological solutions in an attempt to meet the challenge of the growing water demand.

The world water shortage is generating attractive opportunities and is encouraging the growth of global business activities.

Most of the Mediterranean countries, especially in the South and the East, are faced with water shortage dilemma due to the increasing gap between supply and demand. The gap will increase more in the future due to population growth, improved standard of living, urbanization and industrialization. Water demand is growing at an accelerating rate while supply is fixed and limited, thus creating an imbalance. In order to reduce the gap and to balance the water equations, governments often resort to the hard bath solution trying to bring additional water resources or to reallocate the agricultural share to other sectors. The option of bringing additional resources is expensive because most of the cheap resources have been completely exploited. Therefore, these countries are faced with the option of shifting water allocated to agriculture to use in the domestic and industrial sectors. The argument for such a strategy is that agriculture is less efficient and its contribution to the gross domestic product is very low. This argument did not take into consideration the social dimension in terms of social equity and political stability.

Many have recently recognized that the availability of water for irrigation purposes in rural areas has a significant impact on poverty and social equity. The direct impact is represented by increase in crop yield, productivity and farm income while the indirect effects are measured by evaluating rural employment, economic multipliers and immigration. Furthermore, equity which recognizes the population heterogeneity should also be achieved in the filed of irrigation along with poverty and gender.

Solving the water dilemma requires the integration of technical, economic, environmental and social solutions. Adapting the technical processes takes time due to economic and social reasons which are solely related to education and poverty. Such an option needs financial capability and a high education level; both requirements could not be met in developing countries. On the other hand, building desalination plants, transporting water from remote areas and water conveyance schemes require huge investment which is beyond the capacity of many developing countries. Therefore, it would be cheaper for these countries to adopt the demand management approach through water conservation and system efficacy. The problem is not only confined to technical and economic aspects because environmental pollution is also an issue of serious concern. Besides scarcity, water degradation due to over-pumping and diverting treated effluent to surface water are becoming an additional problem.

Water resources have only a limited capacity to match the burgeoning population growth. Surface runoff can be captured and stored for a short-term net gain, as can redirecting and damming surface water and reusing or reallocating water supplies to more critical or higher value uses. Exploiting deep groundwater reserves, however, consumes a non-renewable resource and the currently available desalinization technology is prohibitively expensive for all but the wealthiest states in the region.

None of the above-mentioned remedial measures will adequately expand the resource base enough to meet the expected future demands. Given the unlikelihood of dramatically expanding water resources in the region, there are primarily six ways to address the water shortage problem:

1. inter-basin transfer;
2. reallocation;
3. water conservation;
4. wastewater reuse;
5. institutional innovations;
6. technological breakthroughs.

II – Water Challenges

Many countries, south of Europe and south-east of the Mediterranean, are faced with water shortages, scant rainfall, climate change and frequent drought. The existing water resources are also in short supply when measured against population. The average population growth rate in the southern and eastern Mediterranean region, among the highest in the world, is bringing about a strong water demand. According to predictions, water demand will more than double between 2010 and 2050 in Jordan and Oman, and will increase by half in Morocco, Tunisia, Egypt, Sudan and Yemen.

In addition to scarcity and quality problems, several researchers (Shatanawi, 2007; Abu Zeid and Hamdy, 2002), have identified other challenges that the Mediterranean countries are going to face, which can be listed as follows:

1. Water scarcity compared to population growth;
2. Inefficient management of water resources, especially in the irrigation sector;
3. Lack of data and information about water resources;
4. Overlap between water policy and other related policies like agriculture;
5. Deterioration of water quality and increase in pollution sources;
6. Growing gap between the supply and demand;
7. Ambiguity of roles and mission of water resources institutions;
8. Lack of available funding for scientific research;
9. Urgent need for human resources development and capacity building;
10. Absence of the private sector and civil society in participation in water management;
11. Problems associated with shared water resources;
12. Absence of clear water policies and associated strategies and action plans in many countries;
13. Needs for adopting effective public awareness programmes;
14. Limited use of new technology in irrigation;
15. Groundwater pumping in excess of natural recharge rates.

1. Responses to water challenges

1. Adopt an integrated approach to water resources management in service delivery:
   – consider water as a holistic resource with competing demands;

- promote service delivery on the basis of water user demand and their repayment capacity;
- support private and public water service providers that create economic incentives for sustainable water use.

2. Raise water tariffs, without excluding targeted subsidies to the poorest. This is critical to:
   - promote savings of water use by increasing tariffs;
   - set water charges to cover operation and maintenance costs;
   - ensure financial sustainability of water service providers (irrigation and drinking);
   - save water for ecological reserves and environmental purposes.

3. Promote policy reforms to encourage farmers to shift to irrigated crops, which provide a higher value per unit of water:
   - priority should be given to crops requiring less water;
   - with globalization, the ‘virtual water’ concept becomes an important factor in agricultural trade;
   - given water scarcity, promotion of export crop production should not be based on foreign currency needs but driven by the implications for water resources sustainability.

4. Adopt a sustainable groundwater use strategy: Groundwater control legislation should be issued and enforced to regulate the use of groundwater resources based on the following principles:
   - underground water is owned and controlled by the State, and land ownership does not include groundwater ownership;
   - extraction and use of underground water is authorized by a license to the landowner;
   - the 2002 Jordanian Underground Water Control By-Law is a good example.

5. Decentralize water management responsibility:
   - The management of water distribution networks (except primary canals) should be decentralized and turned over to farmers;
   - decentralization should include poor farmers as members of water user associations.
   - changes in behavioural and social patterns need to be fostered to conserve water (public awareness).

6. Promote cooperation for sustainable management of transboundary water resources:
   - shared ground and surface water resources need to be jointly assessed and monitored (in terms of quantity and quality);
   - concerted action plans should be adopted for sustainable use of shared water resources;
   - the ongoing experience of many European countries in managing their shared rivers could be useful to others. Also, the experience of Egypt in building cooperation with other riparian countries based on mutual benefits.

III – Integrating policies

In many countries irrigated agriculture policy is usually formulated without coordination with the irrigation and water policy. In many instances one can find contradiction or agreement between statements of the two policies.

At farm level, where water conservation is needed, the responsibility is lost between the Ministry of Water and Irrigation and the Ministry of Agriculture. There are many examples, for instance in Jordan, Syria and Egypt. The situation in countries like Morocco, France, Spain and Italy is much better because small-scale irrigation water projects, including dissemination and on-farm irrigation systems, are the responsibility of a single agency as the Ministry of Agriculture. To insure integration and harmonization of the two policies, the following steps shall be considered:

– promoting major water policy reforms;

– adopting water-saving technologies in irrigated agriculture;

– applying water-saving technologies in rainfed agriculture;

– formulating Irrigation water conservation measures within the policy framework;

– developing advanced agricultural technology.

IV – Adaptation to water scarcity

Governments and societies should cope with water scarcity by adapting to existing conditions and taking certain measures. For example, the city of Los Angels has grown by one million people since 1970, but it still uses the same amount of water transported from Northern California and groundwater from adjacent areas. Similarly, the city of Amman has grown by 50% since 2000, but it still uses the same amount of water of about 120 MCM. Farmers in the Jordan Valley have adapted to water shortages by relying on deficit irrigation, changing cropping pattern and utilizing high-tech micro-irrigation. Water conservation is the most cost-effective and environmentally sound way to reduce the growing water demand and to save energy. Water uses in many countries are exceeding by far the international standard because of high water loses and low irrigation efficiency. There is no actual data on water losses in the network, at farm level or in the other sectors like tourism, industry and recreation. Water conservation and efficiency improvement play a major role in mitigating the problem of water scarcity and shall be given high priority in the region. The trend is to increase supply by building additional desalination units and exploiting the already depleted groundwater. Both measures are costly and they adversely effect the marine environment. A simple way of managing water resources consists in following a systematic water conservation approach in a planned manner in all sectors of demand. Examples from different countries around the world should be examined for gain knowledge of how water is being effectively used.

Therefore, governments should undertake all necessary measures leading to the establishment of a comprehensive programme for water conservation, reduction of water losses and improvement of water use efficiency in all sectors. To implement such a policy, the agencies concerned shall pursue a systematic planning strategy according to the following principles:

– establish investment programs to raise irrigation efficiencies and review water charges, considering sustainability, environment and equity;

– create public awareness entities to carry out programmes aimed at encouraging the use of water saving devices and transfer them to users;

– review the possibilities of using low quality water for industrial purposes and encourage recycling of water as long as it is feasible;

- conduct surveys to determine the types of losses along the water distribution network;
- enhance the management and operation skills of managers and technical staff in the municipal sector;
- improve information provided to farmers through extension services;
- provide support to research institutions to enhance their activities related to the determination of crop water requirements, irrigation water management, and optimum water use;
- review relevant laws and regulations in order to promote water conservation.

On the other hand, the following measures have proved to be effective in promoting water conservation:

- utilization of efficient water saving devices for domestic and irrigation purposes;
- use of treated waste water for irrigation (Jordan, Tunisia);
- increasing adoption of new precision irrigation and drainage systems;
- promotion of low-cost water-harvesting technologies (Jordan, Tunisia);
- adoption of conservation tillage and planting on raised beds to use irrigation water more efficiently (Cyprus, Jordan);
- exploitation of available technology for saline water use (the research results of the International Centre for Biosaline Agriculture [ICBA] and IAM-Bari which tested this technology);
- enhancement of small-scale and supplemental irrigation systems to increase productivity of rainfed agriculture (Syria);
- more efficient crop sequencing and timely planting to achieve significant savings in water use;
- development of new low water-requiring crop varieties by research institutions, some of which are already available**.**

1. Crop Water Requirements

Previous calculations of crop evapotranspiration using different formulae and procedures have always overestimated the actual consumptive use of different crops. Due to lack of data and research results, these methods were applied to design many existing projects. In these projects, the system capacity and the delivery schedule allow for overirrigation most of the time. FAO Irrigation and Drainage Paper No 56 suggested a new procedure to calculate ET based on the revision of previous methods. Although FAO procedure is general, the results of field trials showed that about 20% of ET was overestimated by previous methods. For example, the average peak ET for citrus in the northern part of the Jordan Valley was estimated at 5.4 mm/day using FAO methods compared to the previous calculation of 6.5 mm/day according to Blaney-Criddle method. The results of recent research (Shatanawi *et al.*, 2006) and the farmers' practices in the same area showed that average ET, using micro irrigation, dropped to about 4.8 mm/day without any impact on the produce quality and quantity.

On the other hand, crop requirement to near maximum yield is determined by plant physiology although there are some related management factors, manipulating the microclimate environment, that can provide certain advantages. For example, the irrigation requirement of open field vegetables may be up to twice or three times more than that of crops grown under plastic houses. A complementary approach consists in selecting the planting time and growing seasons to minimize the atmospheric demand for water consumption. Another possible action aimed at reducing ET is changing the cropping patterns in favour of high-value crops indented for export, that have a relatively lower water requirement.

With the new technologies available, e.g. real time automatic weather stations and modern devices as the Eddy correlation, it would be possible to determine the exact amount of daily ET. The use of remote sensing data based on satellite images, coupled with ground truthing, made it possible to determine ET and crop coefficient at district and regional level.

The EU has supported a research project (STRP) entitled “Improved Management Tools for Water-Limited Irrigation: Combining ground and satellite information through models, (IRRIMED)” with the participation of 6 Mediterranean countries under FP6. The aim of this project is the establishment of tools to support efficient water management for irrigation as well as to test scenarios for long-term sustainable policies. Accurate knowledge of water demand and use by irrigated agriculture is the key to an effective water management strategy. The general scientific objective is the assessment of temporal and spatial variability of water consumption of irrigated agriculture under limited water resources conditions. Intensive measurement campaigns with the eddy correlation equipment will lead to combine ground and satellite measurements into models, to ultimately produce simple methods to assess evapotranspiration (ET) over large areas.

The accurate assessment of actual ET in selected crops during the growing season will help validating models and updating the crop calendar and crop water requirements. Also, remote sensing of crop extension and evolution during the growing season will make it possible to measure the actual acreages of the different crops. Refining existing methods for simple ET estimation will allow deriving ET maps from satellite data. This research line will continuously update information that can be revised annually based on agro-climatic conditions: “more crop per drop”, or “increase water productivity”. However, this goal may be achieved by improving agronomic practices not reducing water use. Searching for a more efficient water use entails overcoming the concept of irrigation efficiency and looking for the water passways to identify where water may be saved.

2. Precision Irrigation

The issue of irrigation scheduling (when to irrigate and how much water to apply) is a matter of delivery schedule and farmer’s decision. With soil moisture sensors and stem water potential devices available, it is possible to irrigate at the exact time when water is needed by the plant. These devices can be installed in the soil at two depths or can measure the tension on the leaves or fresh stems, may be connected to an electronic control panel that can indicate to the farmers the irrigation needs. Research on how to integrate these modern sensors to the irrigation systems is an option that should be exploited in the future.

Precision irrigation is not limited to irrigation scheduling, but can be extended and incorporated into the design of various irrigation systems. In surface irrigation, laser land levelling can insure good distribution uniformity and improved irrigation efficiency. When pressurized irrigation systems are applied, an automatic control panel can be used. Also, leaks and uneven distribution of irrigation water along the laterals and subunits can be detected easily. The introduction of this technology will certainly improve irrigation efficiency and water productivity and reduce water losses as well.

3. Use of Reclaimed Water

Reclaimed wastewater has become a significant water source in many Mediterranean countries like Jordan, where its contribution to the irrigation sector has reached about 15% in 2005 and will come up to 40% by the year 2020. Research in this area is scattered and limited to treating this source as low-quality water. Therefore, it should be extended to include the long-term effects of reclaimed water use on the soil and the environment, changes in on-farm practices, especially those related to water use efficiency, adoption of higher-value crops and the social and economic impacts of treated effluent reuse. Efforts should be made to develop appropriate tools to help the farmers and the whole farming sector overcoming problems in the future and encourage new attitude and behaviour patterns.

4. Desalination of Brackish Water

The Mediterranean region, especially the South, displays considerable reserves of saline water that are considered a potential resource for the future. It is possible to irrigate certain crops with this kind of water provided that the soil exhibits good drainage conditions, while applying extra water for leaching purposes. Research results have shown that there are few success stories where production proves to be economically feasible. The yield reduction up to 50% may not justify the investment made for the irrigation and drainage systems and the pumping and delivery cost. There are few cases where it is possible to irrigate fodder crops in sandy soils with good natural drainage system.

An alternative to that would be to desalinize this water where the cost is justified. Experience from the Jordan Valley shows that the cost of saline water (2000 to 5000 ppm) desalination can reach as low as 0.2 $\$/m^3$, using medium-size reverse osmosis plants with a capacity of 40 to 50 m^3/hr. Irrigation with 500ppm blended water can increase the yield of high water-consuming crops more than twice. Banana yield increased from 20 ton/ha to 40 ton/ha with good quality produce, while irrigation water requirements were reduced from 2500 mm to 1800 mm.

The investment can be further justified if this water is used to irrigate seedling nurseries and cash crops like strawberry. Therefore, new research lines should be explored conducting comparative studies in order to reduce desalination cost and evaluate the environmental and economic impact.

5. Deficit Irrigation

Deficit irrigation means applying less water than cumulative ET, thereby allowing roots to utilize stored soil water in the winter or pre-season irrigation. Therefore, irrigation water requirements for early irrigation in the spring season can be less than those indicated by ET calculation. In addition, deficit irrigation may be regulated for the rest of the season avoiding critical periods. Such management practices result in water saving for irrigation without affecting or reducing the yield. There are two types of deficit irrigation: sustained and regulated. In sustained deficit irrigation, irrigation is reduced throughout the whole season, while regulated deficit irrigation starts with normal irrigation and then, irrigation is gradually reduced. Regulated deficit irrigation is an irrigation strategy based on limiting non-beneficial water losses by reducing the crop water amount during non-critical phenological stages. Deficit irrigation is controlled in the periods when adverse effects on productivity are minimized. Extensive research on DI that is being done on field crops and vegetables. Field demonstrations carried out by Shatanawi and the French Agriculture Mission to Jordan (1996) showed that a 40% reduction in water consumptive use from the farmers' practices did not affect the yield. Observation and communication with some farmers led to conclude that reducing water application by 30-40% during drought years did not reduce the yield economically. However, research on fruit trees is still limited and it should be based on the estimation of the actual ET under deficit irrigation in order to maximize the water unit productivity. This research line should include the application of different irrigation level while measuring the soil moisture content and the leaf water potential.

In this respect, it is worth mentioning that the EU has supported a research project on deficit irrigation entitled "Deficit Irrigation for Mediterranean Agricultural Systems (DIMAS)". The objective of this project is to evaluate the concept of deficit irrigation (DI) as a means of reducing irrigation water use while maintaining or increasing the farmers' profits. The DI concept will be a subject of multidisciplinary research at different scales, geographic locations, and on different perennial and annual crops. The objective will be the development of a workable, comprehensive set of irrigation (DI) strategies that can be disseminated quickly among the various agricultural systems of the Mediterranean Region. The project addresses directly the first topic of the FP6-INCO-2002-B1.2 specific measure, ‘research on sustainable irrigation, including deficit irrigation’. Eleven partners from seven different countries (Greece, Italy, Jordan, Morocco, Spain, Tunisia and Turkey), including research and water association institutions will work for three years on the project. Their main activities will be: a) the development of a general summary model of crop yield as a function of water supply, b) the validation of the model for the main irrigated annual (wheat, sunflower, cotton,) and perennial crops (olive, pistachio, citrus), using common research protocols, c) a survey on physical, socio-economic and cultural conditions for each crop and irrigated area, and d) scaling up by combining the yield model with economic optimization modules that will generate optimum DI strategies compatible with the specific socio-economic characteristics of each area under study.

The results of the project will provide recommendations for reducing irrigation water use while ensuring the sustainability of irrigated agricultural systems in the Mediterranean basin. Feedback with project end-users will take place via participation of farmers’ associations and irrigation water agencies that will contribute their expertise in managing water scarcity, thus ensuring that all relevant issues are addressed.

6. Irrigation Techniques

On-farm water use efficiency and water productivity can be increased through improved irrigation techniques. In this area Innovation should be pursued jointly by researchers and the irrigation industry. Although micro-irrigation is known to be a highly efficient system, experience shows that if the system is not well designed and not operated probably, efficiency can be as low as 50%. In addition, research on irrigation accessories such as filters, pressure regulators should be incorporated into the system design and management. In this area, the use of sand filter with proper sand gradation automatic filter systems, emitters, acid and chlorine injection should be tested and experimented on crops highly sensitive to water stress. For other irrigation systems e.g. surface irrigation and sprinkler irrigation, there is a high potential for innovation such as moulding of surface irrigation, irrigation cut back and surge flow irrigation. The design of all irrigation systems should provide the flexibility and simplicity required for successful operation under different soil variables and topographic variation. Research should be oriented towards proper and careful selection of pumps, pipes and on-farm sprinkler equipment in order to sustain high uniformity at a specified application rate. Research in irrigation systems should also concentrate on the energy aspects by introducing and testing low-pressure micro and sprinkler irrigation in order to reduce the operation and maintenance costs. So far, technology has produced sprinkler systems of low energy precision application (LEPA) and low pressure compensating emitters that can provide a high uniform application rate and efficient irrigation. A properly designed and managed system, incorporating all the above technology can reach efficiency as high as 98%. Research should be further pursued to explore with the industry the new technology that can save water and produce uniform irrigation.

7. Exploitation of Saline (brackish) Water

Many parts in the region, like Jordan, possess considerable reserves of underground saline water with a variable salt concentration. To date many studies have been carried out to investigate whether this water can be used for irrigation. It was found that certain crops, such as cotton, tomato and melon, readily tolerate saline water (up to 7-8 dS/m electric conductivity, equivalent to salinity of 0.41-0.47% NaCl). For certain crops, there is no doubt that saline water can be used for irrigation instead of fresh water. However, to minimize salt accumulation around the plant roots and facilitate leaching away of salts that do accumulate, it is essential i) to use drip delivery systems and ii) to cultivate the plants in soil-less media or light soils (sandy or loamy-sandy soil).

8. Development of High Agro-Technology

Water constraints and a varied climate should stimulate the development of unique agro-technology, based on high-quality standards according to updated international production and food-safety regulations. Irrigation technology, fertigation, development of greenhouse equipment, seed propagation, fertilizers and pesticides has enabled new agriculture to prosper in adversity. In addition, farmers have learned to develop high value-added and innovative farm products that allow them competing in markets with lower-cost producers. Proper water management, reuse of treated effluent and desalinated water could help the region overcome drastic shortages.

Promotion of advanced agricultural technology would lead to enhance irrigation efficiency, increase agricultural yield and improve quality of life and environmental conditions. The use of soilless media and water-wise gardening have proved to be a determining factor to reduce water consumption significantly.

9. Recycling of Drainage Water

In soilless media culture, the typical leaching fraction which could be applied to remove accumulated salts is between 30% and 50%. As a result, one third to one-half of the applied water drains out, carrying 130 mg/l nitrogen, 2- mg/l phosphorus, and 140 mg/l potassium as well as natural salts. Approximately 1,000 kg of nitrogen, 1,600 kg of chloride and 800 kg of sodium are leached from one hectare of substrates and this is a potential polluting factor for more than 1000 hectares of groundwater. In the last few years, around 25% of the greenhouses using soilless substrates have shifted from open to closed irrigation systems. This shift is even more impressive in rose production, where drainage water is recycled in over 50% of the greenhouses.

Nutrient recycling by reusing water drainage in soilless cultivation appears to be the most logical solution: approximately 50% of water and fertilizer inputs are saved, because of reduced tap-water supply and improved nutrient availability to the plants. The potential pollution of the aquifer from the open irrigation system is reduced. The transition from an open to a closed irrigation system unexpectedly resulted in yield increase and higher fruit and flower quality, due to the higher fertigation control and monitoring applied in the new technology.

V – Adaptation to climate change

Many hydrological models have suggested that most Mediterranean countries will cope also with the effects of climatic change not only as regards water resources supply but also in terms of increasing water demand. In addition to the traditional solutions applied to take up the water scarcity and climate change challenges, it should be appropriate to get a better understanding of these effects and to take some relevant actions by:

– formulating national policies to adapt to the effects of climate change;

– using a decision support system to predict the climate change and its impact on agriculture;

– creating scenarios and models to study the effect of climate change on rivers and groundwater aquifers;

– handling shared water resources issues in diplomatic ways taking into consideration the expected climate changes;

– utilizing efficiently flash floods in water harvesting, artificial recharge of groundwater and promoting vegetation cover in arid areas.

VI – Conclusion

The expanding urban population, as well as the political developments, will likely reduce further fresh water supply for agriculture. The solution lies in the desalination of brackish water and high-level water reclamation. A more significant part of annual crops will be grown under cover, where recycling will become routine. The concepts of ultra-low irrigation rate and vegetable monitoring should be further examined for their contribution to higher efficiency of water utilization. Integration between agriculture and water policies should be strengthened in order to ensure high water productivity and efficiency. To cope with water scarcity and climate change, certain measures could be adopted. Therefore, one of the future solutions to water shortages is to adopt water policies, water-saving technology in irrigated and rainfed agriculture. Irrigation water conservation measures should be formulated within the policy framework and in parallel to the development of high agro-technology.

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Water framework directive and water policies in France:
Evolution and tools for a rational use of water resources

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Abstract. In France water management, in terms of quality and quantity, is based on the Water Framework Directive (WFD), the national legislation, the use of appropriate tools and the involvement of relevant stakeholders (institutional and local).This article reviews the institutional water management in France and in Europe as well as the new trends of the French system following the introduction of the European principles of water management. The pre-existing French institutional, economic and planning tools have been modified and the roles of water stakeholders have changed in order to fully meet the WFD expectations. Considering the actions carried out to promote a more rational resources management throughout the French Mediterranean region (Rhône-Mediterranean-Corsica river basins)., this article shows how the French system has finally developed large-basin water policies. Some examples are given about water quantitative management and rational use with the support of technological innovation.

Keywords. Water Framework Directive (WFD) – Water management tools – Water agency – Governance – Consultation – River basin.

Directive cadre sur l'eau et politiques de l'eau en France: évolution et outils pour une utilisation raisonnée des ressources en eau

Résumé. *En France, la gestion de l'eau, sur le plan qualitatif et quantitatif, repose sur la Directive Cadre sur l'Eau (DCE), la législation nationale, l'utilisation d'outils appropriés et la mobilisation des acteurs concernés (à l'échelle institutionnelle et locale). Dans cet article, on passe en revue les aspects institutionnels de la gestion de l'eau en France et en Europe, et les nouvelles orientations du système français suite à l'introduction des principes européens. En effet, les instruments institutionnels, économiques et de planification existants ont été modifiés et on est également intervenu sur le rôle des acteurs pour satisfaire les exigences de la DCE. Compte tenu des actions entreprises pour promouvoir une gestion plus raisonnée des ressources en eau dans la région méditerranéenne française (bassins hydrographiques Rhône-Méditerranée-Corse), cet article montre qu'en France, des politiques de l'eau ont été mises au point pour les grands bassins. Des exemples sont illustrés sur la gestion quantitative et l'utilisation rationnelle de l'eau à travers l'innovation technologique.*

Mots-clés. *Directive Cadre sur l'Eau (DCE) – Outils de gestion de l'eau – Agence de l'eau – Gouvernance – Consultation – Bassin hydrographique.*

I – Introduction

From 1964 to 2007, several laws were issued in France to set water management in a proper institutional framework.

The law of December 16 1964 provided the basis for a modern principle of river basin management. The implementation of this law led to the establishment of six basin organizations.

Almost three decades later, the Water Law (1992) significantly changed the French water management system with the establishment of the SDAGE (River basin management plans).

In 2000, the WFD took up this principle of management and planning at the basin level.

Until 2006, several national provisions adapted the French water management system to the European rules.

After describing how the French legislation has evolved over the last forty years, this article reviews the main changes in the institutional system and the new tools which allow today an integrated water management.

II – Discussion

1. Towards integrated water management in France and in Europe from 1964 to 2007

- The **law of 16 December 1964** provides the basis for a modern principle of water management by catchment areas. It lays down three main principles that are now generally recognized but which were very innovative at that time:
  - A decentralized management at the level of large catchment areas;
  - A joint management by a local board bringing together local authorities, water stakeholders, representatives from the public administration concerned with water issues;
  - Incentive financial tools for a good qualitative and quantitative management.

The application of these principles represents the first approach to resources preservation within the limited frame of the catchment area. The notion of potential reserve waste due to pollution discharged into the environment and the taxation of water volumes through water charges are aimed at saving water and reducing water demand .

Thus, the French national territory is divided into six large “River Basin Districts” corresponding to the six French Water Agencies of Adour-Garonne, Artois-Picardie, Loire-Brittany, Rhine-Meuse, Rhône-Mediterranean-Corsica and Seine-Normandy.

- The **law of 3 January 1992** entails a shift from a policy based on facilities, as defined by the text of 1964, towards a policy of the environment to support planning and global management aimed at some specific objectives.

This law sets forth the following principles:

- the heritability of water,
- the global and interconnected management of water resources (in all forms, surface water, groundwater, coastal marine water involving all the users),
- the conservation of the aquatic ecosystems and of the wetlands;
- the consideration of water as an economic resource which deserves being enhanced for its different use.

The main management tool is the Water Development and Management Master Plan (or *SDAGE* in French) which, at the basin level, represents the framework and specifies the guidelines for management and planning over a period ranging from 10 to 15 years.

In the sub-basins, a Water Development and Management Plan (or *SAGE* in French) is applied; it is backed by the local stakeholders for water resources management and protection on a local scale.

- The **Water Framework Directive** (WFD), issued in October 2000, reflects the willingness to implement an innovative approach towards water management in Europe. The main objective is to achieve a good ecological status of all water bodies by 2015 and more specifically:

– The sustainable management of water resources;

– The prevention of any deterioration in the aquatic ecosystems;

– Catering for a sufficient supply of good-quality drinking water;

– Reducing groundwater pollution;

– Reducing and ultimately eliminating the discharge of priority hazardous substances;

– Contributing to mitigate the effects of droughts and floods.

To achieve the above objectives three principles shall be taken into account:

Programming and planning: Planning in each district is based on some key steps that should be revised every six years: the elaboration of an assessment plan and a programme of measures that allows to achieve the objectives of the management plan (Water Development and Management Plan in France).

The programme of measures encompasses the main actions that are to be launched by 2015. Adopted by the prefect coordinating the catchment basin, this programme provides guidance for the actions that shall be taken by the partners and the public services in the catchment area. It specifies the time frame of the main measures and lists the regulatory provisions, the financial incentives that are provided and the contractual tools available.

Since the programme of measures is a tool for the implementation of local measures, the directive specifies that the general public – e.g. all the citizens, among whom the water users- should be involved at all stages in the adoption of the management plan and the programme of measures.

It defines three periods of compulsory consultation: 2006, 2007 and 2008.

France has opted for providing information/consultation since 2004 during the work-out phase of the water bodies' assessment (1st phase of the WFD).

The economic analysis: although with a few legal constraints, the WFD foresees an economic analysis at all stages of its implementation (assessment, grounds for derogation to the objectives, optimization of investment choices and pricing).

The principle of costs recovery: water pricing should represent the technical and environmental costs and should include the polluters-pay principle for each of the three large groups of users i.e. the communities, the industries and the farmers. Attractive water pricing should be applied before December 2010.

- The **law for transposal of the WFD** (21 April 2004): this text set very ambitious objectives for the country:
  – Achieve a good ecological status of water bodies by 2015;
  – Reduce, even eliminate, the discharge of hazardous substances;
  – Secure public participation in policy working-out and monitoring;
  – Take into account the principle of recovering the costs of the services related to water use.

The present situation in France is not satisfactory. And the assessment made over the last years by the Water Agencies and the Services of the Ministry of the Environment demonstrated that further efforts are needed before 2015. Indeed, the good ecological status is only achieved for some

50% of the water bodies due to the point sources and diffuse pollution that are poorly managed and to the imbalance between water demand and water supply, which is even stronger during the drought period (summer 2003, for example). To achieve the objectives set, the transposal law completes the procedure for working out the SDAGE (Water Development and Management Master Plan) that should be updated before the end of 2009. It confirms the role of the Basin Committee in setting the water policy objectives at the river basin level. The actions that should be carried out are specified in the programme of measures.

- The **Law on water and the aquatic environments** (LEMA) was issued on December 30 2006. This law was based on two fundamental objectives:
  - Provide the administration, the local communities and the water stakeholders, in general, with the tools to recover water quality; achieve by 2015 the objective of a good ecological status set by the WFD; get a better balance between water resources and needs with a view to achieve a sustainable development of economic activities that exploit water and a closer dialogue with the community;
  - Provide the local communities with the tools to adapt the public drinking water and sanitation facilities to the new challenges in terms of transparency vis-à-vis the users and of environmental efficiency.

To reach the objectives of the French Water Policy specified in the legislation, the institutional system and the management tools need to be adapted.

2. Evolution of the institutional system and the main water management tools in France

According to the WFD principles, the French water policy is now defined on a partnership basis involving the State, all the local Communities and the users associated at each level, since it aims at providing a global management of the resources, by optimizing the needs fulfillment and preserving the aquatic ecosystems.

In France dialogue is institutionalized at ***three levels***:

National Level: The National Water Council brings together the representatives appointed by a decree of the Ministry of the Environment upon a proposal made by the ministers, the users, the general and municipal councils, the administrations concerned and the relevant water experts.

The Minister submits to the Council all matters for which the Council has to express an opinion pursuant to the law amendments of 16 December 1964. The Water Division is in charge of the Council's Secretariat.

It is consulted for guidance on the national water policy and particularly, on the draft legislative and regulatory texts.

The ONEMA, The National Office for Water and the Aquatic Environments, is a national public establishment that falls within the public service of the environment. It was set up to encourage a global and sustainable management of water resources and aquatic ecosystems, recover water quality and achieve the objectives of a good ecological status set under the WFD.

Governance and basin districts: Article 13 of the WFD reads that "There are diverse conditions and needs in the Community which require different specific solutions. This diversity should be taken into account in the planning and execution of measures to ensure protection and sustainable use of water in the framework of the river basin. Decisions should be taken as close as possible to the locations where water is affected or used". The river basin is defined as the appropriate territorial level for water governance, conflict management, with water sharing based on the upstream and downstream uses at the heart of the dialogue process. Excessive upstream pollution or abstraction has, indeed, serious consequences for downstream users. Water governance and management are interdependent and consequently, the governance system implemented has an impact on resources management and vice versa. In article 35, the WFD specifies that “Within a river basin where use of water may have transboundary effects, the requirements for the achievement of the environmental objectives established under this Directive, and in particular all programmes of measures, should be coordinated for the whole of the river basin district”.

The BASIN COMMITTEE, which brings together the different public or private stakeholders acting in the water sector, is designed to jointly discuss and broadly define the policies on water resources management and protection of the natural aquatic environments. It includes the representatives of local communities (40%), the representatives of social and professional organizations and the user organizations (40%) and the State representatives (20%). The committee is responsible for promoting the dialogue since water governance actually depends upon its achievements. The board of the water agencies stems from the Basin Committee, except for the Committee’s chairman who is appointed by the Government. The Government provides guidance on the activities that will be carried out by water agencies and participates in their financial decisions. Since 1992, the Basin Committee has become responsible for the elaboration of the Water Development and Management Master Plan (SDAGE), before its submission to the Government for its approval. The Government follows its implementation and gives its opinion on the schemes defined in the Water Development and Management Plan (SAGE). Pursuant to the law of 21 April 2004, annexed to article L 212-1 of the Environment Code, “Each basin or group of river basins has one or more SDAGE to work out the main lines of a balanced water resources management (…) and define water quantity and quality objectives”. These SDAGEs must be submitted every six years and they can be used to challenge any administrative decision in the water sector; therefore, they have to be in line with town planning. A decree dated 17 March 2006, specifies the SDAGE contents. In accordance with the SDAGE and “to achieve the objectives of the WFD, […] a programme of measures describing the means and the actions to be implemented should be drawn up”.

The Basin Committee is consulted by Water Agencies to determine the rates and the criteria for water charges paid on abstractions and discharge. These rates and charges are introduced at the basin level, and are included in the priorities of the agencies’ action plan to decide how they can be used for investments and operation of public and private water treatment facilities.

Water agencies are managed by a Board that includes: 8 representatives from the local communities, 8 representatives from the different categories of users, 8 State representatives, 1 representative from the Agency’s personnel.

The Chairman of the Board and the Agency’s Director are appointed by the Government.

The scope of their activities can be summed up as follows:

- Providing the financial contribution for the execution of all types of works, construction and management of the facilities that meet the needs set by the Basin Committee;
- Identifying priorities for research on water issues that the agencies must develop

Water Agencies’ financial resources derive from the application of the “user-polluter-pays” principle that enable them to collect the charges on abstraction and discharge from all the users that affect water quality by modifying the water regime.

The Water agencies’ role consists in supporting actions at the river basin level by granting incentives to the local owners who carry out activities complying with the objectives set by the agencies. To achieve this purpose, the agencies rely on the links established with the local stakeholders and look for support by consortia to promote the SAGE or the environment contracts. They can sign framework agreements that are binding for partners from the institutions and the land management sector: the regions, the departments, the town communities, the Public Territorial Basin Establishments, etc. These tools are designed to reinforce collaboration and dialogue.

The water agencies also play a role in disseminating information and raising public awareness. The law for the adoption of the WFD dated 21 April 2004 stipulates that the basin committee is responsible for collecting public opinion on the SDAGE project, "The basin committee can modify the project to take into consideration the opinions that are expressed". The objective of the governance model implemented in the six basins is to ensure proper coordination of various stakeholders. The system that involves the agencies and the basin committees is designed to ensure representativeness of the stakeholders and to foster joint actions. Public participation must allow raising awareness of the measures adopted, or even amending these measures.

At the level of affluents and sub-basins corresponding to a hydrographic unit or an aquifer, a local Water Commission can be set up, where half of the members are representatives from the local communities, one quarter includes users' representatives, and one quarter encompasses the State representatives, and which will be in charge of preparing and supervising the application of the Water Development and Management Plan (SAGE).

The Water Development and Management Plan sets the general objectives for the use, the development and the quantitative and qualitative protection of surface water and groundwater resources and the aquatic ecosystems as well as for the preservation of the wetlands, in order to comply with the principles established by the law. Its extent is defined by the master plan, or if appropriate, by the State representatives, upon consultation with or upon proposal by the local communities and upon consultation with the basin committee.

Once the scheme has been approved, the administrative authorities must adopt consistent decisions in the area concerned, and along its perimeter.

The local communities involved can also act jointly within a Local Water Community to help achieving the objectives set under the Water Development and Management Master Plan.

The "Local Water Community" will be responsible for the assessment activities, the implementation and exploitation of all the works, facilities and plants of general or emergency interest, and will be in charge of:

– the development of a basin or a section of a catchment area;

– the maintenance and management of a non-national water course, including the access to the watercourses;

– the water supply;

– the management of storm waters and runoff waters;

– the floods and sea level control;

– the pollution control;

– the protection and conservation of surface and groundwater;

– the protection and reclamation of the sites, the aquatic ecosystems and the wetlands as well as of the neighbouring woodlands;

– the hydraulic facilities that contribute to civil security.

The tools and institutional systems mentioned above are used in France to develop the water policy. All the plans share the common objective of contributing, through the dialogue, towards a sound water management. Plans are intended only for planning and management. Financial tools, such as the agencies subsidies, assist and support the stakeholders in applying the measures laid down in the plans and to obtaining tangible results.

3. Impacts of the water management system on the land and financial support to the projects: the role of Water Agencies

Based on the SDAGE and the programmes of measures, Water Agencies draw up action plans to achieve the SDAGE objectives. The action plan is a funding programme which establishes to procedures to have access to subsidies. Financial support could be granted to master-builders, industry, local authorities, associations, farmers… for the implementation of measures recommended in the programme of measures. The Water Agency's action plan has to provide results as laid down by the WFD, and therefore, this leads to a selection of the financed actions.

There are six different programmes, adapted to the challenges of each basin and to the stakeholders' concern, but pursuing a single policy for a sound and sustainable management of water resources. The funds granted to the Ninth programme demonstrate how much the Government intends to support the water policy for the six next years. The subsidies amount to more than 11.6 billion Euros, excluding the subsidies and contributions to the National Office for Water and the Aquatic Environments, which replaces the Higher Council for Fishing and whose funding is provided by the water agencies. These programmes are fully funded through the water agencies' charges. The Law on Water and the Aquatic Environments has effectively reasserted the principles which are at the basis of the agencies' success, in particular the environmental taxation which has proved to be effective for 40 years, and relies upon the "water pays for water" principle.

Programmes are designed to achieve two main objectives:

– recover the time lost in France for the application of some European rules, especially, the municipal waste-water treatment directive of 1991, imposing the upgrading of all waste water treatment plants;

– implement the Water Framework Directive that applies a result-based logic to actions and sets out that water agencies must be more focused on local targeted actions and have to progressively increase the remedial actions in the aquatic environments.

To ensure proper resources protection and sustainable development of water-related economic activities, the French Minister recognizes the urgent need for strengthening water agencies' actions in several fields:

– Concerning drinking water, prevention must preferably be applied instead of curative actions, e.g. treat pollution at the source and take into account the objective of the National Health and Environment Plan to complete the scheme implementation in order to protect the water catchment areas from 2010;

– Control of diffuse pollutions is also a major challenge. This is why Water Agencies shall involve all the players upstream and the critical water bodies to implement reinforced territorial actions;

– As for the application of the management plan for water scarcity, the Water Agencies will take actions to reach a balance between the water uses and the resources available, including the development of innovative solutions and exploitation of the new resources;

– The amounts allocated to the management of the aquatic environments are tripled.

The Ninth programme has been elaborated based on a dialogue approach between the Ministry of Ecology and Sustainable Development and the basin committees that are the driving force for establishing a dialogue within the basins, involving the local stakeholders as well as the State services. The law on water and the aquatic environments is effectively reinforcing the competencies of the basin committees that shall express their opinion on the programmes submitted by the agencies.

For example, the article shows some of the actions which could be financed by the RMC Water Agency during the period covered by the ninth programme (2007-2012) (Abstracts from the RMC Agency Intervention Programme)

- ✓ *Support sustainable actions of small enterprises: fight against industrial pollutions*

Less structured than larger enterprises, small companies find it difficult to reduce pollution and remove wastes with sustainable solutions and preserve the environment due to the lack of technology or the disproportionate treatment cost.

Along with the reduction of toxic pollution, one of the objectives of the ninth programme, the Water Agency intends to encourage small enterprises by promoting research development and a technological platform to develop technical and collective solutions to create networks.

One of the aims of the programme is to support the development of waste treatment at the basin level and to make it financially accessible and sustainable for small enterprises.

Table 1. Subsidy rate for sustainable actions of small enterprises in pollution control .

Type of action	Subsidy rate
Application of a research and technology platform	30 to 50%
Removal of dangerous wastes for water	30% (for the first 10 tonnes per year
Waste reception centre (dangerous wastes)	30%

- ✓ *Support sustainable actions in agriculture*

The Agency supports initiatives to create or promote technology which will allow farmers applying a lower amount of fertilizers or pesticides, in particular in organic farming. Innovative technology must be adaptable to the regional context.

Technology promotion must demonstrate the benefits for the environment.

The subsidy rate averages 50%.

- ✓ *Rational use of water*

The Water Agency supports actions for saving or proper sharing of water resources (dams for example).

Savings should concern:

– For drinking water: less waste, leak elimination, rainwater collection for watering and outside washing, recycling of cleaning water…

– For agriculture: best irrigation management (a proper amount at the proper time for crops), crops best adapted to the climate conditions for lower water consumption …

– For industry: targeted technology development, recycling of cold circuit waters…

Action for rainwater collection can be funded provided that they are collective actions supported by local authorities. The same actions can be financed in agriculture but only if they are collective and are carried out in accordance with the Rural Development Plan.

Furthermore, distribution between the various water uses can be rebalanced by modifying the dam management, according to the needs and the rainfall. Additional water flows can then be considered in the lowest water level period, to increase the flows into a river. The Agency can help modifying the management of the hydraulic works only if the new management methods registered with a local authority.

Table 2. Subsidy rate for rational use of water.

Type of action	Subsidy rate
Water saving	30 to 50%
Optimization of hydraulic facilities for several uses (studies and works)	Up to 50%

✓ *Support general studies on research and development*

These studies will be aimed at:

– improving knowledge of the environment and the impact of human action, particularly in critical areas;

– following up or assessing the effectiveness of the operations supported by the Agency with respect to the state of the environment;

– evaluating the socio-economic aspects resulting from the preliminary study, with special emphasis on the relationship between the ecological state and the risks (public health, floods).

They will also cover technical and scientific themes of interest to the Agency's programme. Priority will be given to the projects which fall within the scope of the agreements signed between the Agency and the research organizations (IFREMER, CEMAGREF,…).

Table 3. Subsidy rate for supporting research and development.

Type of action	Subsidy rate
General studies	50%
Research and development	20 to 80%

III – Conclusion

In France the management of surface water and groundwater, considered as the "common heritage of the Nation", is currently based on six main principles:

– Taking into account the geographic characteristics of the main catchment areas since "water knows no administrative boundaries";

– Applying an integrated approach to fulfill the different needs and preserve the aquatic ecosystems;

– Fostering partnership and coordinating the actions of the Authorities and developers: indeed, this is the role of the six Basin Committees and the Prefects who coordinate the basin; this is also the objective of the Water Development and Management Master Plan (SDAGE) and the Water Development and Management Plan (SAGE);

– Using specific financial resources, in accordance with the six Water Agencies' mission, since "water has to pay for water" and the users-polluters shall be the payers,

– Planning on a multi-year basis the priority investments in the framework of the ninth programme of the Water Agencies (2007-2012) and the river contracts;

– Considering the competencies of each public or private owner, in compliance with the framework set by the law.

These principles provide a solid foundation for technology development allowing a rational use of water resources, the implementation of good practices and the establishment of a dialogue among the stakeholders.

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Comparative analysis of water saving policies in agriculture: pricing versus quotas

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Abstract. The 'Water Framework Directive' 2006/60/EC (WFD) recognizes the fact that water management should include an economic analysis of alternatives. In the present paper we propose a methodology based on comparative analysis to carry out an in-depth assessment of the socio-economic impact of two alternative water policies aimed at resource saving: i) water pricing policies (at basin and regional level) and ii) quotas (reduction in the abstraction of daily use). For this purpose, we implement a linear programming model at the territorial level to simulate the effects in terms of water saving and socio-economic impact. This is complemented by an aggregated analysis based upon crop water production and response functions. We analyze the implications of various water policies for the irrigation of one of the most important basins in Spain: the Guadalquivir Valley in Andalusia. The results indicate that application of quotas is more suitable than water pricing policies to achieve a reduction in water use and bring about economic sustainability.

Keywords. Water saving – Water policy assessment – Irrigated agriculture – Linear programming – Integrated model.

Analyse comparative des politiques d'économie de l'eau en agriculture: tarification vis-à-vis des quotas

Résumé. *La « Directive Cadre sur l'Eau 2006/60/CE » (DCE) reconnaît que la gestion de l'eau devrait inclure une analyse économique des alternatives. Dans ce travail, nous proposons une méthodologie basée sur une analyse comparative pour évaluer l'impact socio-économique de deux politiques de l'eau alternatives, qui visent l'économie de l'eau: i) les politiques de tarification de l'eau (à l'échelle du bassin et de la région) et ii) les quotas (réduction du captage pour l'utilisation journalière). A cette fin, nous avons appliqué un modèle de programmation linéaire à l'échelle territoriale pour simuler les effets sur le plan de l'économie d'eau et des impacts socio-économiques. En plus, une analyse agrégée a été réalisée sur la base des fonctions de production et de réponse à l'eau des cultures. Parallèlement, nous avons évalué les implications des diverses politiques de l'eau pour l'irrigation de l'un des principaux bassins hydrographiques en Espagne : la vallée du Guadalquivir en Andalousie. Les résultats indiquent que l'application des quotas est un système plus performant que les politiques de tarification pour réduire l'utilisation de l'eau et déterminer la durabilité économique.*

Mots-clés. *Economie d'eau – Evaluation des politiques de l'eau – Agriculture irriguée – Programmation linéaire – Modèle intégré.*

I – Introduction

Agriculture is the main component of water use, with a share ranging from 60-70% of fresh water bodies in the Mediterranean regions. The main driving force behind the use of water in agriculture is irrigation water demand. The demand for irrigation water is increasing, and simultaneously other sectors are also expected to increase consumption in the near future. Non-agricultural sectors are using water more efficiently and they account for the lower share of the total abstraction; therefore it is generally agreed that the main changes in water management, to regulate water supply and demand, should take place in the irrigation sector.

Current management of water resources is subject to uncertainty and scarcity, and new institutions and technical tools are now being used, including the implementation of EC Directive

2000/60, the “Water Framework Directive” (WFD). The main objectives of the WFD are to restore good ecological and chemical status for all water bodies across the Community by 2015. Good ecological status for all water masses is defined as reaching the target of 40% use of renewable resources to satisfy the minimum ecological flow.

Within this period, changes are expected to the water regulatory framework and in the adoption of measures to achieve these goals. Nevertheless, WFD recognizes the fact that water management should include an economic analysis of alternatives.

Water pricing is seen in the WFD and in many other sources (OECD) as an efficient system for management of natural resources in general, and specifically for water management. It is seen as a way to ‘internalize’ cost, and reflects scarcity in resources that lack a proper market.

The economic theory suggests that the most suitable water pricing scheme is represented by direct pricing methods, based on volumetric systems. In this way, users will pay proportionally to their consumption, and a certain degree of fairness among users will be also pursued. Rodríguez Díaz (2004) shows that an irrigation district with volumetric (i.e. two-tier tariff) system in Guadalquivir (southern Spain) consumes on the average 10-20% less than the flat rate systems, regardless of the amount of the variable rate. However, numerous obstacles hinder progress in replacing flat rate with volumetric rate. Among them is the fact that it may not be efficient to do so, in a broad range of realistic situations. Work done by Tsur and Dinar (1997) illustrates how the gains in efficiency may not justify the costs of restructuring tariffs.

Changes in pricing schemes might achieve results in terms of water saving, but increased water charges will not always provide the right incentive for users to save the resource. This is the case, for example, when water price elasticity of demand is close to zero, which can occur when the total water bill accounts for only a small proportion of farmers’ total production costs or income; when alternative crops or irrigation practices are not available due to technical, social or economic constraints, or when the bulk of total water charges consists of fixed costs. Bontemps *et al.* (2003) show that water demand in southern France is inelastic for low available volumes, and depends crucially on weather conditions. Dono and Severini (2001) add further evidence from southern Italy to the inelasticity hypothesis, and suggest that water demand becomes increasingly inelastic as water charges increase, because the crops that may be able to pay higher prices are mainly high-value vegetables and fruits, which can support high increases in water price. Massarutto (2003) concludes that the demand inelasticity hypothesis should be framed in relation to the concept of ‘exit price.’ He claims that the effects on water demand are due to the fact that if water prices are below the exit threshold, they result in reduced demand caused by marginal adaptation of irrigation demand to price variations. Water demand elasticity is always very small, especially once the most obvious water saving techniques have already been implemented. Above the exit price, water demand falls to zero because farmers do not cover input costs and they should not use water. Finally, where water is a very limiting factor, like in Mediterranean areas, farmers will potentially respond to increasing water price by intensifying the agricultural activity and by shifting cultivation patterns towards more efficient crops. Moreover, improved water use efficiency will not be effective in reducing the overall water demand (at farm level), since the amount of water consequently made available by enhanced efficiency may be easily used to increase the irrigated area on the same farm (Gatta *et al*., 2007).

Rieu (2005) shows that, although demand in Charente (France) is elastic, local authorities have established quotas to avoid negative effects on farmers’ income. Montginoul and Rieu (2001) report that irrigators in Charente (France) are charged two-tier tariffs, nevertheless, because the variable rate is lower than the marginal benefit of water use on the farms. This implies the need to impose water quotas in years of scarcity. In situations of water scarcity where volumetric control is possible, such as in Iran, Tunisia, Morocco, France, Italy, Spain, Jordan, and the United States, water quotas are often used (Molle and Berkoff, 2007).

Quotas are generally easy to understand, equitable, effective in reducing diversion, and have less impact on net revenue than price-based regulations. Quota allotments are often used in these situations to mitigate equity issues or resource management issues and water conservation (Johansson *et al*., 2002). Generally with quotas the farmers are allowed to make the best use of a limited amount of resource, for which they pay a tariff.

The objective of this research is to evaluate alternative policies of water saving, considering the fact that the most important yield will be provided by agriculture.

In this research we have adopted a methodology based on comparative analysis to carry out an in-depth assessment of the socio-economic impacts of two water policy scenarios aimed at resource saving: i) water pricing policies (at basin and regional level) and ii) quotas (reduction in abstraction of daily use). For this purpose, we have implemented integrated linear programming models at territorial level that simulate farmers' behaviour and their response to the different policy scenarios in terms of water saving and socio-economic impacts. The model has been integrated with the water production functions.

II – Methodology

We implemented integrated linear programming models at territorial level that simulate farmers' behaviour and their response to the different policy scenarios.

The models' objective function optimizes water allocation within the farm clusters by solving how to best allocate land among different crops and irrigation levels, and at the same time, maximize profit from water use. The resulting optimum cropping pattern is the temporal and spatial combination of different crops that return the maximum net margin above water use within the given agronomic and socio-economic constraints.

The basic assumption used in the development and application of the model includes the following: (1) the objective function determines the optimal water input into each cluster-farm based on maximizing the net margin associated with the cropping pattern and per capita water consumption; (2) water allocation is performed on an annual basis according to monthly availability; (3) the water used by each cluster-farm generates a return that is independent of the quantities allocated to the other farmers; (4) water crop functions are taken into account.

The model assumes the neoclassical economic hypothesis of profit maximization (net margin) and it was performed in the short term.

Table 1. Income definition.

A) Gross output	• Income • Subsidy
B) Expenses on Variable costs	• Inputs • Services • Salary • Rent
C) **A-B = GROSS MARGIN**	
D) Expenses on Fixed costs	• Asset Depreciation • Irrigation fees
E) **C-D = NET MARGIN**	
F) Remuneration	• Own labour • Interest on financial capital • Interest on asset • Own land
G) **E-F = PROFIT**	

The objective function was subjected to a set of constraints depending on the cluster features. These include total area, availability of water and labour, crop rotations and CAP subsidies. Specific restrictions for farm types regarding existing quotas of tree crops were included.

For each cluster a different model was developed.

The aggregation of farmers was performed by cluster analysis. The current crop mix, irrigated land, water consumption, farm size and farmer age were taken as the classification criterion.

This research uses a methodology based on comparative analysis to carry out an in-depth assessment of the economic impacts of two water policy scenarios aimed at resource saving: i) water pricing policies (at basin and regional level) and ii) quotas (reduction in abstraction of daily use).

1. An application case

A. Area description

The Guadalquivir River Basin (GRB) is located in southern Spain; it has a surface of 57,527 km^2 and a population of more than 4.2 million people in 476 municipalities (MIMAM-CHG, 2005).

The GRB is located in a semi-arid area with fluctuating precipitation and increasing man-made pressures.

The administrative water right[1] for agriculture is set to 3,365 hm^3/year. The level of abstraction is high (close to 50% in an average hydrological year) with inter-annual fluctuating precipitation; therefore the fulfilment of the administrative water right is low. Agriculture accounts for almost 87% of the administrative water right (unrestricted year), however, in case of scarcity or drought, other sectors have legal priority over irrigation to fulfil their needs.

The minimum ecological criterion applied to Guadalquivir implies limiting consumptive use below the target of 40%·(6,900hm^3 vs. 2,760 hm^3). This level of consumption is close to the current overall sector average use of 2,942hm^3 (42% of renewable resources) and consequently achievement of the 40% target implies an overall reduction of 6.5% of the current level of consumption.

Irrigated agriculture produces more than 60% of the basin's agricultural GVA (Updates of Art 5 DMA MIMAM-CHG, 2005). The Guadalquivir River Basin has an estimated irrigated area of 752,000 ha, which accounts for 25.5% of the total area under cultivation. Water used for irrigation is 80.9% surface water, 18% groundwater and 1.1% wastewater, but the trend is towards increasing use of groundwater.

Since 1900, the irrigated area in the Guadalquivir has increased by 500% from 142,000 ha in 1904 to 715,000 ha in 2004 and 752,000 ha in 2008. The increase in irrigated area has been particularly rapid in the last decade, coming up to around 60% in the period 1988-2004 (Parias, 2007). Due to this expansion, water consumption has increased considerably. As a result, there is now significant pressure on local water resources. Growth in the use of irrigation water, has coincided with a series of drought years and reduced aquifer recharge, and this has meant increased difficulties in ensuring supply.

Today, the irrigated area is grown with six main crops. Olive trees cover 45% of the irrigated area and consume 31% of water used; cotton occupies 10% and uses 17% of the water, rice occupies 5% and uses 12% of the water; maize covers 6% and accounts for 10% of water use; vegetables cover 6% and use 7% of the water; winter cereals (mainly wheat) account for 8% of the irrigated area and 6% of the water consumed.

The water is allocated through a system of crop-based water quotas, coupled with a binomial tariff (flat rate for 90% and volumetric for 10%). The current average tariff in the GRB is 0.0178 €/m^3 for abstraction, plus a distribution tariff amounting to a total of 0.0346 €/m^3.

The costs and the prices are interrelated and managed by the Confederacion Hidrografica Guadalquivir (CHG).

B. Empirical application

Empirical application was carried out in the Fuente Palmera area (GRB). The area covers 1,500 ha, 38% irrigated with 5,000 m^3/ha of water rights allocation. Water is paid by farmers at volumetric tariff with a price of 0.04 €/m^3.

By cluster analysis two types of agricultural systems were obtained: extensive cereals and intensive tree crop systems. For each cluster a different model was developed.

Data for application of the model were based on official statistics at 2005 prices (production functions, input and output prices, technical coefficients and crop patterns) and additional information was obtained by survey.

Table 2. Cluster features.

	Cluster 1 Extensive cereals	**Cluster 2 Intensive arboreal**
Crop pattern		
Wheat	52.8 %	0 %
Cotton	20.3 %	1 %
Sunflower	7.8 %	0 %
Corn	7.5 %	8.3 %
Vegetable	0.4 %	1 %
Olive	2.5 %	59.2 %
Citrus	2.3 %	29.9 %
Set-aside	6.3 %	0.6 %
Farm size	28.8 ha	16.8 ha
Farmer age	57 years	46 years
Irrigation system	Aspersion	Drop
Income	915 Euro/ha	4,328 Euro/ha
Subsidies (CAP)	413 Euro/ha	52 Euro/ha
Employment	6.3 day/ha	33.4 day/ha

C. Policies scenarios

The baseline case refers to an average year (2005) and represents the basis of the assessment of change impact. Two water saving scenarios have been implemented: (1) water pricing; and (2) restrictions/quotas. Both scenarios have been designed to deliver (within existing constraints and case study characteristics) the same outcome in terms of water saving. This makes it possible to undertake the comparative analysis among the scenarios from an economic point of view. The case study has been investigated in the context of unchanged technology and alternative water supply.

Table 3. Policies scenarios.

<table>
<tr><th>Scenario</th><th>Approach</th><th>Assumptions</th><th>Limitations/uncertainties</th></tr>
<tr><td>Water pricing</td><td>- Aggregated area response to rise in price is simulated.
Curve is built by aggregating water demand and value for 2 cluster farm.</td><td>- Water demand is a function of water value, and therefore, the response to water price is the marginal water value.</td><td rowspan="2">- The models make use of average values, but there are uncertainties regarding variation in yields, costs and prices.
- Uncertainties in real irrigated area, i.e. illegal extractions are not known exactly and have been estimated at 20% of the ‘legal area’.</td></tr>
<tr><td>Restrictions/quota</td><td>- Farm response model is developed to simulate cropping pattern responses to quota.</td><td>- Average water right is used as baseline (average year is similar to 2005 conditions).</td></tr>
</table>

III – Results and discussion

Figure 1 shows the water demand of each cluster and the aggregate demand of Fuente Palmera. The response curve obtained by the LP model illustrates the existence of a rigid response in this area where a large percentage of land is devoted to olive and citrus.

Simulation of the water saving response in Fuente Palmera shows that when prices go up to 0.1€/m^3 (a 150% increase compared to the current level), the potential water saving amounts to 9% because the cultivation of maize (a low value crop) is abandoned. The simulation results show that in order to achieve a 40% water saving, a price of 0.4€/m^3 needs to be implemented. This is 9 times higher than today’s price and reduces the farmers’ net margin by 47% because the additional savings imply the abandonment of profitable crops such as cotton (cf. Figure 2).

The increase in price may result in different impacts for each local condition, i.e. a price increase of present level induces a drastic change where herbaceous crops such as maize are cultivated, inducing water saving and changes in land use and irrigation systems (Cluster 1); while this increase does not affect the consumption for citrus or olives that require a higher price increase of over 0.50 €/m^3 to induce significant changes (Cluster 2).In areas of high value crops such as citrus, olives and vegetables, prices on water abstraction need to be substantially increased in order to achieve water savings. When prices go over the ´break-even point’, well above current levels, an increase in price will lead to savings, but not without severely affecting the farmers’ income. The case of Cluster 2 with 60% of olive is an example of this consequence.

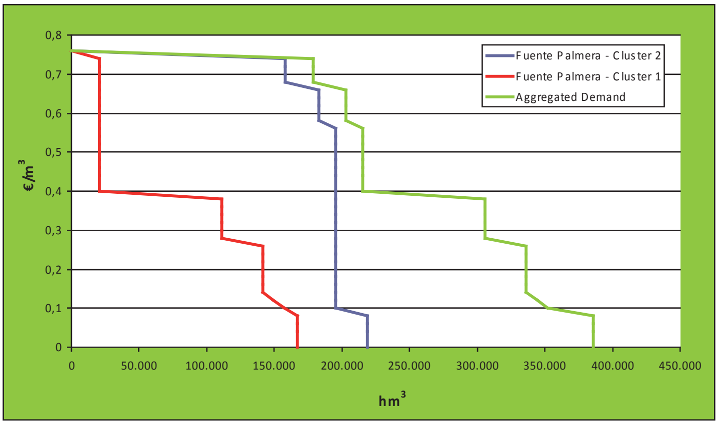

Figure 1. The water demand in Fuente Palmera.

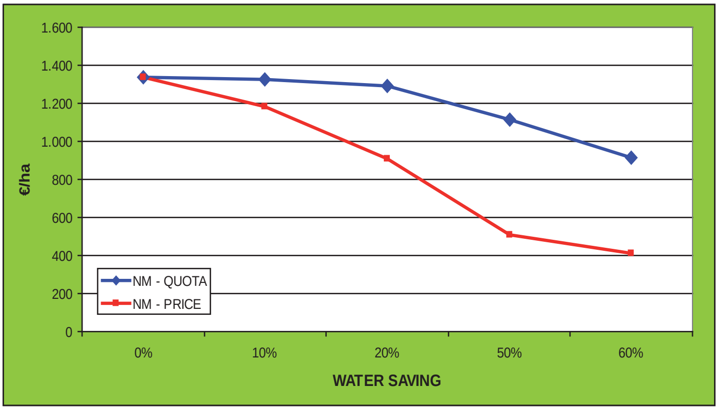

Figure 2. Farmers' net margin.

The use of quotas may achieve objectives of water saving with a moderate economic impact on farmers' income, but the use of prices requires reaching high tariffs to produce a significant reduction in water use. This is due to the high level of productivity of Mediterranean crops and systems which imply the extreme low elasticity of demand.

At the same time, water use efficiency increases when quotas are applied (Figure 3).

The analysis of efficiency of the water policies (euro/m^3) shows a great difference between the two systems, thus demonstrating that the introduction of quotas increases the efficiency levels when compared with pricing. Since water demand has a low elasticity, the price increase produces a direct withdrawal from the farmers.

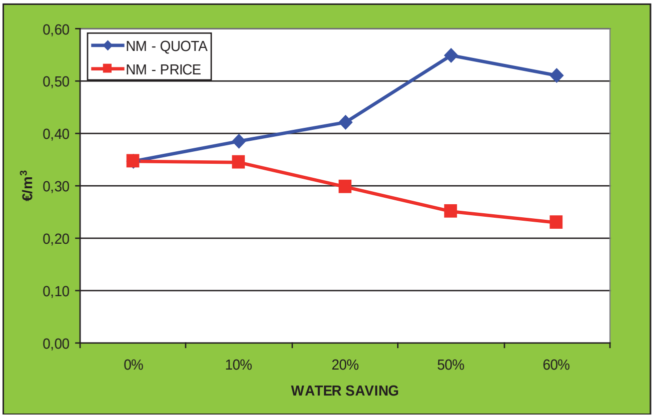

Figure 3. Water use efficiency.

The overall purpose of the proposed water management scenarios is to save water in order to contribute to sustainable water management and restoration of a sustainable water balance at a regional level.

The use of quotas may achieve ecological objectives of a minimum flow and 40% use of renewable resources with a moderate impact on farmers' income, but the use of prices requires imposing high tariffs in order to produce a significant reduction in water use. This is due to the high level of productivity of Mediterranean crops and systems which imply the extremely low elasticity of demand, and therefore, of the price in some areas.

For this basin, the use of quotas appears to be a better instrument than pricing to achieve water savings, because the impact on farmers' income is less when compared to the severe impact of water pricing. This is due to water scarcity and to the high value of the cultivated crops. Quotas can also be implemented because the majority of farmers using surface water have access to supply through a Water Users' Association. However, a moderate water price increase to recover the full cost of surface water is also expected in the GRB.

Additional work is needed in various fields: (i) knowledge of the long-term adaptation of farmers to scarcity and water pricing; (ii) analysis of the impact of seasonal use of water by agriculture (iii) knowledge of the impact of climate change in the basin.

The situation in the GRB makes water saving and water demand management compulsory since there is no alternative water supply available to reach a balance in the use of water resources.

IV – Conclusion

This research analyses the impact of two policy instruments to save water in irrigation. The case study shows that pricing has a dramatic effect on farmers' income. On the contrary, the use of quotas allows water saving at a reduced cost for farmers, because water is used more efficiently and concentrated on the more productive crops by improved management of the irrigated area and of the irrigation supply per hectare.

This result shows the need for further research on the use of water saving instruments on a local scale and at the aggregated basin level.

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[1] The Administrative water right ("concesión") is the water allocated to a user according to Spanish Water Law. However, in practice the full unrestricted water allocation is rarely supplied as there is great intra-annual and inter-annual variability in precipitation.

Modernization of irrigation systems: measures to reduce pressure on water demand in Lebanon

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Abstract. In Lebanon water balance will reach its limits by 2020. Agriculture sector is the main consumer of water (around 70% of the total needs). In order to support water saving, the Lebanese government is applying a long term plan aimed at rehabilitating and modernizing the water sector. The policy adopted includes a number of strategies: institutional reforms, new legislation and administrative structure, application of an integrated water management plan, rehabilitation of existing schemes, water storage capacity improvement. This policy must be completed and further actions should be envisaged. The application of this new policy is encountering many difficulties which need to be solved. The present paper aims to give an overview of these problems considering some case studies and to outline the measures that should be adopted in order to improve water use efficiency. Many recommendations are given but the involvement of farmers in the processes, through water user associations, is still the main goal to achieve in order to obtain significant results.

Keywords. Integrated water management – Water policy – Water saving – Irrigation efficiency – Modern irrigation techniques – Water user association – Extension.

Modernisation des systèmes d'irrigation: Mesures pour réduire la pression sur la demande en eau au Liban

Résumé. *Au Liban, on prévoit qu'avant 2020 de fortes contraintes pèseront sur le bilan hydrique. Actuellement, le secteur agricole reste le principal consommateur d'eau (environ 70% des besoins totaux). Afin de promouvoir une stratégie pour l'économie d'eau, le gouvernement libanais a lancé un programme à long terme, qui vise à dynamiser et à moderniser la gestion de l'eau dans son ensemble. La politique adoptée repose sur différentes stratégies: des réformes institutionnelles, une nouvelle législation et une nouvelle structure administrative, l'application d'un programme de gestion intégrée, la réhabilitation des périmètres existants, l'amélioration de la capacité de stockage de l'eau. Cette politique nécessite aussi des actions d'accompagnement qui doivent encore être définies. L'application de cette nouvelle politique se heurte à de nombreuses difficultés auxquelles il faut faire face. Le but de ce travail est donc de donner une vue d'ensemble de ces problèmes en s'appuyant sur des cas d'étude et de passer en revue les mesures qui devraient être mises en œuvre en vue d'améliorer l'efficience d'utilisation de l'eau. Plusieurs recommandations sont aussi présentées bien que la mobilisation des producteurs, à travers les associations des usagers de l'eau, reste encore l'objectif principal pour atteindre des résultats significatifs.*

Mots-clés. *Gestion intégrée de l'eau – Politique de l'eau – Économie d'eau – Efficience de l'irrigation – Techniques d'irrigation modernes – Association des usagers de l'eau – Vulgarisation.*

I – Introduction

The World Bank has warned the MEA region against the looming water shortages. Indeed, overuse of water resources is putting the region at high risk. The amount of water per person in the Middle East will be reduced by half by 2050. However, the crisis can be avoided provided that the regional governments take actions towards managing properly waste water, building more efficient networks and reducing water use.[1]

In 2020, water balance in Lebanon could become negative if all the players involved in water management do not apply water saving policy. Since the population is rapidly growing, water demand is increasing across the country. At present the agriculture sector utilises the vast majority of available water resources.

The irrigated area in Lebanon is now around 90,000 ha, of which 55,466 ha are still under traditional gravity system and only 25,564 ha are under pressurized systems. Technological inadequacy prevails both in water irrigation systems at farm level and in water conveyance and distribution systems.[2]

However, according to Dr. Fadi Comair, poor management is the main cause of these problems, along with political interference and misunderstanding about how to improve water delivery and sanitation services. In contrast to the region's booming growth, water infrastructure and the management capacity are lagging behind. "What Lebanon needs is better management".

Dr. Comair also highlights that we must take up the challenge of water policies, in particular, those concerning drinking water, agriculture, industry and sanitation, by adopting innovative techniques within the framework of integrated management, ensuring protection from socio-economic and environmental impacts.[3]

A sound management of the system and of irrigation water is as important in pollution control as proper design. In addition, a sound management almost always implies water and energy savings, thereby increasing productivity per dollar invested[4].

Today the irrigated area accounts only for 42% of the total irrigation potential, with great efforts on technical improvement aimed at:

- rehabilitating and improving efficiency of the present irrigation and domestic water network;
- enhancing "on-farm" irrigation efficiency;
- limiting degradation and improving water quality;
- reusing treated wastewater.

Since 1960s, the Lebanese Agricultural Research Institute (LARI) and the Litani River Authority (LRA) have undertaken many research works, experiments and investigations in the field of irrigation. At the beginning of 1970s, the first pilot pressurized irrigation project was implemented (by LRA) in southern Lebanon. The pressurized irrigation system equipment, such as the sprinkler, began to be familiar to the farmers. Since that time modernization and water saving concepts, at governance and farmers' level, have been based on pressurized systems including scheme network and on-farm equipment. This type of equipment is increasingly adopted in the private irrigation projects of the Bekaa valley exploiting underground water. In the last few years, new management tools have been introduced to Lebanon to help decision-makers manage more properly irrigation water at field level. However, only few practical experiences are known with successful application to irrigation systems.

The objectives of this paper can be summarized as follows:

- to describe the measures taken by the Lebanese government in the framework of water management at the national level and to provide some recommendations in order to draw up an appropriate policy;
- to analyse some case studies from the South Bekaa Irrigation and Drainage Scheme and the Southern Lebanon Scheme in order to discuss the problems encountered in modernizing irrigation and propose management alternatives in the light of the knowledge gained in this field;

- to focus on the importance of shared management by stakeholders, especially the water user' associations which represent the rural communities, in modernization and water saving policies.

II – Description of the irrigated area in Lebanon:

As shown in table 1, the irrigated area can be divided into two categories: Scheme and private Irrigation.

Table 1. Irrigation area in Lebano

Description	Area in Ha			
	Equipped	Net Irrigated	Traditional Gravity System	Pressurized System
Scheme Irrigation	65,600	59,070	53,270	5800
Private irrigation	24,400	21,960	2196	19,764
Total	90,000	81,030	55,466	25,564
Actual efficiency			0.45	0.7
Potential future efficiency			0.6	0.8

1. Scheme Irrigation

The total irrigated area comprises 67 schemes covering approximately 59,000 hectares. All traditional irrigation schemes are open channels with low-efficiency traditional irrigation systems (Table 1), while the new schemes (Pilot sector,1200 ha, in southern Lebanon, and South Bekaa irrigation project first phase over 2000 ha) implemented by LRA are pressurized networks allowing the application of on-farm pressurized irrigation systems.

Water saving will pursue two main objectives: shifting towards pressurized irrigation techniques and rehabilitating the already existing networks.

2. Private irrigation

Groundwater resources are usually extracted from individual wells, and sometimes from river basins, and the farmers support all costs. Therefore, 90% of these farmers use pressurized irrigation systems. A detailed study[5] has demonstrated that when farmers use private wells, 77.66 % of the area is irrigated by sprinkler, 11.58% by trickle and 10.75% by traditional techniques. Irrigation modules are excessive and many problems arise at the farm level.[6]

The uncontrolled rapid growth of private groundwater irrigation induces many problems affecting water quality and continuity. The excessive uptake of groundwater and the lack of artificial feeding lead to:

- seasonal and inter-annual deepening of the watershed level in the Bekaa region, inducing severe water scarcity in the wells in dry years;
- marine intrusion bringing about a progressive deterioration of the watershed water quality in the coastal plain.

Nowadays, there is not a law restricting the water amount withdrawn from the wells. Beside on-farm extension, legislation on underground water is highly needed.

III – Modernization measures at the government level

Water balance will reach its limits in 2020. The total water needs will grow by 83% compared with the present water needs.[7] Of course, these figures take into account the implementation of new irrigation systems and the strengthening of the existing water projects.

To overcome the problems related to water scarcity, in the late 1990s the Lebanese Government undertook a new water management policy based on:

- the rehabilitation of the already existing irrigation schemes;
- the reorganization of the water sector;
- the launching of the ten-year Master Plan for water storage in dams and mountain ponds;
- the implementation of new irrigation schemes using advanced pressurized distribution systems.

1. Institutional reform:

The law n. 221, of May 2000, reformed the water sector in Lebanon. Under the governance of the Ministry of Energy and Water (MEW), 22 water authorities were grouped in four regional authorities besides the existing Litani River Authority (LRA). As far as irrigation is concerned, the Litani River Authority controls the domain of the Litani river basin in the South Bekaa Valley, and the region of Southern Lebanon. All water authorities along with LRA are under the umbrella of the MEW.

Nowadays, LRA manages 34.1% of scheme irrigation in Lebanon and is responsible for 73.29% of the ongoing and proposed irrigation projects. The tasks subdivided between LRA and RWA are summarized in the following table.

Table2: Subdivision of irrigation projects between LRA and RWA by surface area (ha).

Designation	Existing Irrigation	Ongoing & Proposed irrigation projects	Total
Total Lebanese Schemes	65,600	82,000	147,600
LRA Schemes	22,370	60,100	82,470
LRA versus Lebanon (%)	34.1	73.29	55.87

The Ministry of Energy and Water is in charge of water policies whereas the Water Authorities are entrusted with the implementation of MEW master plan. The Regional Water Authorities (RWA) are responsible for integrated water management: domestic, irrigation and wastewater. RWA and LRA are involved in direct water management. On the other hand, the Ministry of Agriculture is responsible at farm level.

In accordance with the law, the MEW and the Ministry of Finance appoint a committee for the evaluation of the water authorities' procedures and work.

2. Application of an integrated water management plan:

Many studies, plans and actions have been undertaken so far. A short description of the achievements and of the future goals is given below.

A. Rehabilitation of existing schemes

Thanks to a loan from BIRD, approved in 1993, Lebanon could rehabilitate five medium-sized and ten small-sized schemes representing a total equipped area of 27,200 ha. The remaining areas, accounting for about 58% of the total, still need rehabilitating. These schemes are under the responsibility of RWA and LRA. The main objective of rehabilitation is to increase efficiency of the network and of water collection systems.

B. Water Storage Capacity improvement:

The Lebanese government prepared and approved a ten-year action plan for the construction of dams, reservoirs and mountain ponds[8] in 2003. The new works aim at adding 743 MCM/year to the existing storage capacity. MEW and LRA (according to its statutory mission) are in charge of this plan.

a] Water Resources Quality Protection:

Water control and monitoring are the responsibility of MEW and the Water Authorities. The main problems and the related actions for water quality protection can be summarized as follows:

- Wastewater Treatment:

The Lebanese government elaborated a master plan for second-level wastewater treatment. According to predictions, the wastewater treatment plants will serve 87.9% of the total Lebanese population and will keep operating until 2030[6]. This plan intends to prevent pollution of underground and surface water. At present, the Lebanese population is still connected to a sewage network or septic tanks. Raw sewerage is directly discharged into the environment, including rivers streams, dry riverbeds and underground water (through dry wells). Pollution prevents water from being used and can seriously affect the available water resources.

- Pollution from agriculture:

It is related to intensive agriculture. The main farming region concerned with this kind of pollution is the Bekaa Valley. Excessive use of fertilizers and pesticides is affecting water quality. The investigation results demonstrate that the nitrate level in groundwater is high whereas pesticides are below the detection limits.[9] Finding a solution to this problem is the responsibility of agricultural of the extension service.

- Solid waste:

In many regions, riverbeds, streams, dry riverbeds are frequently used as a landfill. This practice has two major effects: flooding by decreasing the flow in riverbeds and leaching problems. In many municipalities land filling can seriously damage the environment. The resulting liquid and gas emissions may pollute underground and surface water. To prevent this contamination, sewage water must be collected, controlled for quality and treated before discharge into watercourses.

- Sea-water intrusion:

Underground water use is not regulated in Lebanon. In coastal areas, the domestic water shortage brings about over-pumping from underground water. This entails the degradation of water quality due to seawater intrusion. As a result, coordinated action needs to be undertaken: a law should be issued to regulate water uptake from wells and groundwater abstraction should be limited and controlled by MEW.

- Industrial pollution:

Many factories discharge their wastewater in riverbeds or wastewater network without any treatment. To fight against industrial pollution, the Ministry of the Environment issued a law whose enforcement could help solving the problems induced so far.

b] Unconventional water Reuse[10]

Total possible collected wastewater for treatment in Lebanon is estimated to reach 213 MCM by 2015. All treatment plants are planned to work on secondary treatment. This treated water represents 10% of the water needs in Lebanon. The topographical, demographic and urban conditions and economic considerations have paved the way to the implementation of a master plan according to which most wastewater (55%) shall be collected in the coastal area; 36% of the treated wastewater can be used in agriculture. A third treatment is required in order to recover this percentage and use it for domestic purposes.

In 2006, LRA created its Water Quality Department and launched, jointly with Abdel Aal Association (an NGO), a water quality awareness campaign for local communities.

c] Improving on-farm irrigation

Special attention has been given to the enhancement of Water Economic Return at farm level: the goal is to optimize regulated deficit irrigation (RDI) practices. Some experiments and studies have been conducted or are still underway :

- in Lebaa center[11], a cooperative study was carried out by LRA and the Lebanese Agricultural Research Institute (LARI) on cucumber and tomato under greenhouse conditions. The technique applied was trickle irrigation. For two years, the results demonstrated that farmers could save up to 40% of the water used;
- LRA and LARI are partners in the EU research and dissemination project “Sustainable orchard irrigation for improving fruit quality and safety”, started in July 2006. The main objective is the regulated deficit irrigation for citrus in the coastal area and peach in the inland region.

In order to improve on-farm irrigation practices, emphasis should be laid on:

- extension services improvement. Up till now, RDI research results have not been disseminated and they will be hardly accepted by the farmers. Indeed, these results must be a pillar in extension activities;
- developing applied research on practical irrigation schedules and doses for different crops. Special attention on regulated deficit irrigation research is required;
- a water tariff policy can be adopted to encourage irrigation water saving by shifting to on-farm pressurized irrigation systems in the traditional scheme. A two-tier tariff could be applied, where a fixed share per hectare is related to maintenance and a variable share is determined by the water volume used. This tariff must and can be applied in pressurized irrigation schemes.

IV – System Modernization

According to data in the literature, at scheme level, overall efficiency, which is the result of storage, conveyance, network and on-farm efficiency, is between 40 and 45%[12]. At farm level, irrigation efficiency is on average 50% with traditional irrigation techniques, such as the basin and furrow systems, but it could reach 70%-90% when modern pressurized techniques are used.

The flexibility degree in water delivery systems is a crucial issue in any irrigation scheme[13]. The question remains about how flexible present and future schemes are with respect to water delivery in order to meet the farmers’ effective needs. “On-demand” water supply systems would respond fully to this concern, while rotational supply schemes are rigid and lack this flexibility[14]. In this case farmers have to adapt and make the best use of water when it is provided. Moreover, water user associations (WUA) are the essential link between the farmers and the water supply bodies. On-demand pressurised irrigation systems generally provide good flexibility. Rotational water supply systems are not really suitable for new irrigation technology, especially drip irrigation, unless individual on-farm reservoirs are constructed.

A significant improvement can be attained by shifting from the traditional gravity to the pressurized system by:

- converting open channel networks and distribution to pressurized pipes;
- using adapted on-field irrigation equipment;
- constructing all new irrigation projects as pressurized systems: the area which should be equipped amounts to 82,000 ha.

Table 3. Potential water saving by shifting to pressurized systems.

Description	Actual Efficiency	Potential Efficiency	Efficiency gain (Related to new pressurized System)	Percentage out of the total area
Actual Gravity System	0.45	0.6	0.35	26.52
Actual pressurized system	0.7	0.8	0.1	12.22
New pressurized System (gain obtained versus gravity)			0.2	61.26
Overall Efficiency Gain			0.23	

Considering the above changes and actions, a simple calculation can give the weighted average of efficiency gain for all irrigation systems in Lebanon. Table 3 reports the data and results of this calculation which demonstrate that a 0.23 efficiency gain can be reached by applying a pressurized irrigation system.

Two experiments, run by LRA and aimed at enhancing efficiency by the pressurized system, will be analyzed: preferential tariff and implementation of a pressurized irrigation project network.

One more interesting topic to discuss is the involvement of farmers in the implementation of a new irrigation project in Southern Lebanon.

1. Preferential tariff

Applied in Qasmieh Ras el Ain Scheme to encourage the use of on-farm pressurized equipment and yielding the following results:

- shifting from gravity to pressurized system over about 30% of the scheme surface (1000 ha out of 3400ha);
- partial saving but overuse due to the distribution system:
  - Saving on-farm irrigation:
  - Lack of efficiency at the distribution system level due to:
    - Lack of efficiency at the channel level;
    - Distribution system by “Tour d’eau”: the related outlet remains open for a long time exceeding the parcel needs.

Distribution needs to be adapted by creating an individual outlet at the parcel level.

2. Existing Pressurized irrigation network project:

A. South Bekaa irrigation project Phase I (2000ha) scheme

LRA carried out and still manages the South Bekaa irrigation project Phase I (2000ha) scheme. This scheme displays a wide range of irrigation conditions required for practical evaluation of water management options and their feasibility from both a technical and a socio-economic point of view.

a] Description:

The selected irrigation scheme is located within the South Bekaa Irrigation and Drainage Scheme (SBIDS), whose command area covers 23,500 ha, divided into three districts; the first one is located on the eastern side of the Litani River, also called the Left Bank (8700 ha), the second one is located on the western side of the Litani River, also called the Right Bank (9200 ha), and the third one is located in the northern area of the Litani River (5600 ha). The Qaraoun dam, with its average storage capacity of 220 MCM, is the main water source for irrigation in the project area. The project area lies between the two levels of the 900 m altitude curve of both the eastern and western side of the Litani River.

The scheme is located on the eastern side of the Litani River, or the Left Bank, with its 8700 ha command area; only 2000 ha are equipped with pressurized pipelines, allowing the use of modern irrigation systems such as sprinklers and trickles.

Channel “900” supplies irrigation water to the Left Bank and is located at a 900 m altitude. A main pumping station, consisting of 4 pumps, 1.5 m3/s discharge each, is located at the foot of the Qaraoun dam that feeds the channel with 30 million m3 annually. Moreover, four local wells feed the “Canal 900”, supplying 12 million ^{m3} per year whereas 2 million ^{m3} come from the Chamsine spring in the northern area of SBIDS.

Water is stored in 3 reservoirs, one per each district (Quaraoun I, Quaraoun II and Jebjennin). The reservoirs supply the district distribution network and the branched irrigation networks. At the end of the reservoir, there is a control unit equipped with a gate, and a recording Venturi meter. In this scheme, water is delivered to farmers on demand, by the hydrants, which are equipped with outlets containing pressure regulators, volume and flow meters. Pressure is set at 3.5-5kg/ cm^2 and discharge is a function of the area of the land parcels equipped with those outlets. The irrigation parcel equipment uses new pressurized techniques.

b] Problems observed

The studies and on-the-spot checks conducted in this scheme highlighted the following problems:

- Vandalism of the outlet:
  - breaking of flow meters;
  - removal of flow and pressure regulators.
- Outlet misuse:
  - poor connection between the outlet and the parcels’ irrigation system leading to severe leakage and pressure loss;
  - excessive number of sprinklers on the laterals and on the hydrant outlet;
  - connection of two outlets in order to get a higher flow on a lateral.
- Bad use of equipment: inadequate design of the irrigation system at the parcel level:
  - different types of sprinklers or drippers on the same lateral;
  - inadequate fittings.

- Inadequate irrigation schedule:
  - lack of knowledge of the irrigation module;
  - wrong ideas about irrigation practices (leaves burnt, no irrigation with temperature variation between water and soil etc…).Farmers tend to irrigate at night thus inducing a poor performance of the network, which irrigates only 30% of the area that it was designed to cover;
  - lack of incentives to save water.
- Some types of irrigation equipment, commonly used on the farm and available on the market, are not reliable:
- Lack of a shared policy for water allocation;
- Lack of cooperation between farmers.

B. Southern Lebanon scheme-First phase - Pilot sector

a] Description:

The Litani River Authority has started to evaluate the Hydro-agricultural Development Project of Southern Lebanon (35000 ha), in cooperation with UNDP and FAO, since the seventies. The first phase of this project concerned the Canal 800 (15000ha). In 1975 the Lebanese war interrupted the evaluation of details and implementation of the Canal 800 project.

In 2002, after a reviewed and updated pre-design and feasibility study, the Lebanese Government decided to start implementing the project including two main components: Irrigation and Domestic Water supply. The irrigation project is focussed now on on-demand and pressurized water irrigation with full telemetry SCADA control system.

In order to solve the different problems that can be encountered during the design and implementation phase, a pilot sector (Marjeyoun North) is selected.

The Gross Irrigated area of Marjeyoun North equals 745 ha and the Net Irrigated Area amounts to 470 ha.

The Gross irrigated area is determined considering the 1/20,000 land classification. The Net irrigated area is assumed based on a comparative study between 1/20,000 and 1/2,000 scale land classification on ability to irrigate.

The cadastral district of Marjeyoun North scheme comprises nine villages, namely Dibbine, Marjayoun, Khiyam, Boueyda, Qlaiaa, Borj El-Moulouk, Kfar Kila, Deir Mimas and Houra.

b] Problems to be solved[15]

- Cadastral maps: In the region of Southern Lebanon, there is an area which does not have any cadastral delineation, whereas some other areas have a temporary delineation and a few a final delineation.
- Detailed land classification for ability to irrigate: Irrigation water resources for Southern Lebanon are very limited. The decree n.14522 sets out water allocation by geographic area where only 17% of this area will be irrigated. Based on economic criteria, a land classification for ability to irrigate is made on a 1/20.000 scale. Taking into account the results of this study, combining technical and economic criteria, irrigation schemes are delineated for technical, economic and equity (between farmers) reasons. Two studies (FAO1972, LRA Dar el Handasa Chaer, 2002) show the differences between the two scales (Variable between 2 and 86%), with an average of 30%. For this reason a detailed classification is needed to determine the parcels that shall be irrigated inside the schemes.

- Land reclamation designs and works: the region of Southern Lebanon is hilly and requires land reclamation works on a scheme basis. Under the current legislation, these works must be done at the owner's request or at least upon his agreement. Two solutions can be adopted: either amending the legislation in force or involving the local civil society in facilitating the process. Setting up associations like the Water User Associations (WUAs) will prove to be very helpful.
- Network design and expropriation: the first step in distribution network is the Hydrant Implementation Plan (HIP). This plan must be drawn up in full collaboration with farmers. Parcel tenure in Southern Lebanon is very limited (on average less than 0.3 ha). Therefore, the project designer must face the following problems:
  - the high density of the tertiary network will increase the expropriation cost;
  - the expropriation for tertiary network at parcel level will decrease the irrigated area at farm level due to the high network density and the parcel size;
  - access to the hydrant: in many cases, due to economic and technical reasons, the designer has to assign one outlet to more than one user. The right of access to the outlet must be assured to the neighbours of the parcel where the hydrant is established.

The establishment of a water user association can help solving these problems because the owners concerned will be more willing to give access to:

- the irrigation scheme manager (at present the LRA, in the future the WUA) in order to facilitate the maintenance;
- the neighbour's parcels to operate their outlets.

Nowadays, the WUA has to play a decisive role during the preparation and verification of the "Hydrants plans" in order to allow each user to have a proper access to his hydrant.

The traditional concept of on-demand irrigation has always posed some problems in South Bekaa irrigation project (first phase, Scheme 2000 ha). These problems concern the misuse of the network by the farmers due to:

- the use of overdose water by farmers.
- under-use of the outlets allocated by parcel over time: farmers provide one water application per day instead of two or more.

Pressure on water demand is very high during the timing adopted by farmers: In a 24 hour-use per day, farmers irrigate 12 hours from 6pm to 6 am. All these traditional concepts limit the network capacity. More or less, fifty percent of the irrigated area can be served. The network management, extension excluded, does not have allow any intervention to re-establish the full network capacity.

The pre-programming hydrants (e.g. Aquacard) are a new generation of hydrants which can solve management problems related to the traditional hydrants, including water shortage in dry years. They can also solve the problems concerning the fees which will be collected by a pre-paid card (the same card is used for programming irrigation schedule and quantities).

V – Measures to be adopted

1. Reinforcement of Extension services

- Awareness of the existing irrigation facilities: training courses, data sheets, laboratory analyses, technical assistance; meteorological information;

- Ongoing production of new technical materials to solve future problems;
- Farmers’ capacity building:
- Technical assistance to farmers:
    - o Establishment of a laboratory to check the performance of the different irrigation equipment brands available on the market;
    - o Assistance in field equipment design, acquisition and use;
    - o Application of scheduled irrigation;
    - o On-farm technical assistance.

2. Establishment of Water User Associations

– Issue and enforce a new legislation ensuring proper performance and sustainability of WUAs: at present, there is not a legislation regulating WUAs in Lebanon;

– Actual implementation of WUAs: awareness campaigns, monitoring by social experts;

– Capacity building of WUA members at technical and administrative levels.

Integrated water resources management is a high-profile issue as it involves national governance and high-value global, socio-cultural, environmental and economic resources. The prevailing system of uncoordinated water resources management cannot sustain the ever-increasing water needs in the different expanding sectors. Therefore, it is necessary to work out a strategy to integrate the needs of the various sectors and the available water resources in order to attain both economic and environmental sustainability.

A participatory approach is needed to allow the stakeholders facing several key issues. Stakeholders capacity building in the field of water natural resources management policies, water rights and enforcement of laws would be an important input for a participatory integrated water resources management where roles and responsibilities have to be specified.

A. Role of WUAs

In the present Lebanese legislation, two forms of associations are recognized: the Agricultural Cooperative and the “Hydraulic Syndicate Association” (Association Syndicale Hydraulique). The former has a different mandate from the Water User Association. The latter was established by decree n. 320 in 1926. The principal objective of this association is to provide protection from flood damages; irrigation is just mentioned without any detail.

WUAs are indispensable for a sound management and implementation of irrigation projects.

In addition to playing a crucial role during the irrigation project assessment and implementation phase (for instance, for the Southern Lebanon scheme), they are very important in order to:

- provide the missing cadastral information on the scheme;
- assist in drawing up a detailed land classification for ability to irrigate to ensure the fair allocation of water resources, by properly selecting the parcels which shall be irrigated;
- participate in the land reclamation process and facilitate the works implementation;
- help getting the right of access from the parcel’s owners for operation and maintenance of the hydrant network.

a] Short and medium term role of WUAs in the existing pressurized schemes

- Ensure the management, operation and maintenance of the tertiary network.
- In the short run:
    - o Ensure the functioning of the tertiary network according to the rules;
    - o Protect the tertiary network from vandalism;
- Participate in the elaboration of modernization plans;
- Replace expropriation by « right of way » for the new secondary and tertiary networks projects;
- Adopt drip irrigation technique, more suitable with respect to the crops grown and the scarce water resources.

b] Long-term role of the WUA

- Take over the management, operation and maintenance of the whole scheme.
- This objective will be achieved by the establishment of a consortium of WUA's after having acquired the experience needed.

Role of WUAs in private irrigation

In the absence of continuous control, the legislation alone will never be able to solve the problems related to the excessive groundwater uptake. The role of WUAs in private irrigation would mainly be to provide an extension service aimed at water saving, to control the water uptake from the wells and the collective exploitation of the wells. The exploitation sustainability could explain the collective interest in joining regional groundwater user associations.

3. Establishment of a river basin agency responsible for water management and the main structures in the river basin

The river basin management entails water resources management at an integrated catchment level (including both surface and underground resources). Sustainable management of water resources is an important goal that must be pursued at national and international level in an effort to face water shortages, inequity, pollution and many other water problems. One of the introduced key innovative elements results from recognition that upstream/ downstream effects require management based on a basin approach. Accordingly, many countries are introducing new institutional patterns for water resources management, including organizations entrusted with water resources management at the basin level.

Creating new structures, or modifying the old ones, to meet the goals of integrated water resources management, is not an easy task considering that the establishment of new river basin organizations will require a great effort in many countries. As a result, it would be advisable to review the status of the existing water authorities in order to promote river basins as management entities.

VI – Conclusion

Much is still to be done to achieve a rational use of water resources in Lebanon. Water infrastructure needs being upgraded to meet the modern irrigation system requirements. Integrated participatory irrigation management must be fostered through the establishment of WUAs in each irrigation districts. The water pricing policy is to be reviewed in order to encourage water saving at farm level. Farmers' capacity building and extension services are highly needed to gain knowledge and apply crop water modules at farm level. Groundwater uptake should be monitored, socio-economic awareness campaigns should be conducted in order to make farmers assume a new attitude towards water use efficiency at farm level etc.

Moving towards an IWRM approach at national level means changing the enabling environment, the institutional roles, and the management tools. This includes a change in (water) governance, that is to say in the political, social, economic and administrative systems to develop and manage water resources and provide water services, at different levels in the society.[16] The creation of the High Council for water is a major step towards coordinating the decision makers' activities, sharing knowledge and exchanging experience. The role of the Council will be decisive for updating and modifying the Water National Master Plan.

"Principled pragmatism" stresses the importance of economic principles, such as ensuring that users take the financial and resource costs into account when using water, and the need to tailor solutions to specific, widely varying natural, cultural, economic and political circumstances.[17]

The absence of Water User Associations and extension in water management, bad maintenance and water pollution are the major causes of water losses. Legislation, law reinforcement, research and establishment of education centres, tariff policy, stakeholders' capacity building are the main factors for water management enhancement.

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Ecohydrology and groundwater resources management under global change: A pilot study in the pre-Saharan basins of southern Morocco

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Abstract. The Tafilalt Oasis, which is part of the UNESCO Biosphere Reserve, is located in the pre-Saharan region of Morocco. Due to the arid conditions of this area, the local population, infrastructure and livestock farming are concentrated around the rivers and the oases. The ephemeral river flows force the population to use groundwater (GW) in order to meet water needs. Consequently, GW proves to be of utmost importance for water management. The Driving force-Pressure-State-Impact-Response (DPSIR) framework was applied to ensure a proper relationship between policies, economic issues and the most important GW development and management issues. The aim of this paper is to review the Water Evaluation and Planning (WEAP) model and its application to the Ziz basin. This model allows to simulate and analyse various water allocation scenarios and, above all, a number of scenarios concerning the users' behaviour. Water demand management is one of the options discussed in more detail. There is ample evidence of degradation, pollution and overexploitation of water resources, resulting from inappropriate groundwater management systems based on the administrative division. But it is possible to achieve sustainability in groundwater use by integrating the hydrological and ecological approaches. The ecohydrological method, based on profound understanding of the complexity of the ecosystem processes at different levels, provides new opportunities for groundwater resources protection compared with traditional, exclusively technologically-oriented methods

Keywords. Ecohydrology – Oasis – Sahara – Climate change – Adaptation – Management.

Éco hydrologie et gestion des ressources en eau souterraines dans le cadre d'un changement global : une étude pilote dans les bassins hydrographiques présahariens du sud du Maroc

Résumé. *Les oasis de Tafilalet, qui font partie des Réserves de Biosphère de l'UNESCO, se trouvent dans la région présaharienne du Maroc. Vu les conditions arides de cette région, la population locale, les infrastructures et l'élevage sont concentrés autour des rivières et des oasis. Les flux éphémères des rivières obligent la population à exploiter les eaux de nappe afin de satisfaire leurs besoins. Par conséquent, les nappes jouent un rôle primordial pour la gestion de l'eau. Le modèle DPSIR (Driving force-Pressure-State-Impact-Response) a été appliqué pour établir la relation correcte entre les politiques, les problématiques économiques et celles relatives au développement et à la gestion des eaux de nappes. L'objectif de ce travail est de passer en revue le modèle d'Evaluation et Planification de l'Eau (WEAP) est ses applications au bassin de Ziz. Ce modèle permet de simuler et d'analyser les différents scénarios de distribution des ressources en eau par rapport au comportement des usagers. La gestion de la demande d'eau est l'une des options illustrées en détail. De nombreux facteurs contribuent à confirmer que la dégradation, la pollution et la surexploitation des ressources en eaux représentent un problème important, causé par une gestion inappropriée de la nappe basée sur la division administrative. Cependant, il est possible d'assurer une utilisation durable des eaux de nappe, en intégrant les approches hydrologiques et écologiques. La méthode écohydrologique, qui évalue d'une manière approfondie les processus complexes de l'écosystème à différents niveaux, offre de nouvelles opportunités pour la préservation des eaux souterraines par rapport aux méthodes traditionnelles, exclusivement orientées aux applications technologiques.*

Mots-clés. *Ecohydrologie – Oasis – Sahara – Changement climatique – Adaptation – Gestion.*

I – Introduction

In most oases the Moroccan groundwater systems are submitted to drastic changes due to both global scale stresses and the cumulative effects of local and regional scale impacts. GW adaptive capacity and resilience are severely affected by the high drivers' magnitude. The Tafilalt Oasis is located in the pre-Saharan region of southereastern Morocco (Fig 1), covering an area of about 1,370 km^2, Ramsar site no. 1483, which is part of the UNESCO Biosphere Reserve, a site of Biological and Ecological Interest. This site comprises a series of oases and the reservoir of one of the oldest dams in Morocco (Hassan Dakhil). Some important atmospheric events occur in the region, such as sand invasion. The environment degradation, caused by deforestation and over-harvesting, has become a matter of great concern, because floods and drought are increasingly reported. Irrigation in the oases mostly depends on a dense and intricate network of canals distributed across the oasis. In the northern part of the Tafilalt oasis, since the late-14th century, water for irrigation canals has also been supplied by khettara (subterranean channels draining perched water table). Starting from the early 1970s, the remaining active khettaras have showed a reduced flow, and over the next two decades many more khettaras have dried up and have been abandoned. The reduction and abandonment of khettaras can be attributed to the Hassan Adakhil dam and its new reservoir upstream of Tafilalt oasis. Due to the dam's control of downstream water release, many river channels downstream only have water during certain times of the year, a phenomenon which is worsened by excessive water abstraction for agriculture and human consumption and drought, that has become more frequent during the past two decades. Farmers are adopting too slowly proper techniques and equipment to save irrigation water. The low-cost boring technology and the cheaper imported and locally produced pumps have enhanced GW mining in Tafilalt. Pumps have had a decisive role in green revolution and poverty alleviation but the present development of uncontrolled GW markets is posing a threat to the sustainable use of GW reserves.

The downstream reservoir, Hassan Dakhil, located near Errachidia, the regional capital city, strongly depends on water input from the mountain catchments. Over the past few years, there have been large fluctuations of water input into the reservoir and often, its minimum capacity is not reached. Apart from being negatively affected by several years of water shortage, the Hassan Dakhil dam has also been subject to substantial infill by sediments and consequently, to a rapid capacity loss.

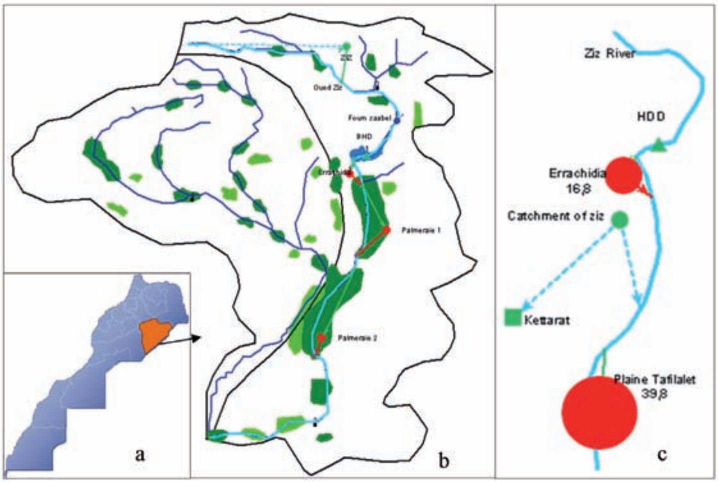

Figure 1. a) Ziz basin in Morocco b) schematic representation of the Ziz basin for the WEAP analysis c) scheme detail.

The climate is continental and arid. Rainfall ranges from 70 mm in the extreme South, at Erfoud, to 290 mm in the extreme North, at Imichil. These climatic conditions inhibit rainfed agriculture and make the use of irrigation necessary .

This paper outlines the rationale for a new approach to integrated water resources management from the local farm scale to the watershed and basin scale, which incorporates the proper balance of green and blue water flows in agriculture and freshwater to sustain the ecosystems and the downstream water use for human consumption.

II – Methods

The Driving force-Pressure-State-Impact-Response (DPSIR) framework was applied to ensure the proper relationship between policies and economic issues and the most important water development and management issues*.* Land-use scenarios for qualitative and quantitative analysis were designed and formulated in detail to face specific problems. The following aspects were taken into account: climate change, population dynamics, socio-cultural change, institutional change, economic development, and technological innovation.

The Upper Ziz hydrology was represented by the WEAP (Water Evaluation and Planning System) model (SEI, 2005). The model was adapted, calibrated and validated for the Ziz Basin in the framework of MIOS (Modèle Intégré des Oasis du Sud) and allowed the analysis of different hydrological parameters in different climate and policy scenarios. With WEAP, the first Current Account of the water system under study was created. Then, based on a number of demographic, hydrological, and technological trends, a “reference” scenario projection was elaborated, referred to as the Reference Scenario. Furthermore, one or more policy scenarios were developed with alternative assumptions about future developments.

Only the major water users were described along with the activity level, the annual water demand (net values after loss account), the monthly variation as well as the return flow.

Growth rates between 1993 and 2030 were estimated as follows: domestic 1.12-1.2%, livestock 1.2%, and irrigation 1.2%. (IRATE, 2006).

The work was based on detailed information including ecological, meteorological, hydrological, hydroeological, sedimentological, water management, GIS and remote sensing, vegetation, social, cultural and economic data (Ait Boughrous, 2007; Cappy *et a*l. 2004; De Jong *et al*., 2004; Ilahiane, 2004; Knippertz *et al*., 2003a,b ; Messouli *et al*., in press; Zeroual, 1995).

III – Results and discussion

In Moroccan oases many driving forces (Table 1) are leading to irreversible changes in the subsurface environment. The trend is the subsurface being increasingly used for different functions. In particular, in densely populated areas, along the Ziz and Draa Rivers, these functions may be in conflict with each other. These functions go beyond water demand for different proposes and also need physical space in the subsurface. These multiple uses of the subsurface according to the functions will lead to extend more the physical planning policies to the subsurface.

The reference scenario is the basic scenario that includes the actual data to gain knowledge about the period under study. The aim of a reference scenario is to help the planner and the water resources manager understand what can likely occur if the current trend continues, and the current status of affairs. Reference scenarios can also be useful to identify the weaknesses of knowledge and if more information needs to be collected. They can help design contingency plans where risk and uncertainty level is high.

Table 1. The major global threats to the surface/ groundwater systems in the Oases and the related issues (modified from Meybeck, 1998 and Meybeck, 2003). The scope and intersections of the several forcing and system impacts require an interdisciplinary and systematic research approach. A: human health, B: water cycle, C: water quality, D: carbon balance, E: fluvial morphology, F: aquatic biodiversity. Only the major links between issues and impacts are listed

Environmental state change	**Major impacts**	**Global issues**					
		A	B	C	D	E	F
climate change	Change in flow regime (recharge, runoff volume and timing)		■	■		■	
	Change in wetland distribution	■	■	■	■		■
	Change in erosion and sedimentation				■	■	
	Chang in chemical watering				■		
	Accelerated salinisation through evaporation	■	■				■
	Development in non-perennial rivers and desertification		■	■	■	■	■
Water management (including dams, diversions, khettaras and channelization)	Nutrient and carbon retention				■		
	Particulate retention				■	■	
	Change in flow regime (runoff volume and timing)		■	■		■	
	Stream flow variability and extremes		■				
	Loss of connectivity (L, V and H) *						■
Land-use change	Wetland filling or draining		■	■	■		■
	Change in sediment transport				■	■	
	Change in vegetation cover		■				
	Alteration of first order streams					■	■
	Nitrate and phosphate increase	■		■	■		
	Pesticide increase	■		■			
Irrigation & water transfer	Change in flow regime (runoff volume and timing)		■	■			■
	Salinisation through evaporation		■	■			
Release of domestic wastes (latrines, manners)	Heavy metal increase	■		■			
	Eutrophication	■		■	■		■
	Development of water diseases	■					
	Organic pollution	■		■			■
	Persistent organic pollutants	■	■	■			

(L, V and H)* = Lateral, Vertical and Horizontal

Due to evapotranspiration, water in the catchments will not totally run off to the rivers. WEAP uses the rainfall runoff method (FAO) to calculate the ratio between the crop demand and the runoff to the river. The Rainfall Runoff Method applies the crop coefficients to calculate the potential evapotranspiration in the catchment, then it determines any irrigation demand that may be recorded to face the amount of evapotranspiration requirement that cannot be met by rainfall.

The remaining rainfall not consumed by evapotranspiration is simulated as runoff to a river, or it can be proportioned considering the runoff to a river and the flow to groundwater via catchment links (SEI, 2005a).

Figure 2 shows the inflows and outflows of the main reservoir in Ziz basin. The graph is a balance between inflow and outflow. This graph is very useful to understand the operation of the reservoir throughout the year. The outflow from the reservoir is recorded in the summer time, when there is no rainfall and the “lachers” are necessary. The “lachers” bring about the storage volume decrease in the reservoir. Approximately 25% of the reservoir volume is lost by evaporation. At present, some problems of evaporation estimation and modelling are still unsolved and as a result, measures aimed at reducing evaporation from the lake reservoir surface are under discussion. The reservoir maximum capacity is used yearly, but with declining refill levels no water storage is possible on an annual basis. The combined effects of water planning for the lachers and of drier conditions compared with the annual average have resulted in a large drop in average water allocation for the irrigated date palm groves since the 1980s. During very dry years the lachers are not used for crop irrigation and are instead exploited to replenish GW levels.

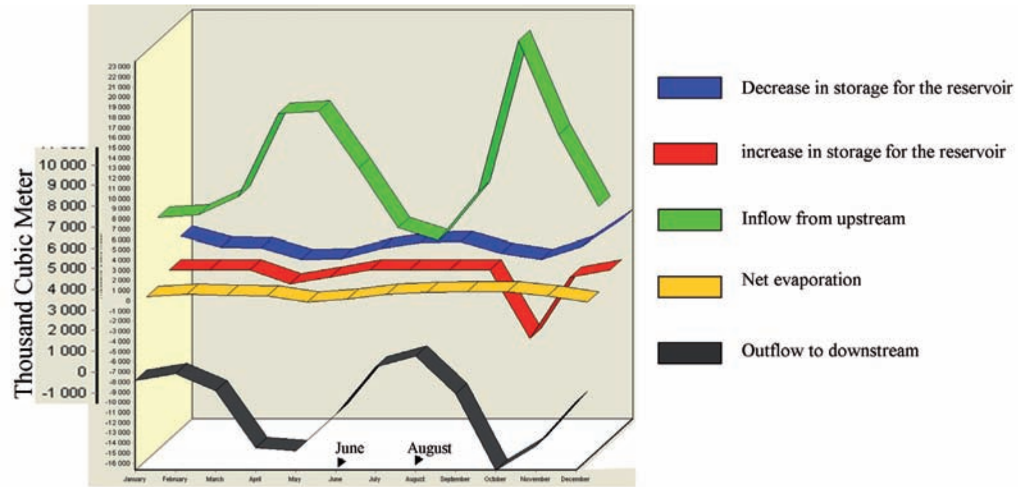

Figure 2. Monthly Ziz inflows and outflows (average 1976-2007).

1. Soil degradation and colmation

Water-induced soil erosion is a severe problem in the Ziz Basin region as demonstrated by the analysis of sedimentation in the reservoir Hassan Dakhil, located in the middle of the catchment. If the rapid dam infill due to high sediment transport into the rivers continues at the present rate, the dam will no longer be fully operational for irrigation by the year 2030. Even now, the dam capacity is insufficient to meet the needs of the downstream consumers during drought and in water-shortage conditions. Once the dam reaches a critical silted level (at about half its capacity), it will loose its regulatory flow. Irrigation will increasingly be subject to irregular, flood-dominated flows and will rely more heavily on groundwater resources. As a result, evaporation will show a decrease in the climate scenarios (figure 3).

In the future, the extensive spread of the oasis area at the outlet of the mountain areas must be controlled, since extensive water withdrawal in these higher regions can strongly affect the amount of water left for irrigation from the dam.

Increase in sediment colmation and in clogging intensity is currently observed, related to human activities. This may alter the hydrological and biological exchange through the hyporheic zone and, more specifically, modify the ability of the hyporheic interstice to provide a refugial area to benthic invertebrates. Moreover, the aquifer recharge can be interrupted (Messouli *et al*. in press). Xerophytes are widely exploited as a source of domestic energy near the grouped or scattered houses, thus contributing to the expansion of desertification. Livestock farming is dominated by goats and sheep which have increased along with the population. The resulting increase in grazing pressure has caused a decrease in the vegetation density and some changes have occurred in the vegetation diversity in both the lowlands and the highlands.

In general, groundwater storage declines across all the scenarios (not illustrated), except for downstream of the dam where the recharge will increase following the rapid dam infill. However, the decline rate is variable. As expected, for Water in the Environment scenario, the imposed restrictions for groundwater withdrawal limit the storage decline in the 2025 scenario. The effects of land use change and climate change on storage are also clearcut. More groundwater is extracted under the combined land use and climate change scenario because of increased evaporative demand for agriculture. Furthermore, under the Water for Food scenario, the current withdrawal rates are not sustainable. These findings can be generalized across the individual groundwater sub-basins, although the depletion severity varies widely.

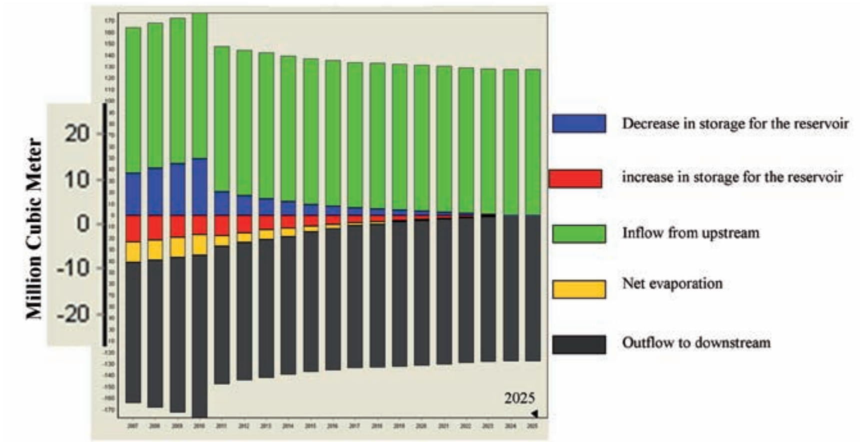

Figure 3. Yearly inflows and outflows simulated with WEAP for the 2025 scenarios in the Ziz basin.

The simulation results shown in figure 4 demonstrate that the average annual unmet demand will dramatically increase up to 70% and 90% of the total annual demand, respectively for January and July. For Errachidia, which lies in the middle of the basin, the simulation with WEAP suggests that the requirements for July will be hardly met in normal years. This is probably due to their position in the basin, and consequently, investigation should be furthered. On the other hand, in other locations, limited efforts appear to be sufficient to meet the local requirements.

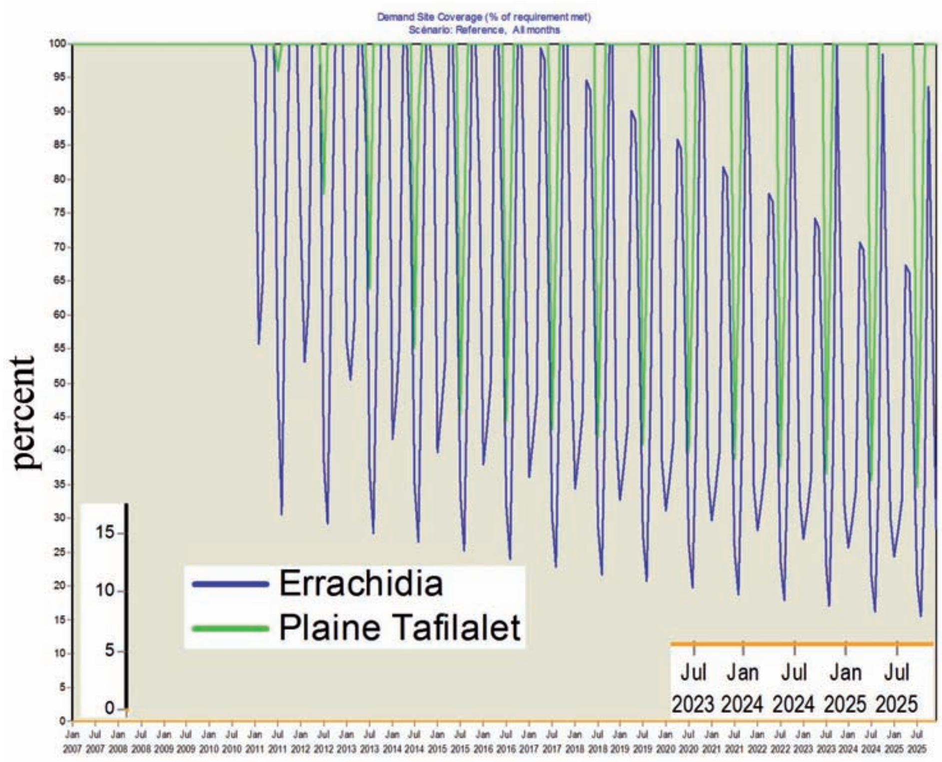

Figure 4. January and July water demand coverage (%) for each year simulated with WEAP for the 2025 scenarios in the Ziz basin.

It has been underlined that many users have developed their own strategies to cope with water shortage: for instance, using boreholes or developing their own storage systems (Matfia). These "shortages" sometimes represent half of the demand. But in general, they are quite limited (e.g. 20% in the case of irrigation schemes). Therefore it is necessary to accurately validate these results through further field surveys in order to ascertain the possible effects of data uncertainty and the extent to which water-users adopt alternative strategies, applying ecohydrology

Ecohydrology is more than just hydrology and ecology combined. It is fully functional only if science, engineering and construction, public administration and political decision assist each other in an integrated scheme and on a common scale. The Biosphere Reserve "Tafilalt Oasis", in southern Morocco, depends on all the four aspects to be sustained.

The results of the first phase of the work implementation show the potential for the application of ecohydrological and phytotechnological measures in the Ziz Basin, which have raised the interest of local and regional authorities. The integrated approach to Ziz catchment and river-reservoir management has to address several aspects. Hydropower generation requires stabilisation of the hydrological cycle in the catchment by setting spatial planning and land-use regulations. Improving water quality requires several parallel actions, including wastewater technology for sewage treatment and ecohydrological methods. Based on ecohydrology, a simplified model of sustainable groundwater management can be developed (figure 5).

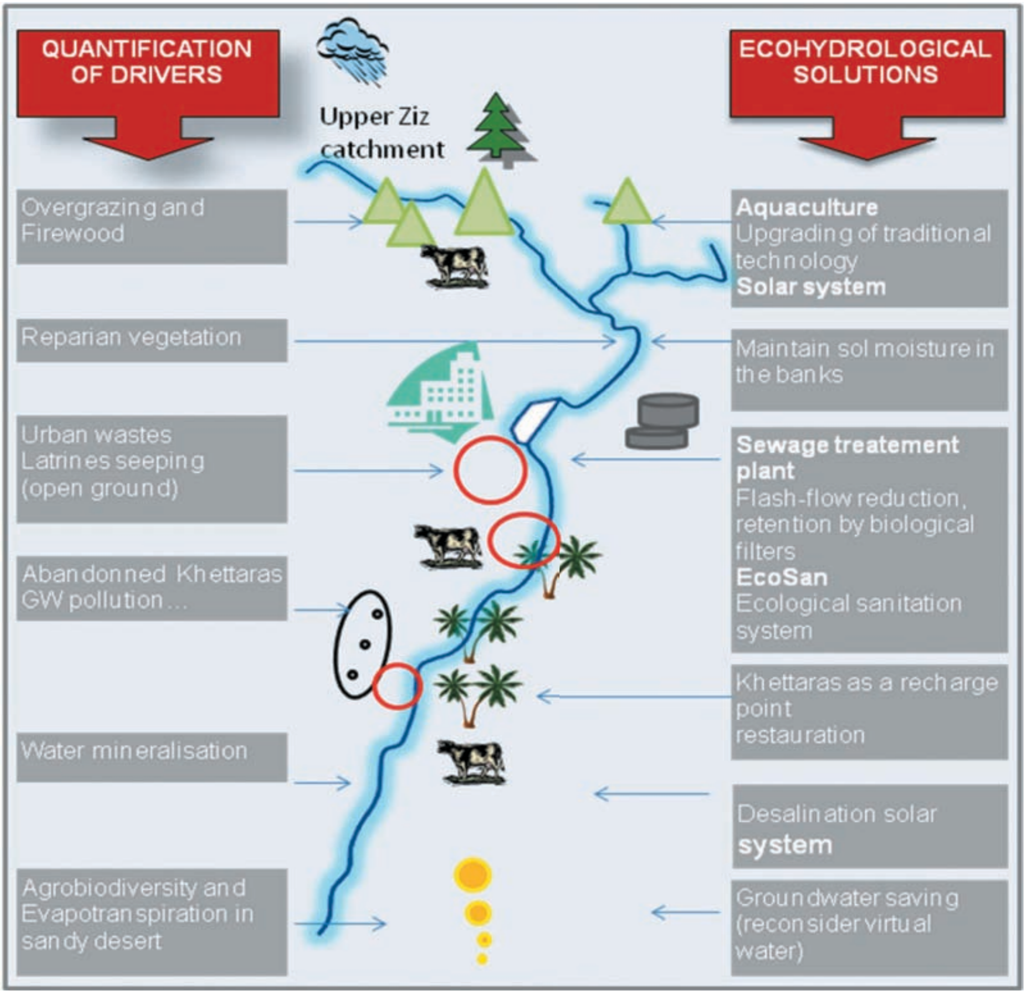

Figure 5. Application of ecohydrology: ranked impacts and adaptation.

The integrated approach to catchment and river-reservoir management has to address several aspects. Hydropower generation requires stabilisation of the hydrological cycle in the catchment by setting spatial planning and land-use regulations. Improving water quality requires several parallel actions, including wastewater technology for sewage treatment and ecohydrological methods. Hydraulic modelling will enhance sedimentation in controlled areas at the river mouth. The removal of sediments, which can be used as fertilizers by the local farmers, will reduce internal nutrient loading. Special attention shall be given to increasing environmental awareness in local communities. This will entail the enhancement of traditional aquaculture technologies, the reduction of environmental degradation (e.g., ecotone vegetation zone degradation,) and new economic opportunities (e.g., new farming opportunities).

IV – Conclusion

This study represents a first attempt at applying and testing the WEAP model as a means to address water allocation issues in a water-stressed river basin in Moroccan oases.

Groundwater will continue to be used intensively and the spread of irrigated agriculture will likely develop new groundwater sources, particularly as the markets for agricultural produce change. This process will be accompanied by land exclusion from irrigated production caused by physical depletion, migration of low-quality water, economic depletion (where pumping costs become excessive), waterlogging and salinisation, and groundwater use outside agriculture. The ecological impact on some ecosystems seems strong and probably irreversible. As a result, it is appropriate to be very cautious when simulating the hydrological impacts of CC or when analyzing runoff trends. Land-use change may have serious effects on hydrological processes; so far they have been more significant than any perceived or predicted CC impacts. It is necessary to take them into account explicitly by using, for instance, an appropriate hydrological model. In any case, CC impacts have to be separated from land-use impacts. The on-going PhD study (by Ben Salem) is improving the scenarios developed and the weaknesses of the current methodology. Therefore the following results may be envisaged: a) a better-performing simulation of the dam operating rules and of the restriction impact during drought, b) the assessment of the social and economic consequences of the different scenarios, c) the evaluation of the impact of further groundwater resources (i.e. conventional aquifers and dewatering of abandoned khettaras) development and use, and d) the evaluation of the possible impact of climate change.

Acknowledgements

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Fifth part

Tools for water quality-quantity monitoring and modeling: telemetry, satellite image processing for management of water resources

Technical perspectives of irrigation efficiency improvement in the oasis systems - cases of southern Tunisia

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Abstract. The irrigated area in Tunisia covers around 400,000 ha (8% of the total suitable agricultural lands). Under periodical water shortage conditions an expertise in water management was acquired. Several research works, focused on the main aspects of irrigation, allowed a real advance in promoting water use efficiency. However, the situation is still rather precarious in the southern part of the country. Oases heavily depend on the availability of underground water resources. Due to water resources scarcity and deficit, the irrigation efficiency in these regions is a key element for their development. Since the PDES (Water Master Plan of the South) in 1979, the irrigation scheme has been subject to several works, to cope with the oasis expansion. The rehabilitation works aimed to overcome water losses within the distribution network. The most works were those undertaken within the framework of *APIOS* project (Project of irrigated area improvement in Southern Tunisia oases). Indeed, the concerned area concerned covers 23000 ha in the provinces of Gabes, Gafsa, Kebilli and Tozeur. Since 1996, the rehabilitation works, still in progress, have been already completed in 90 out of 153 (58,82%) initially-scheduled oases. Nevertheless, a continuous decrease in fossil underground water resources and their quality deterioration under intensive pumping threaten the weak ecological equilibrium of those regions. On the other hand, surface irrigation remains the main irrigation method widely used within parcels. Research review showed that farmers are still practicing over-irrigation, high amounts of water are applied and lost over the root zone, also through earth ditches. Such behaviours hamper the rational water use. Also, risks of shallow water table rise and soil salinization become permanent. Under such conditions of water management, the sustainability of these ecosystems is definitely compromised. In this regard, the improvement of water distribution efficiency has to be followed by a complementary research work, aiming to enhance irrigation efficiency within farmer's parcels. The introduction of different improved surface irrigation methods should be implemented. Their adaptation to irrigation technical conditions that prevail within the oasis (water quality, water flows and available charge) has to be validated. This couldn't be reliable without further involvement of farmers and their commitment to modernize irrigation practices but they are still reluctant despite the government subsidies and encouragements for water-saving equipments within parcels.

Keywords. Efficiency – Oasis – Irrigation – Improvement – Sustainability –Tunisia.

Perspectives techniques de l'amélioration de l'efficience de l'irrigation dans les systèmes oasiens – cas du Sud de la Tunisie

Résumé. *En Tunisie, la surface irriguée couvre environ 400.000 ha (8% de la surface agricole utile). Dans un contexte de pénurie d'eau périodique, une expérience significative a été acquise en matière de gestion de l'eau. De nombreuses recherches, portant sur les principaux aspects de l'irrigation, ont permis de faire des pas en avant dans la promotion de l'efficience d'utilisation de l'eau. Toutefois, la situation reste encore assez précaire dans le sud du pays. Les oasis dépendent considérablement de la disponibilité de ressources en eau souterraine. Vu l'insuffisance des ressources en eau et le déficit hydrique, l'efficience de l'irrigation dans ces régions représente un élément fondamental pour leur développement. Depuis le lancement du PDES (Plan directeur de l'eau du Sud) en 1979, plusieurs travaux ont été entrepris dans le périmètre irrigué pour faire face à l'expansion des oasis. Les travaux de réhabilitation ont eu pour objectif la réduction des pertes d'eau sur le réseau de distribution. La plupart des travaux ont été réalisés dans le cadre du projet APIOS (Amélioration de Périmètres Irrigués dans les oasis du Sud tunisien). La zone intéressée couvre 23.000 ha dans les provinces de Gabes, Gafsa, Kebilli et Tozeur. A partir de 1996, les travaux de réhabilitation, encore en cours, ont déjà été achevés dans 90 des 153 (58,82%) oasis visées initialement. Cependant, une réduction continue des ressources en eau souterraine fossile et la détérioration de la qualité à cause des pompages intensifs constituent une menace pour l'équilibre écologique fragile de ces régions. Par ailleurs, l'irrigation de surface demeure la principale méthode d'irrigation, largement répandue dans les parcelles. Les* *résultats de ces recherches ont montré que les exploitants pratiquent encore une irrigation excédentaire et que de grandes quantités d'eau sont apportées et perdues dans la rhizosphère, aussi à travers les fossés. Tout cela ne fait qu'entraver l'utilisation raisonnée de l'eau. Egalement, la remontée de la nappe superficielle et la salinisation du sol deviennent un risque permanent. Dans ces conditions de gestion de l'eau, la durabilité de ces écosystèmes est compromise. Parallèlement, l'amélioration de l'efficience de la distribution de l'eau doit être soutenue par une recherché visant à accroitre l'efficience de l'irrigation à l'échelle de la parcelle. Il serait nécessaire d'introduire différents équipements pour améliorer l'irrigation de surface. L'adaptation aux conditions techniques de l'irrigation qui prédominent dans les oasis (qualité de l'eau, flux de l'eau et charge disponible) doit être validée. Pour atteindre un tel but, il faudrait promouvoir la participation des exploitants et leur engagement dans la modernisation des pratiques d'irrigation. En effet, les exploitants sont encore réticents, malgré les subventions du gouvernement et les mesures d'incitation pour l'acquisition d'équipements permettant des économies d'eau à l'échelle de la parcelle.*

Mots-clés. *Efficience – Oasis – Irrigation - Amélioration – Durabilité -Tunisie.*

I – Introduction

Over the centuries, the existence of the southern Tunisia oases (see Fig. 1) has always been conditioned by the availability of water resources and by the irrigation techniques deployed. De Hass (2002) defined the oases as agricultural sites in arid environments where agriculture is normally not possible without irrigation. Created at first, around natural sources, the Tunisian oases observed a real mutation in their landscape. Thanks to the development of drilling techniques, the very deep drillings replaced natural sources which dried up under the growing water demand that became progressively unable to overcome to the irrigated area extension.

Since the 1980s, within the framework of the Master Plan of Southern Water (PDES), the irrigation knew an important development. After the rehabilitation of the hydraulic infrastructures within the old traditional oases, the commitment of the authorities was focused on the enhancement of the irrigation efficiency. Several research works undertaken in these regions showed an alarming balance on the water management in the oases. Significant water losses were still occurring in the parcels where the competent authorities' efforts should be focused on farmers. This article is focused on the perspectives of irrigation efficiency improvement within parcels where the experience feedback often showed that, besides the technical aspects, the extension and awareness building on the water saving are a crucial tool that has to be certainly intensified.

Figure 1. Localization of Southern Tunisia Oasis (adapted from SAPI, 2005).

II – Water management issue in the oases

The major underground water resources, supplying the southern Tunisia oasis, are not renewable. It gathers the North-Western Sahara Aquifer System (NWSAS), this basin covers an area of 1 million km^2 located in the western part of North Africa, about 80,000 km^2 in Tunisia, 700,000 km^2 in Algeria, and 250,000 km^2 in Libya. In Southern Tunisia, water of the SASS is used through the Continental Intercalary (CI) and the Complex Terminal (CT) aquifers. The depth varies between 60 and 2800 m for the CI and from 100 to 300 m for the CT.

Under intensive pumping and overexploitation, the continuous decrease in the piezometric level has led to the complete drying up of natural sources. Water became gradually more expensive due to the rise of pumping costs, and to the deterioration of water quality (i.e. water salinity from CT reached 6 g/l in Douz Eastern Kebili). Furthermore, the multiplication of illegal wells (see Fig 2) accentuated this phenomenon.

Figure 2. Illegal drilling supplying private oasis in Kebili (photo Till Loeper).

III – Efficiency improvement within farmers' parcels

To optimize irrigation water supply in these regions, the APIOS project feasibility study considered the crop water requirements following four different empirical methods (Pan class-A; Penman; Blaney Criddle; Espinar). The modified Penman method under FAO recommendations was finally adopted but there are no important differences observed between the four methods for the southern governorates (Gabes, kebili, Gafsa, Tozeur). Therefore, crop water requirements within the oasis systems were valuated to 1025-1510 mm/year in Gafsa, 1150-1669 mm/year in Tozeur, 1170-1670 mm/year in Kebili and 820-1240 mm in Gabes (SAPI, 2005). Based on these estimations, the rehabilitation works that aimed to enhance distribution efficiency within the Southern Tunisia oasis allowed 25 to 30% saving of water losses within the rehabilitated oases.

The irrigation interval was shortened by 3 to 2 weeks (SAPI, 2005). Therefore, the inventory of 17 sampled oases that observed rehabilitation works led on the distribution network revealed a total saved water amount around 7,500,000 m^3 (see Fig. 3). The crop intensity was enhanced from 143 to 164%, the crop yield was improved by 35% for palm dates, 36% for olives.

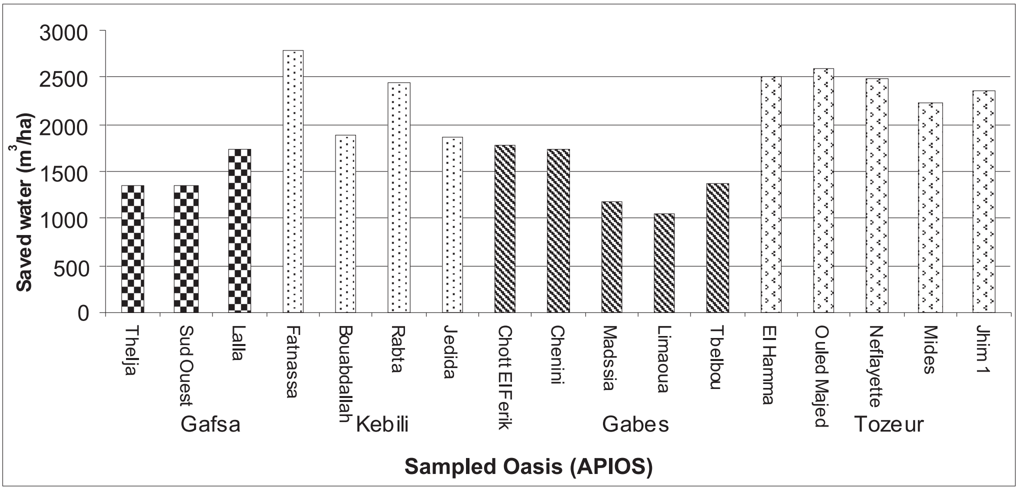

Figure 3. Impact of irrigation network rehabilitation on the delivered water amounts in southern Tunisia (Adapted from SAPI, 2005).

Despite the rehabilitation works undertaken, water shortage persists in the summer season when the network distribution capacity reaches its limits; on the other hand, the extracted water volumes still exceed the real water requirements, and such over-irrigation supplies groundwater table that rises to rather unacceptable levels (Prinz *et al.*, 2005).

Nevertheless, water consumption in farmer's parcels remains very high and their productivity does not show any significant improvement. Traditional irrigation method remains the main hindrance to the irrigation efficiency improvement in the field; this subject revealed an obvious need for irrigation modernization.

Mechergui and Van Vuren (1998) showed for the case of *Rahmat* oasis in Kebili that many inconsistencies occurred during irrigation. In the absence of any specific recommended method, each parcel managed the water in its own way. Some farmers did not any levelling inside the parcel which leads to considerable water loss. Whilst the required dose was 50 mm, observed irrigation amounts were 100 to 300 mm and more.

In 1970, the CRUESI (Research Center in Use of Saline Water to Irrigation) research works had been the initiator in the matter; several studies targeted the improvement of water management within parcels efficiency. Determination of crop water requirements (e.g. *Alfalfa*) under oases climate had been undertaken using lysimeters notably in experimental parcels of Helba in Tozeur. These works had been followed by many other and it was evident that even the research works led on the drainage topics had been faced to take into account the irrigation aspects. The relation between them both is being often close in such complex environment.

For the case of Ibn Chabbat Oasis in Tozeur, Goussi (1996) studied the contribution of excess water providing from private wells to the rise of the water table, which led to permanent risks of water logging and soil salinization. Ounis (1999) demonstrated the impact of drainage deficiency on the crop yield and putted in evidence the inadequacy of the leaching fraction during irrigation. Such conditions led to positive salt balance ad a chronic water logging, cultures damages had been observable especially at the downstream part of the oasis due to a low slope. Kacem (1990) put in evidence a significant flow between parcels during irrigation, the cumulative water surplus coming towards parcels near to the lower part oasis, where alarming water logging signals became evident.

Louhichi (1999) showed for the case of Gabes oasis, that terminal irrigation network settlement (until 400 m) allows to economize 14344 m^3/year. The average total cost is 523 DT, which equals to 0,036 DT/m^3. Whereas the unitary mobilization cost is 0,091 DT/m^3, the difference between both becomes more significant, when the calculation takes into account several depreciation costs (storage facilities, exploitation fees). Total mobilization cost reaches then 0,416 DT/m^3 equalling 10 times the saved cost (0,036 DT/m^3). This demonstrates that water economy is more efficient, if it passes through the water demand control. On the other hand, the actual method of water ratemaking commonly used within the oasis is fixed and the amount to pay (DT/ha) takes into account only the irrigated surface as standard. Sghaier (1995) claimed that such water rate marking doesn't valorise water irrigation. A rate marking policy covering the economic cost of water should be instituted. The water amount used every irrigation by farmers has to be the main standard of these watermarking policy.

The traditional irrigation method still widely used by farmers within the oasis (see Fig 4), this water over application leads to hamper water and brings out the shallow water table rise. Other consequences of such irrigation method could be an outflow between parcels. Risks of water logging become evident, particularly for parcels located downstream the oasis.

Figure 4. Traditional irrigation method inside a farmer's parcel in Kebili oasis (Photo Nizar Omrani).

The introduction of water-saving equipment in the oasis parcels remains rather limited. Low technical know-how of local farmers hampers their multiplication. Furthermore, some pre-conceived ideas inhibit the fully commitment of farmers to invest in such equipment. Most of them consider that "as *soon as the water enters the parcel, we cannot qualify the excess as losses; sooner or later it will be available to crops*". Nevertheless, the Ministry of Agriculture, Direction of water –saving in irrigated agriculture is making huge efforts to develop the irrigated sector (at national scale, the contribution of the irrigated sector is supposed to increase, at long term, from 32% to 50% of the total agricultural production). The water-saving programme applied to parcels has progressed since 1995. Several financial subsidies were granted to equip the irrigated schemes with modern and performing irrigation systems: 40%, 50% and 60% respectively for the large, medium and small farms (Hamdane, 2004). The situation is rather complicated in the Southern Tunisia oases where the traditional irrigation method is still the most common despite the above-cited government subsidies. The traditional methods prevailing in the parcels cause important water losses, especially along unlined feeder and when farmers widely overtake the irrigation period fixed by the calendar.

In this respect, the evaluation made during the faisaiblity study for the APIOS project in 1996 revealed unlined feeder water losses higher in the newly created oases, where the soil is still very sandy and highly permeable (see Fig. 5). These losses had been estimated to average about 25% per 100 m length. Nevertheless, this rate is not proportional to the canal length. At the *Rahmat* oasis, Mechergui and Van Vuren (1998) measured canal losses of 30 to 60% over a length of 400 to 1000 m. The occurrence of such losses depends exclusively on the canal management by farmers.

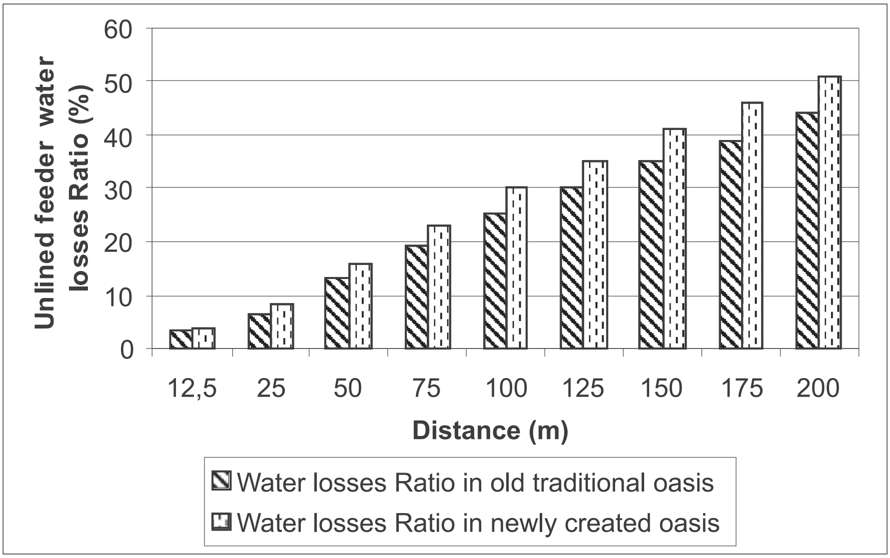

Figure 5. Evolution of water losses along unlined feeder in Southern Tunisia Oases (Adapted from SANYO, 1996).

Added to these losses, the operator drills that having significant repercussions on the water turn. The opening degree of the outlet isn’t the same in each water turn. On the other hand, the operator decides of the opening degree of the outlet, that having significant repercussions on the water turn.

1. Technical Constraints

There are several constraints within the oasis systems. Water losses occur along the distribution system, starting from the pumping station until the parcels entrance. These losses affect especially connections between seguia transects where joints (Nardyl matter made) don’t present a good resistance to high temperature and often break out inducing huge water losses. Due to such dysfunctions, the water flow becomes lower and contributes to increase water temperature through the distribution network. The problem is more acute in the oases supplied by artesian wells on the CI. In the absence of suitable proportions of water mixture between CT and CI water, during electricity cuts, only high-temperature (60-70°C) CI water runs within the network, which obliges the farmers to let it directly runoff to drainage canals to avoid crop burning.

2. Oasis Extension

The oasis extension is one of the most important current challenges to face within the next coming decades. The multiplication of private parcels occurs always at the oasis periphery. Their water consumption is very high, as twice as that of the public irrigated area. This induces important water wastage and significant drainage water amounts. The water surplus provides the shallow water table that rises up and leads to water logging phenomena, all the more so the private extensions are mostly located downstream and do not benefit from sufficient differences in level, which allows a far distant drainage water evacuation. Also, salinization risks become very imminent in such water management conditions (see Fig. 6).

Figure 6. Accumulation of drainage water in the oasis depression (Photo: Dieter Prinz, 2006).

IV – Conclusion

Oases in southern Tunisia are facing a very complex hydraulic situation, characterized by water shortage and by increasingly expensive irrigation water (continuous decrease in the piezometric levels of deep aquifers, pumping operations on the major CT drillings, CI water cooling). On the other hand, the expansion of irrigated area is moving towards the depressions and chotts, the contamination risks by salty drainage water become very imminent. An example is given by the regions of Hssay, Douz and Ziret Louhichi in kebili where the water salinity ranges between 4 and 6 g/l. The rehabilitation of the distribution network allowed saving about 7,500,000 m^3 as in the case of the seventeen oases sampled through the four governorates. The implementation of underground drainage systems also allowed a good drainage efficiency. Nevertheless, even after the improvement of the distribution network efficiency (25 to 30%), considerable water amounts are still lost within the parcels, the research carried out still reveals a low water application efficiency in the parcels, important water losses resulting from inappropriate soil and water management combined to a low farmers' commitment to modernize surface irrigation method in their parcels. In the absence of any assessment of the social conditions prevailing within the southern oases, notably a permanent dialogue between competent irrigation authorities and farmers who are the main stakeholders in the water management, acting on a strictly technical aspect becomes insufficient to improve irrigation efficiency. It is therefore necessary to intensify awareness raising campaigns on water saving in the parcels. More farmers' categories should be targeted, particularly the owners of small-sized farms.

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SAMIR a tool for irrigation monitoring using remote sensing for evapotranspiration estimate

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Abstract. SAMIR is software computing spatialized estimates of evapotranspiration (ET) and irrigation water budget on large areas, based on the use of satellite images. Remote sensing offers a synoptic view of the vegetation development, which is a key information for ET reliable computing. ET is obtained using the FAO method, well suited for computation over large areas, where little information is usually available about crops and soils. The computation of the water budget requires climatic data (reference ET — namely "ET0" — and rainfall data), land cover data, and crop development data (for estimating crop coefficients of the FAO method), these last two types of data being obtained from remote sensing. Irrigation may be an input when it is known, but it is most of the time estimated from the computation of the water budget, using hypotheses on the water management modes and especially the average water stress level allowed. The irrigation estimates at the scale of irrigation sectors may be compared with known water inputs from dams and traditional seguias (traditional channels deriving water from rivers) to estimate pumpings in the aquifer. In a context of strong pressure applied on water resources, we emphasize the potential of satellite images for irrigation monitoring and water management at watershed scale.

Keywords. Evapotranspiration – Irrigation – Remote sensing – Water budget – Pumpings.

SAMIR, un outil pour le suivi de l'irrigation estimant l'évapotranspiration par télédétection

Résumé. *SAMIR est un logiciel qui calcule la spatialisation de l'évapotranspiration (ET) et le bilan de l'eau d'irrigation à l'échelle régionale, en utilisant des séries satellitaires. La télédétection permet d'avoir une vue d'ensemble du développement de la végétation, ce qui représente une information fondamentale pour un calcul fiable de l'ET. L'ET est déterminée en utilisant la méthode FAO, qui se prête particulièrement aux calculs sur les grandes surfaces où généralement, les informations sur les cultures et les sols sont insuffisantes. Le calcul du bilan hydrique nécessite des variables climatiques (l'ET de référence — à savoir, l' "ET0" — et les données sur les précipitations), des données sur l'occupation du sol et sur le développement des cultures (en vue d'estimer les coefficients culturaux de la méthode FAO) ; ces deux derniers types de données sont déterminés par télédétection. L'irrigation peut être une autre variable si elle est connue, mais le plus souvent, elle est déterminée sur la base du bilan hydrique, en avançant deux hypothèses sur les modalités de gestion de l'eau et surtout, sur le niveau de stress hydrique admis. Les données estimées pour l'irrigation dans les différents secteurs peuvent être comparées avec les quantités d'eau d'irrigation apportées par les barrages et les seguias (les canaux traditionnels de déviation de l'eau des rivières) afin d'estimer les pompages réalisés dans la nappe. Vu la pression considérable à laquelle sont soumises les ressources en eau, il y a lieu de mettre en évidence le potentiel des images satellites pour le suivi de l'irrigation et la gestion de l'eau à l'échelle du bassin versant.*

Mots-clés. *Evapotranspiration – Irrigation – Télédétection – Bilan hydrique – Pompages*

I – Introduction

The SudMed project is aimed at developing methods for the sustainable monitoring of water resources in the Tensift basin (Marrakech, Morocco), based on ground data, remote sensing and physical modelling. The climate of this area is semi arid, characterized by low rainfall amount (240mm on average) affected by a strong spatiotemporal irregularity. Several drought periods occurred during the last years. Irrigated cultivation covers about 450000 ha and uses about 85%

of the whole available water, which means that optimal use of the resources is one key to the development of the area. Irrigation optimization requires the control of all the terms of the water budget, and especially the crops water consumption, i.e. their evapotranspiration (ET). This means that at any time, estimates of their past consumption are needed for computing the water budget of the crops. Moreover, forecasting of their water requirements is necessary for a better irrigation planning. This knowledge is useful for the irrigation manager, but it is also useful for the water resources manager, i.e. the watershed agency, as this flux is one major component of the water cycle in this watershed. To fulfil these objectives, we designed the SAMIR tool (Satellite Monitoring of Irrigation) dedicated to the water management of irrigated areas, making extensive use of satellite images. SAMIR is designed to compute the evapotranspiration and water budget of irrigated crops, and thus to estimate irrigation requirements at the irrigation scheme scale. It should be noticed that we don't target the irrigation management at the plot scale. We consider that the farmer may get — by direct observation — more valuable information for water budget assessment than what satellite can offer. This detailed information is not available on the large areas observed by satellite, which conversely allows less accurate water budget but on much larger areas on which local errors are assumed to compensate somehow. We briefly present the main features of this tool.

II – State of the art

Some tools for water budget of crops already exist, which are based on more or less complex soil-vegetation-atmosphere models (Butler 1998, Raes, 2001). Due to their complexity and the detailed parameters needed, they are usually valid at the plot level. Other models like CROPWAT (Clarke, 1998) are based on the well-known FAO method (Allen et al., 1998) and may provide budgets for agricultural areas only on the basis of the area covered by each crop. Applications providing an actual spatialization of the water budget, including the spatialization of climate and phenology of the vegetation, are much rarer.

Remote sensing provides a spatialized and regularly updated information about vegetation, which is primarily and widely used for land cover mapping. Temporal image series also provide information about the vegetation development, which is a major driving factor of ET. The low availability of such time series, for financial as well as technical reasons, has for a long time limited their use, but they should soon become more widely available thanks to new or forthcoming missions (Formosat, Venµs / GMES).

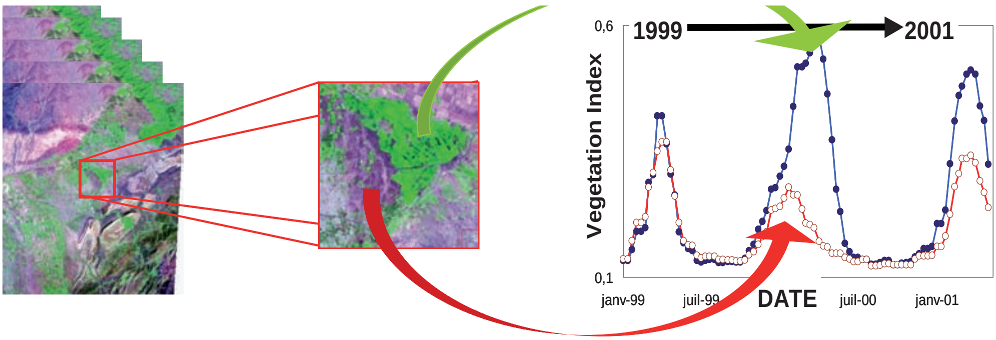


Figure 1. The interest of satellite vegetation indices. On the right part of the image time series extract an area with high vegetation development (in green) and associated high vegetation indices (blue curve). Conversely, the left part of the extract shows an uncultivated area (purple) and a low index (red curve).

III – SAMIR tool features

SAMIR provides for each pixel, at the daily step, ET estimates and a water budget of vegetation. The originality of the approach lies in the extensive use of satellite image time series, which allows an accurate monitoring of the actual vegetation development, and not an assumed one. The images acquired are also used to identify or refine the land cover identification during the acquisition time range. The ET is computed using the FAO dual crop coefficient method, which consider separately the Evaporation and Transpiration processes. The crop coefficients (Kcb) are determined on the basis of vegetation indices like NDVI, obtained from satellite images, and interpolated between two dates of image acquisition. Several land cover classes are considered to define specific NDVI – Kcb relations. The soil water budget is computed using the soil model proposed by Zhang (2006). Although the FAO method is less complex than those based on physical modelling, its simplicity makes it well suited for ET assessment on large areas, for which detailed data needed by more complex models, regarding soil and vegetation, is rarely available. This method has been calibrated and validated on our study area for the main crops encountered (Olive, citrus, wheat) (Er-Raki, 2006). Its implementation was validated on the Haouz area using a Landsat TM image time series (Simonneaux, 2008), and also using low resolution images (BenHadj, 2007). The collaboration with the office in charge of irrigation (Office Régional de Mise en Valeur Agricole du Haouz (ORMVAH)) led us to adapt the tool to the needs of the end-users. Conversely, the end-users needs, which were not accurately expressed at the beginning of the process, became refined along with their takeover of the tool.

1. Method for water budget computing

The evapotranspiration of a field is the sum of the transpiration of the vegetative parts and of the soil water evaporation. The FAO dual crop coefficient method calculates the total ET of any vegetated surface using the following equation:

$$ET = ET0 * (Kcb * Ks + Ke) \tag{1}$$

where ET0 is the reference evapotranspiration, i.e. the evapotranspiration of a standard well watered grass that would be in the same condition. Kcb is the basal crop coefficient accounting for the transpiration of the vegetation fraction (fc), Ks is the stress coefficient based on the soil water availability obtained from the soil module, and Ke the evaporation coefficient accounting for evaporation of the soil fraction (1 – fc). Computing equation (1) requires basically three types of data: climatic variables for the calculation of reference evapotranspiration (ET0), land cover, and periodical information about crop development for adjusting the Kcb and Ke.

The soil module was adapted from Zhang et al. (2006) and includes three compartments: (1) a surface compartment, (2) a root compartment whose thickness is variable and linked to vegetation development, and (3) a deep compartment. Water goes down the compartments by gravity, and is also able to rise by diffusion. These fluxes are linked to the relative humidity of the compartments. This soil model enables the separated calculation of transpiration (from the root compartment) and evaporation (from the surface compartment), taking into account the water availability in each compartment and thus a stress coefficient Ks.

For each day SAMIR computes the water budget using equation (2). It should be noticed that lateral flows are not taken into account here, as they are considered negligible in irrigated areas.

$$ET + DP + \Delta SW = R + I \tag{2}$$

with : DP deep drainage
Δ SW soil water content variations
R rainfall
I irrigation

2. Input and Output data

The climate module needs daily values of ET0. These values may be taken from climate statistics (e.g. LocClim CD published by the FAO), and interpolated at the daily time step. It is also possible to introduce ground data from climate recording stations. One station only may be used, if homogeneous climate is assumed over the studied area. If several stations are available, they will be interpolated over the area using robust algorithms (Inverse distance or kriging) that prevent from drifts occurring when interpolating far from the input points. However, one interesting data source is the daily fields of climatic variables produced according to a regular 16 km grid by the ALADIN model of the Moroccan Meteorological Agency (DMN).

The soil module assumes a homogeneous soil over the area, for which field capacity and welting points are input by the user. It is also possible to enter a soil map if available, offering a spatialization of these values.

The land cover module offers to the user standard maps of the area, but it is recommended to use an updated land cover map based on the satellite images of the year, as this input may vary greatly from one year to another. The study area tested, the Haouz plain, is covered by 25% trees plantation, from which 80% are olive trees, and 75% annuals, from which 75% are wheat. Tree areas are rather stable over years, whereas the variability of annuals area is very high according to the water availability for the season. This availability is driven mainly by the quotas of dam water granted to ORMVAH by the Tensift Hydraulic Watershed Agency (ABHT), and also by the rainfall amount at the beginning of the season, these two factors conditioning the decision of the farmers about whether or not to sow. Thus, satellite images may be very useful for controlling the extent of annuals.

The phenology module offers the possibility to use standard Kcb profiles issued from the FAO tables, but the interest of SAMIR is rather to use satellite time series (about 10-12 images each year). Such a time series was previously used by Ray (2001) on only three images. Kcb-NDVI relations are available for all crops of the area, some of them were tested on some fields of olive trees and wheat (Duchemin et al., 2006 ; Er Raki et al., 2006). These relations are usually linear, of the following type:

$$Kcb = A * (NDVI - NDVImin) \qquad (3)$$

with A and NDVImin constants to fit to each crop.

Various options were developed to take the irrigation into account. The first option is to introduce irrigation data into the model, but this option is rarely used as irrigation data usually lack, especially at the plot scale. The more realistic option is to let SAMIR estimate the irrigations, on the basis of decision rules for irrigation which are linked to soil water content, irrigation amounts observed, etc.

The water budget is computed daily for each pixel, but considering the uncertainties related to the input data, especially regarding soil and irrigations — vegetation being rather well monitored thanks to satellite — the results should be considered at the scale of larger irrigation units. As actual irrigations are the result of complex human decisions, SAMIR will not be able to reproduce them exactly. Thus, the water budget and irrigation amounts shouldn't be considered daily but for longer time intervals.

IV – SAMIR outputs

1. Evapotranspiration Estimates

Evapotranspiration was estimated for the whole Haouz plain during the 2002/2003 season, on the basis of nine Landsat TM images acquired from November to May (Simonneaux, 2008). Accuracy assessment was possible for the wheat class, on the basis of ground measurements of the actual ET using eddy correlation systems installed on three plots (fig.2). The average error between remote sensing estimates and ground measurements was 27% at the daily scale, 18% when aggregating results at the weekly scale, and only 5% when considering the full data set (160 days of measurements available when merging the three plots).

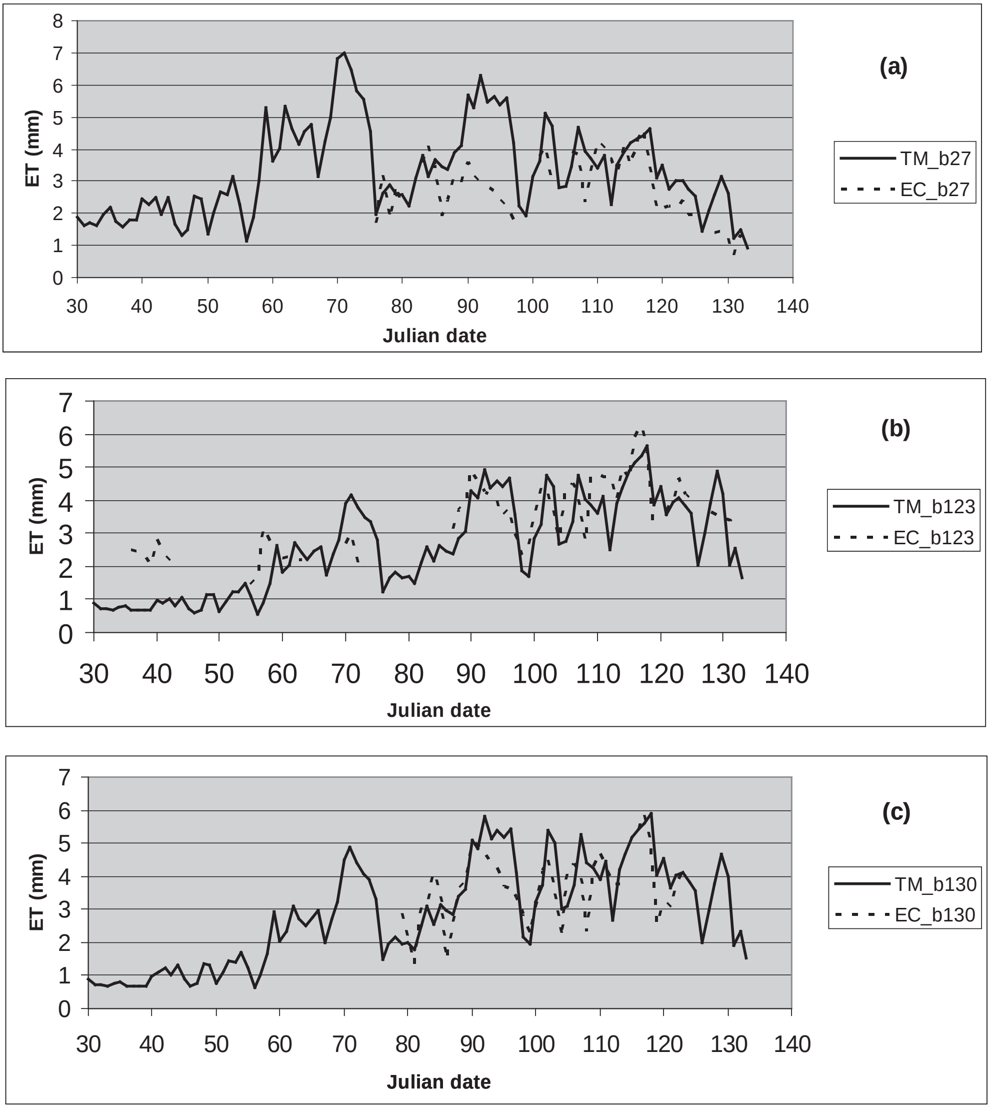
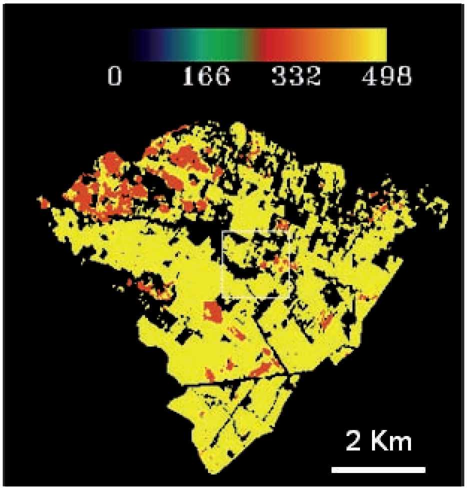


Figure 2. Comparison of actual (EC) vs satellite estimated (TM) evapotranspiration. Example of a plot in the Haouz Plain.

The ET computed only on the basis of kcb obtained from NDVI is a better estimate of the actual ET than the one based on standard Kcb profiles assuming ideal growing conditions throughout the cycle, because it considers the actual vegetation development. The ET obtained using the two methods are very different (Fig. 3).

(a) 

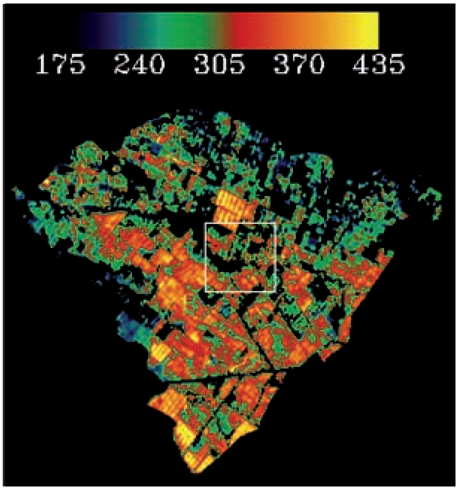
(b) 

Figure 3. Maps illustrating the benefit of using satellite monitoring of the vegetation compared to standard development. (a) Cumulated ET estimated from standard FAO values : 13.1 Mm3, (b) Cumulated ET estimated from remote sensing : 8.2 Mm3.

2. Pumping estimates

Farmers do not only use surface water distributed from the dams to irrigate their crops but also water pumped directly from the aquifer. Owing to the overexploitation of the Haouz aquifer, it is of a great matter for water managers to assess the volumes of irrigation water and particularly the volumes of pumpings. Irrigation amounts were estimated using SAMIR for the 2002/2003 season using the above mentioned Landsat TM time series. The ORMVAH provided us with the volumes of surface water irrigation distributed on each irrigation sector, including modern irrigation and traditional irrigation through the seguia network (traditional channels diverting water from rivers). The following equation was used to model the water budget :

$$\begin{gathered}\text{ET} + \text{Percolation} + \Delta\,\text{Soil Water} \\ = \\ \text{Rainfall} + \text{Surface Irrigation} + \text{Pumpings}\end{gathered} \tag{3}$$

To validate SAMIR pumping estimates, we used investigations made by the ABHT regarding the water pumping points all over the Haouz plain. For each point, three estimations of pumped water volumes had been made: energetic, hydraulic and agronomic. The confrontation between the investigation data and results obtained through the SAMIR tool show a significant correlation with the agronomic assessment (fig.4).

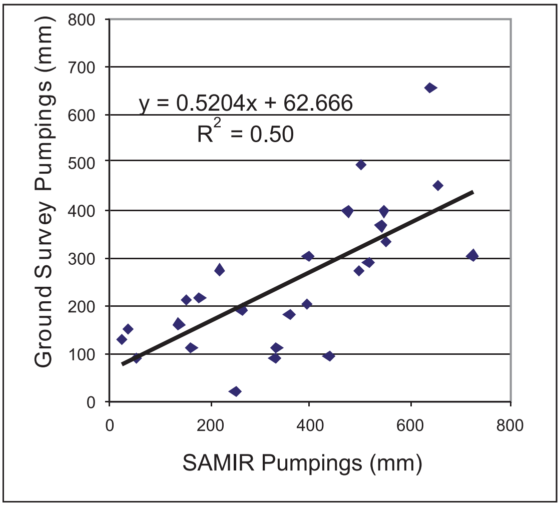


Figure 4. Comparison between pumpings estimated using SAMIR for the 2002/2003 campaign and values obtained from the watershed agency (agronomic method) for the irrigated sectors of the Haouz plain.

However, a bias can be observed in the relation, which can be due to an overestimation of the irrigation volumes with the SAMIR tool. This bias may also be due to the possible non-exhaustivity of the agronomic assessment method or of the ground investigations conducted. The hydraulic and energetic methods show very bad correlations, emphasizing the fact that farmers usually underestimate these values as they fear the questions of investigators associated with fees collection. It is less possible to lie with farm areas which are easier to control. Pumping estimates appears to be a very touchy task, as it is very difficult to validate these estimates on large scales. It requires huge amount of reliable data, which is hardly found.

V – Conclusion

Thanks to the information regularly provided regarding vegetation, remote sensing is a particularly valuable data source for the water budget monitoring of irrigated areas. SAMIR is a first version of a tool dedicated to irrigation budget management on large scale, especially useful in arid and semi-arid areas where this information is scarce although critical for the regional water budget.

One weakness of the tool lies in the difficulty to control the soil water content and actual water inputs. Thermal satellite data may help getting direct information about plant stress to improve the soil water management and thus ET assessment. In this manner, Er-Raki (2007) has successfully assimilated ASTER thermal data in an FAO model to improve the water budget assessment. One other difficulty of this approach is the lack of accurate validation data needed to validate the results on large scales, but this problem should be solved by using many local validation datasets on various crops.

Managers of irrigation and water resources need forecasting of water requirements over large areas, at various runs going from the next day to the end of the season. Forecasting for the whole season is already made by ORMVAH to plan the water distribution, on the basis of previous year data. These forecasts are adjusted two times during the season, on the basis of visual observation of actual crop areas. In order to better account for the actual vegetation development, we are developing in SAMIR forecasting capabilities based on the image set acquired from the beginning of the season. Finally, SAMIR should help testing land cover and climate change scenarios on large scales.

VI – Acknowledgments

This work is going on in the framework of the MedMex project (formerly named SudMed, www.irrimed.org/sudmed), managed jointly by the Institute of Research for Development (IRD, UMR CESBIO, France) and the Cadi Ayyad University of Marrakech (Morocco), with the support of the Regional Office of Agricultural Development of the Haouz plain (ORMVAH) and the Tensift Watershed Agency (ABHT). We also thank the European Community for its financial support via the IRRIMED project, and the CNES (Toulouse, France) for its support in providing us with satellite images via the ISIS action. We are also grateful to the CMIFM (Comité Mixte Interuniversitaire Franco Marocain) for funding the Programme d'Action Intégrée Volubilis: « Gestion durable des ressources en eau dans le bassin-versant de Tensift (région de Marrakech) » n° MA/148/06). SAMIR is developed in IDL, language associated with the ENVI image processing software (© RSI).

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On-line satellite-assisted tools for participatory irrigation water management

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Abstract. We briefly present the concept and some applications of irrigation water management assisted by Earth observation satellites and Information and Communication Technologies. Jointly, these tools provide easy-to-use access to information on key parameters for monitoring and management of irrigation schemes, farms, and river basins.

Keywords. Irrigation water management – Irrigation advisory service – Earth observation satellites – Information – Communication Technologies – Participatory Geographical Information Systems.

Outils satellites en ligne pour la gestion participative de l'eau d'irrigation

Résumé*. Dans cette contribution, nous allons donner un bref aperçu du concept de gestion de l'eau d'irrigation et de certaines applications, en utilisant les satellites d'observation de la Terre et les Technologies de l'Information et de la Communication. La combinaison des ces outils peut faciliter l'accès aux informations sur les paramètres clés pour le suivi et la gestion des périmètres irrigués, des exploitations et des bassins versants.*

Mots-clés. *Eau d'irrigation – Assistance technique pour l'irrigation – Satellites d'observation de la Terre – Technologies de l'Information et de la Communication – Systèmes d'Information Géographique participatifs.*

I – Introduction

Saving water in irrigated agriculture can be achieved through the use of Earth observation (EO)-derived information in operational irrigation scheduling at farm and field scale. End-users of the information are the farmers, who experience benefits in the form of "more crops per drop" (enhanced water productivity) and "more jobs per drop" (boost of rural development). Space-assisted Irrigation Advisory Services (IAS) at community level provide the EO-derived irrigation scheduling information to them, interacting with water management decision makers at river basin level, and serving as a potential policy instrument at national and European scale.

The concept of irrigation modernization has evolved over the years from the mere introduction of new technical infrastructure and equipment towards a more holistic concept including measures to optimize water application. Such a system now includes also tools to generate information on most efficient water use and mechanisms to transmit this information to farmers. Irrigation Advisory Services (IAS) are ideal management instruments for this purpose and they are gradually adopting this extended role.

New tools are needed to support this process. Current IAS are normally not able to cover each agricultural holding in extended areas at regular short time intervals. Earth observation (EO), in combination with Geographical Information Systems (GIS), is naturally destined to fill such a gap. In parallel, last-generation Information and Communication Technologies (ICT) open vast possibilities to transmit spatialized information to users in a personalized way using internet and mobile phones.

II – Online space-assisted irrigation advisory service

The project DEMETER (Demonstration of Earth observation Technologies for routine irrigation advisory services) was designed to assess and demonstrate in an operational perspective how the integration of New Technologies can improve the efficiency in the use of water for irrigation (Calera et al., 2005; Osann Jochum *et al.*, 2006). The DEMETER prototype e-SARAS® (e-Servicio de Asesoramiento de Riego Asistido por Satélite) or e-SAIAS® (online Space-Assisted Irrigation Advisory Service) is the central outcome of the project. Its key feature is the operational generation of irrigation scheduling information products from a virtual constellation of high-resolution EO satellites and their delivery to farmers in near-real-time using leading-edge on-line analysis and visualization tools. It is supported by a methodology package to derive crop coefficients and further advanced parameters from EO satellite images in an operational processing chain on one hand and a software package for spatial data handling, visualization, and on-line analysis on the other hand. Jointly, these two packages provide a tool for upgrading conventional IAS or for implementing similar new services. Figures 1 and 2 show schematically the functioning of the new service. Figure 3 shows a screen example.

The IAS of the Instituto Técnico Agronómico Provincial (ITAP, Spain) has served as the perfect testbed for demonstrating the water-saving potential of space-assisted IAS. It is a highly sophisticated IAS, which over 18 years of operation has built a strong confidence link with the farmers (Montoro et al., 2002). Initially based on traditional IAS methodology and a personalized service to one third of the area (100.000 hectares of irrigated land), the e-SAIAS allows them now to extend this personalized service to the whole area and reach more farmers. Estimates of water saving (depending on annually varying cropping patterns) have been shown to be on average 10-20%.

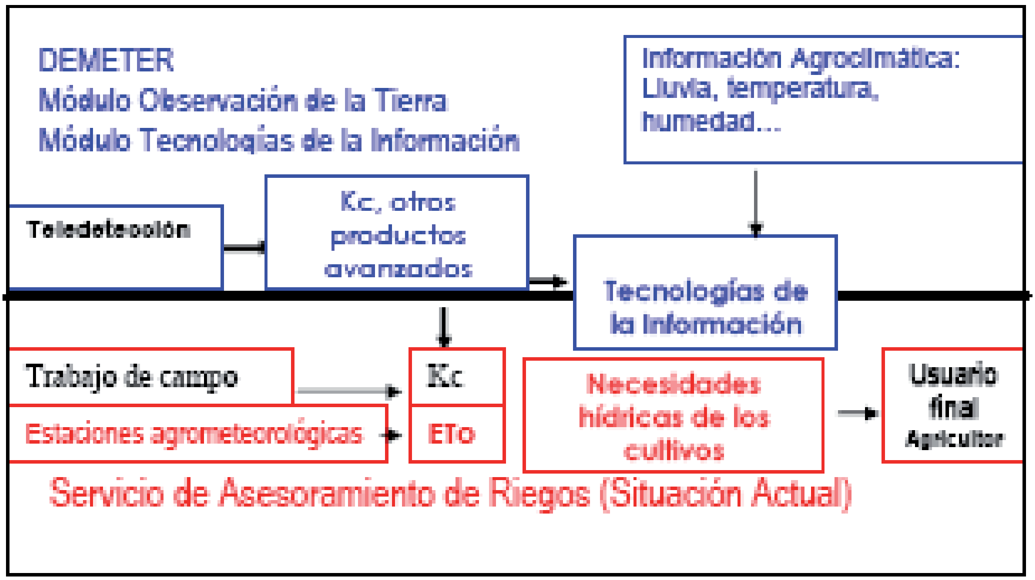

Figure 1. Concept and functioning of current IAS (lower part) and new IT-and-Space-assisted Irrigation Advisory Service (e-SaIAS, upper part).

Figure 2. Schematic overview of e-SAIAS®.

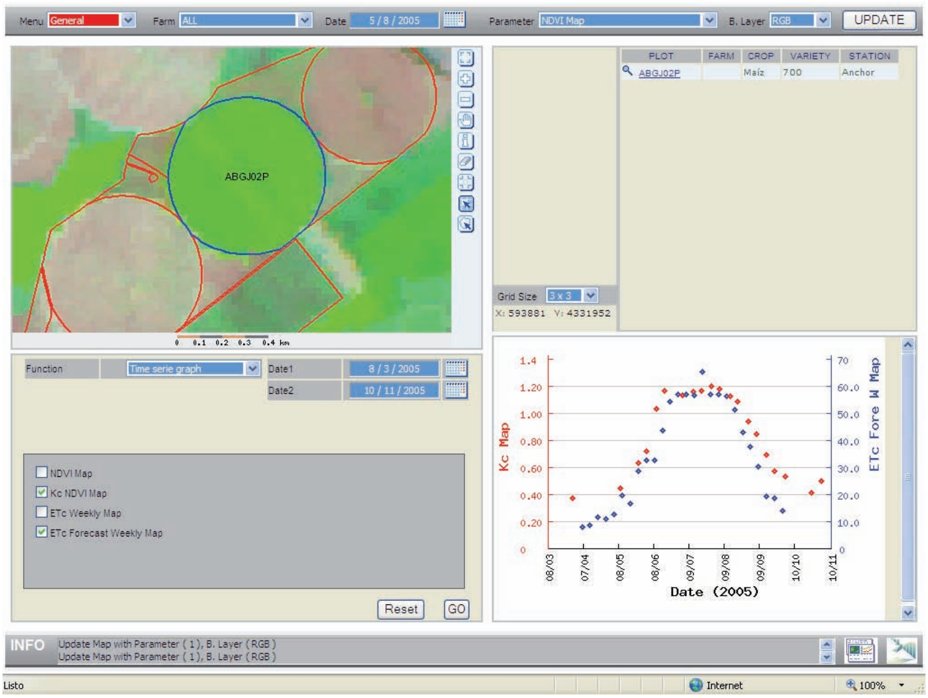

Figure 3. Example of irrigation scheduling information provided to farmers by online system e-SAIAS®.

III – Space-assisted integrated water resources management

The concept of online space-assisted IAS has been extended to include all dimensions of water resources management in an integrated way. We consider the economic, environmental, technical, social, and political dimensions through a synergy of leading-edge technologies and participatory approaches. These technologies provide easy access to information for all stakeholders while active participation will be effected by spatial information and innovative networking tools.

The project PLEIADeS (Participatory multi-Level EO-assisted tools for Irrigation water management and Agricultural Decision Support) aims at improving the performance of irrigation schemes by means of a range of measures. Major technical innovation is made possible by the comprehensive space-time coverage of Earth observation (EO) data and the interactive networking/connecting capabilities of Information and Communication Technologies (ICT).

Figure 4 shows an example of a multi-scale online interface for water managers.

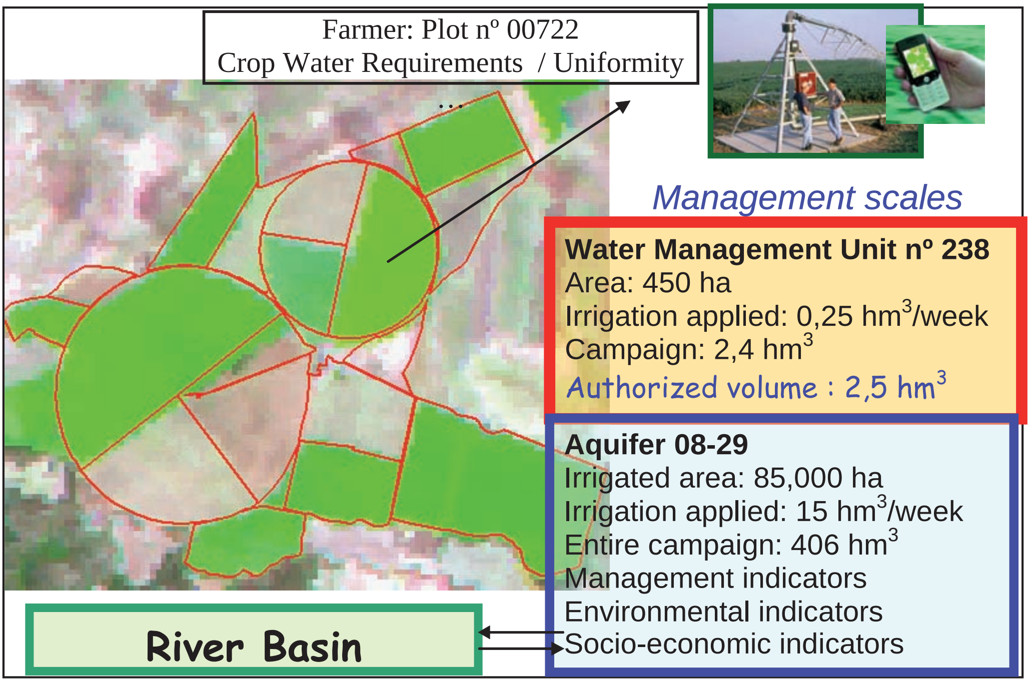

Figure 4. Example of online interface for water managers of a water management unit within an aquifer, with downlink to individual farms and uplink to aquifer and river basin.

IV – The PLEIADeS approach

PLEIADeS is being developed in a set of nine pilot Case Studies that represent a sample of the wide range of conditions found in the Mediterranean and in the Americas, covering Portugal, Spain, Italy, Greece, Turkey, Morocco, Mexico, Peru, and Brazil.

The project revolves around users (irrigation water managers and farmers) and other stakeholders. The first project phase was dedicated to assessing and analyzing their situation in each pilot area, covering technical data as well as the stakeholders' perceptions on current needs and future perspectives. Along with reports on stakeholder analysis and baseline descriptions of pilot areas, a set of video Pilot Stories was created. The first of these Pilot Stories have been made available on www.youTube.es/pleiades8stories.

The technical development is based on a joint vision of stakeholders (articulating their requirements) and system developers (proposing tailor-made technical solutions) and a continuous dialogue between them. The common goal is to offer the information to a wide range of stakeholders at their required space-time resolution in non-academic, non-technical, easy-to-use and intuitive form that encourages participation. Working directly with key users and the relevant government organisations, including active stakeholder participation and gender mainstreaming, increases the chances for successful implementation in policy and practice.

V – Technological innovation to support monitoring, management, and participative decision making

The technical innovation is based on the complementary use of mature EO methodology in GIS-based web services with online analysis capability. The design of the System of Participatory Information, Decision support, and Expert knowledge for irrigation and River basin water management (SPIDER) was oriented towards its global application, including the capability to be configured and installed by the responsible partner in each pilot area.

For farmers and irrigation scheme water managers, SPIDER generates weekly or bi-weekly irrigation scheduling information products from a virtual constellation of high-resolution EO satellites and delivers them to farmers in near-real-time using leading-edge on-line analysis and visualization tools. It is supported by a methodology package to derive crop coefficients and further advanced parameters from EO satellite images in an operational processing chain. The satellite can "see" for example the actual crop vigor and water requirements (in combination with agrometeorological data) over extended areas and can detect non-homogeneities within individual fields.

For water managers at irrigation district and river-basin scale, SPIDER provides monitoring products, like maps of consumptive water use, with options to derive values aggregated over an irrigation season and/or over spatial water management units and/or crop types.

In support of participatory processes, be they incipient or ongoing, SPIDER can first collect all available information and then provide this information from local to river-basin scale to all stakeholders involved and thus facilitate discussion, enhance transparency, and enable informed and shared decisions.

The development of SPIDER in each pilot area is being driven by the needs and perceptions of the users. At all project stages, it is a joint venture of the project team composed of selected key stakeholders, information service providers, and research groups. The general philosophy is that of an open-source system that is made available to users on a non-commercial licence basis. The clear intention is to implement an operational version in some pilot areas by the end of the project time. The details of this implementation will depend on the local situation and will be worked out jointly on a case-to-case basis.

VI – Participatory evaluation with stakeholders

The central hypothesis of PLEIADeS is that a tool like SPIDER can make an essential contribution to changing irrigation water management at several levels. Social and technical learning are an important part of this process. We intend to initiate this process by means of pilot campaigns which are conducted in each pilot area. There, the core users (irrigation scheme managers, farmers, and river-basin authorities) are provided with SPIDER and its products and services during several months. The local project teams provide technical training at the beginning and support during the whole campaign. Group meetings are held to discuss their experiences, comparing the situation with or without SPIDER.

Furthermore, a set of frameworks for performance and impact assessment has been developed, each of which is being thoroughly tested in one pilot area. The set includes frameworks for irrigation performance assessment, environmental performance assessment, socio-economic assessment and cost-benefit analysis, for the assessment of impacts of climate- and policy-related external drivers, and for social multi-criteria evaluation. Stakeholder group meetings serve to jointly evaluate the findings from these assessments and to develop visions of a sustainable future in each pilot area.

VII – Conclusions and recommendations

Online geospatial information and communication systems provide powerful tools to enhance the participation and transparency needed in the social and political process to achieve a rational use of water resources. The use of technological tools has always to be integrated in the social and political context. Otherwise they can contribute to reinforcing existing inequalities or even bring about a result that is opposite to the initial objective.

VIII – Acknowledgement

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Technical efficiency of water use in the irrigated private schemes in Smar watershed, south-eastern Tunisia

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Abstract. In this paper, data envelopment analysis (DEA) is used to asses the farm-level technical efficiency measures and sub-vector efficiencies for water use of a sample of irrigated farms based on surface wells in Smar watershed (south-eastern Tunisia). In the study area, private irrigation schemes play an important role in rural development, but the water scarcity and the increasing pressure on these resources calls for a more efficient water use. With the Data Envelopment Analysis (DEA) techniques used to compute farm-level technical efficiency measures and sub-vector efficiencies for water use, it was shown that under Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS) specification, substantial technical inefficiencies, of 26% and 15% respectively, exist among farmers. The sub-vector efficiencies for water proved to be even lower, indicating that if farmers became more efficient using the technology currently available, it would be possible to reallocate a fraction of the irrigation water to other water demands without threatening the goal of surface wells irrigation. In a second stage critical determinants of sub-vector efficiency are determined using a Tobit model. Farm size, age of the household head, the number of year of schooling, the type of irrigation scheme, crop choice and the irrigation methods applied showed a significant impact on the sub-vector efficiency for water. Such information is valuable for extension services and policy makers since it can help guide policies towards increased efficiency.

Keywords. Irrigation – Technical efficiency – DEA method – Surface wells – Tunisia.

Efficacité technique de l'utilisation de l'eau dans les périmètres irrigués privés du basin versant de Smar, dans le Sud-est tunisien

Résumé. *Dans le présent travail, nous allons illustrer la méthode DEA (analyse d'enveloppement des données) utilisée pour évaluer les mesures de l'efficacité technique à l'échelle de la ferme et l'efficacité allocative de l'utilisation de l'eau sur un échantillon d'exploitations irriguées utilisant des puits superficiels dans le bassin versant de Smar (Sud-est tunisien). Dans la zone d'étude, les périmètres irrigués privés jouent un rôle important dans le développement rural, mais la pénurie d'eau et la pression croissante sur ces ressources imposent une utilisation plus efficiente de l'eau. Les techniques DEA, employées pour calculer les mesures de l'efficacité technique à l'échelle de la ferme et l'efficacité allocative de l'utilisation de l'eau, ont montré que dans le cas des rendements d'échelle constants (REC) et des rendements d'échelle variables (REV), on observe chez les exploitants des inefficacités techniques significatives, de 26% et 15% respectivement. L'efficacité allocative de l'eau s'est avérée être même plus faible, ce qui indique que si les exploitants pouvaient accroître leur efficacité en utilisant les technologies disponibles actuellement, on réussirait à réallouer une fraction de l'eau d'irrigation à d'autres demandes sans pour autant compromettre l'objectif de l'irrigation par les puits superficiels. Dans un deuxième temps, nous allons parcourir les déterminants critiques de l'efficacité allocative en appliquant le modèle Tobit. La taille de l'exploitation, l'âge du chef de ménage, le nombre d'années de scolarisation, le type de périmètre irrigué, le choix de la culture et les méthodes d'irrigation utilisées ont un effet significatif sur l'efficacité allocative de l'eau. Cette donnée est importante pour les vulgarisateurs et les politiciens dans la mesure où elle peut contribuer à orienter les politiques vers l'objectif d'une plus grande efficacité.*

Mots-clés. *Irrigation – Efficacité – Méthode DEA – Puits superficiels –Tunisie.*

I – Introduction

Water scarcity is a growing problem in Tunisia. Hence, irrigation systems, being a main consumptive user, experience pressure to release water for other uses and to find ways in which to improve performance. South-eastern Tunisia is a water-stressed region. Moreover, because rainfall is low (<200mm per year) and extremely variable in space and time there, irrigation is a key factor indispensable for agricultural production.

Irrigation water is becoming an increasingly scarce resource for the agricultural sector in many regions and countries. A common ground in past policy schemes was the development of adequate irrigation infrastructure to guarantee the supply of irrigation water as the demand for agricultural products was increasing. However, these expansionary policies have resulted in a massive use of irrigation water at a heavily subsidized cost and physical scarcity. Water scarcity has become an increasing social and economic concern for policy makers and competitive water users. Particularly, agriculture is becoming the sector at which policy makers are pointing out at the core of the water problem.

As in many areas in south-eastern Tunisia, small-scale irrigation schemes are of great importance for the livelihood of many families there.

It is believed that small-scale irrigation schemes could play an important role in rural development because of their potential to provide food security, income and employment opportunities (Al Atiri, 2005). On the other hand, performance and economic success of these schemes have been poor, which raises questions on their level of efficiency (Albouchi, 2007; Chemak, 2007). Moreover, the new water policy regards water as an economic good and thus charges will be levied on its use. Currently, water use of farmers at small-scale irrigation schemes is subsidized. However, these subsidies will gradually decrease and in the future farmers will have to pay to ensure cost recovery (Al Atiri, 2003). Hence, small-scale irrigators will face two new problems in the future: firstly, less water will be allocated to the agricultural sector, due to the increasing water scarcity, and secondly, they will have to pay for the water they use. In other words, they will have to deal with a reality where water becomes a limited input for which they have to pay. The impact of this new reality is unclear, but it will definitely have an impact on the production system and stress the importance of using water in a more efficient way.

This paper analyses the efficiency with which water is used in small-scale irrigation schemes and studies its determinants, with data of a sample of 50 farmers in smar Medenine watershed being used. Although the sample is relatively small, the case study will provide insights that reflect the typical situation of rural areas in south-east Tunisia. It is nevertheless difficult to ascertain whether the use of water is efficient or not, since irrigated agriculture is a multiple input-multiple output process. Furthermore, it is important not to consider water as a resource in an isolated manner (Malana and Malano, 2006; Rodríguez Díaz *et al.*, 2004b).

Studies on efficiency differentials among farms often use simple measures, such as yield per ha or output per m^3, which are easy to calculate and understand. However, such measures tell very little about the reasons for any observed differences among farms. Output per m^3, for example, does not take into account the differences in non-water inputs among farms (such as labour, fertilizers etc…) (Coelli et al., 2002).

In the first step of the analysis in this paper, a Data Envelopment Analysis (DEA) is used to calculate more consistent measures of efficiency (Fraser and Cordina, 1999). This is a system approach widely used in management science and economics, in which the relationships between all inputs and outputs are taken into account simultaneously (Raju and Kumar, 2006). The method enables the relative efficiency of a farm to be determined and to examine its position in relation to the optimal situation. Moreover, this methodology allows not only technical, but also subvector efficiencies to be calculated, which can be used to specifically monitor the efficiency of water use.

A second step of the study consists of analysing the determinants of efficiency measures. Separate Tobit models are estimated as a function of various attributes of the farms within the sample (Chavas *et al.*, 2005; Binam *et al.*, 2003), allowing a pointing out of which aspects of the farms' human and physical resources might be targeted by public investment to improve efficiency (Wadud and White, 2000).

Although there have been several studies that have analysed the efficiency of agricultural production in developing countries (Haji, 2006; Malana and Malano, 2006; Chavas *et al.,* 2006; Abay *et al.,* 2004; Binam *et al.,* 2004; Dhungana *et al.,* 2004; Binam *et al.,* 2003; Coelli *et al.,* 2002, Wadud and White, 2000), most of them have focused on monocropping of major food crops like rice, maize or wheat or on cash crops like coffee and tobacco. However, these studies have not specifically focused on the use of water. The novelty of this paper is that it has a clear focus on water of which the sub-vector efficiencies are calculated and analysed. This is highly relevant given the growing water scarcity and the future introduction of water pricing. It is of significant importance for policy makers, because it not only creates awareness concerning inefficiencies in water use, but also provided insight into possible improvements by exploring the determinants of these inefficiencies.

The remainder of the paper is organised as follows. The next section elaborates on the efficiency concepts and their measurement and discusses the theoretical background for DEA and in section 3, data collection is described. Obtained efficiency scores are presented with the determinants of inefficiency in section 4. Section 5 provides some conclusions.

II – Methodology

1. Efficiency measures

The absolute efficiency position of farmers is usually not known. Therefore the problem is to measure the efficiency of one farm relative to others.

There are two main competing paradigms for estimating the relative efficiency of farms: parametric and non-parametric. The parametric approach assumes a functional relationship between outputs and inputs and uses statistical techniques to estimate the parameters of the function. The sampling theory estimators that are typically used have statistical properties that are known in large samples. The non-parametric approach, in contrast, constructs a linear piecewise function from empirical observations on inputs and outputs without assuming any a priori functional relationship between them. Simar and Wilson (2000) show how a simple statistical model of the data generating process can be used to determine the statistical properties of a non-parametric (DEA) estimator, which is analogous to the parametric method. However, DEA is also not without criticism – it is deterministic rather than stochastic, so it is sensitive to outliers and data measurement errors. Comprehensive reviews of the two approaches are provided by Kalirajan and Shand (1999); Coelli (1995); Lovell (1993); Bravo- Ureta and Pinheiro (1993); Bjurek et al (1990) and Bauer (1990).

Given the alternative empirical tools available, the choice as to the 'best' method is unclear (Olesen *et al.*, 1996). Few rigorous empirical analyses have been carried out in assessing the sensitivity of efficiency measures to the choice of DEA and parametric methodology in agriculture (e.g., Sharmaet al.,1999; Wadud and White, 2000). The limited findings show that efficiency score estimates from each approach differ quantitatively, although the ordinal efficiency ranking of farms obtained from the two approaches appear to be quite similar. The evidence would suggest that the choice is somewhat arbitrary, though to a certain degree the choice between alternative modelling approaches depends upon the objectives of the research, the type of farms and assumptions regarding the data generating process. We used the non-parametric DEA technique developed by Charnes et al. (1978) (CCR) and Banker et al. (1984) (BCC). We could have used a stochastic frontier approach instead, but we expect qualitatively the results would be similar under both approaches.

2. Data envelopment analysis

Data envelopment analysis (DEA) was developed by Charnes, Cooper, and Rhodes (1978) based on M.J. Farrel's contribution to productive efficiency. The data envelopment analysis technique uses linear programming methods to construct a non-parametric frontier. The technique also identifies efficient production units, which belong to the frontier, and inefficient ones, which remain below it.

Data envelopment analysis (DEA) uses a non-parametric piecewise linear production frontier in estimating technical efficiency. A DEA model may be either input-oriented or output-oriented. Both output-oriented and input-oriented DEA models produce the same technical efficiency estimate for a farm under the assumption of constant returns to scale in production.

In deciding on the orientation of a DEA model, one should also consider over which variables decision making units (DMUs) have most control. If DMUs have more control over output variables than input variables, the DEA model should be output-oriented; otherwise, the model should be input-oriented. Agricultural farms, such as irrigated private perimeters (surface wells), usually have more control over their inputs than their outputs. Input-oriented models were chosen in this study to reflect the reality where the main aim is not to increase production but to use different resources more efficiently (Rodríguez Diaz *et al.*, 2004a).

The model is presented here for the situation with n firms or decision making units (DMUs), each producing a single output by using m different inputs. Here, Yi is the output produced and Xi is the $(m \times 1)$ vector of inputs used by the ith DMU. Y is the $(1 \times n)$ vector of outputs and X is the $(m \times n)$ matrix of inputs of all n DMUs in the sample.

The DEA model to calculate the technical efficiency (TE) is in this case (equation 1):

$$\begin{aligned} &\mathrm{Min}_{\theta\lambda}\theta, \\ &\text{Subject to} \quad -y_i + Y\lambda \geq 0 \\ &\qquad\qquad\quad \theta_i x_i - X\lambda \geq 0 \\ &\qquad\qquad\quad \sum_{i}^{n} \lambda_j = 1 \\ &\qquad\qquad\quad \lambda \geq 0 \end{aligned}$$

Where θ_i is a TE measure of the ith DMU and λ is an $n \times 1$ vector of weights attached to each of the efficient DMUs. A separate linear programming (LP) problem is solved to obtain TE score for each of the n DMUs in the sample. If θ =1, the DMU is on the frontier and is technically efficient under CRS. If $\theta \prec 1$, then the DMU lies below the frontier and is technically inefficient. It should also be noted that equation 1 has a variable returns to scale (VRS) specification which includes a convexity constraint ($\sum_{i}^{n} \lambda_j = 1$). Without that constraint, equation (1), would have constant returns to scale specification (CRS). Using that specification, it is assumed that farms are operating at their optimal scale (Fraser and Cordina, 1999). In the case of agriculture, increased amounts of inputs do not proportionally increase the amount of outputs. For instance, when the amount of water to crops is increased, a linearly proportional increase in crop volume is not necessarily obtained, one reason why the variable return to scale option might be more suitable for our problem (Rodriguez-Diaz *et al.*, 2004b). Coelli *et al.* (2002) and Haji (2006) on the other hand found that for small farms like the ones considered in this study, little scale economies could be realised, hence both specifications will be modelled. In addition, a comparison of both scores is interesting because it provides information on scale efficiency (SE). Coelli *et al.* (2002) showed that the relation is as follows:

$$SE = \frac{\theta^{CRS}}{\theta^{VRS}}$$

To calculate the efficiency of use of an individual input or subset of inputs, the "sub-vector efficiency" concept can be introduced. This measure generates a technical efficiency for a subset of inputs while remaining inputs are held constant (Speelman *et al.*, 2007). Using the notion of sub-vector efficiency proposed by Färe *et al.* (1994), the technical sub-vector efficiency for the variable input k is determined for each farm i by solving following programming problem (equation 2):

$$\begin{aligned}
& Min_{\theta k}\theta^{k}, \\
& subject\ to \qquad -y_i + Y\lambda \geq 0 \\
& \qquad\qquad\qquad \theta^{k} x_i^{k} - X^{k}\lambda \geq 0 \\
& \qquad\qquad\qquad x_i^{n-k} - X^{n-k}\lambda \geq 0 \\
& \qquad\qquad\qquad \sum_{i=1}^{n} \lambda_j = 1 \\
& \qquad\qquad\qquad \lambda \geq 0
\end{aligned}$$

Where θk is the input k sub-vector technical efficiency score for farm i. The terms x_i^{n-k} and X^{n-k} in the third constraint refer to x_i and X with the kth input (column) excluded, whereas, in the second constraint, the terms x_i^k and X^k include only the kth input. All other variables are defined identically as in equation 1.

3. Determining factors affecting efficiency

Analysis of the effects of firm-specific factors on productive efficiency has generated considerable debate in frontier studies (Sharma *et al.*, 1999). Use of a second stage regression model to determine the farm specific attributes in explaining inefficiency is suggested in a number of studies (e.g., Parikh and Shah, 1995; Hallam and Machado, 1996; Sharma *et al.*, 1999; Shafiq and Rehman, 2000; Wadud and White, 2000). An alternative to this approach is to incorporate farm specific attributes in the efficiency model directly (e.g., Battese *et al.*, 1989; Kumbhakar et al., 1991; Battese and Coelli, 1995).

The present study employs the former approach and uses a model to analyse the role of farm specific attributes in explaining inefficiency of water uses in private irrigated farms based on surface wells. To motivate our empirical model we assume

$$\theta k^* = \beta 0 + \beta 1z1 + \beta 2z2 + ... \beta jzj + e \quad = Z\beta + e \qquad (3)$$

where θ_k is the DEA sub-vector efficiency index used as a dependent variable. Z is a vector of independent variables related to farm specific attributes, β is the unknown parameter vector associated with the farm specific attributes, and e is an independently distributed error term assumed to be normally distributed with zero mean and constant variance, σ^2. The dependent variable in the regression equation (3) cannot have a normal distribution. The efficiency parameters vary between 0-1, they are censored variables and thus a Tobit model needs to be used. The variables included in the Tobit model are discussed in the following section.

4. Study area and data collection

The watershed of Smar is located in south-eastern Tunisia (South west of the city of Médenine). It covers an area of 55,700 ha. The population is estimated, according to the census of 2004, at 48,188 inhabitants. The region is marked by high dependence of its predominantly rural population on smallholder agriculture and wage labor.

The groundwater resources are scarce and over-exploited. This exploitation reaches 183% with annual renewable resource of 1.39 Mm3. Two subsystems can be distinguished: the sub-system of private irrigated farms is based on surface wells (432 surface wells). The subsystem of public irrigation schemes is based on collective tube-wells (3 collective tube-wells), normally established by the state. The water management is ensured by a water user association known as the 'GDA'. The agricultural production is based on vegetables and fruit trees.

Data was collected from private irrigated farms based on surface wells situated in Smar Watershed (South-eastern Tunisia) from February to March 2008. The data was obtained from interviews with 50 randomly selected irrigated farming households selected from the 240 households. During the interviews information was gathered on the irrigation schemes, household characteristics, farm activities, quantities and costs of inputs used in production, quantities and value of output, the quantity of water consumed and irrigation practices. For the purpose of efficiency analysis, output is aggregated into one category (vegetable production) and inputs are aggregated into four categories, namely, land, water, labour, fertilizers, seeds and pesticides. Summary statistics of these variables is given in table 1.

Table 1. Descriptive statistics on outputs and inputs used in efficiency analysis.

	Unit	Mean	St.dev.	Min	Max
Output	TD	19240,5	11466	1590	51200
Inputs					
Land	ha	1,94	0,9	0,5	4
Expenditure on Seeds	TD	2957,77	1586,99	253,125	8475,25
Expenditure on pesticides	TD	530,8	545,24	30	3000
Expenditure on fertilizers	TD	1505,1	1457,28	200	8900
Labour man	Days	471,64	295,68	40	1588
Water	m^3	22755,4	1988	3942	94608

In the Tobit analyses various farm-specific factors are analysed to asses their influence on the sub-vector efficiencies for water. The share of family labour, farmer's age and its square, farmer's education, land fragmentation index, Irrigated area equipped with water saving technologies and farmer's training.

To examine the role of relevant farm-specific factors in sub-vector efficiency the following equation is estimated:

$$\theta_i = \beta_0 + \beta_1 \text{FA} + \beta_2 \text{ EDU} + \beta_3 \text{ AGT} + \beta_4 \text{ FSA} + \beta_5 \text{ FA} + \beta_6 \text{ FS} + \beta_7 \text{ EIA} + \varepsilon_i \tag{4}$$

Where:

- θ_i is the DEA sub-vector efficiency index;
- FA is the farmer's age, measured in years;
- EDU is education dummy variable, = 1 if farmer accumulated at least 6 years of schooling, 0 otherwise;

- AGT is agricultural training dummy variable, = 1 if the farmer has gone through agricultural training, 0 otherwise;
- FSA is the square of farmer's age measured in years;
- FL is the share of family labour;
- FS denotes the size of a farm, defined in terms of the number of hectare;
- EIA is the irrigated area equipped with water saving technologies (drip and PVC irrigation technologies); and ε_i is random error.

III – Results

1. Data envelopment analysis efficiency measures

Both the CRS and the VRS DEA models for overall technical efficiency (equation 1) are estimated using the program DEAP (Coelli, 1996). Sub-vector efficiencies were modelled in GAMS using the methodology proposed by Färe *et al.* (1994) and the modelling suggestions of Kalvelagen (2004).

Table 2 gives the frequency distribution of the efficiency estimates obtained by the DEA methods. The average overall technical efficiencies for the CRS and the VRS DEA approaches are 0.74 and 0.86 respectively, indicating that substantial inefficiencies occurred in farming operations of the sample farm households. The average efficiency provides information about the potential resource saving that could be achieved while maintaining the same output level. In our case, results show that the same level of output can be reached by only using 74% and 86% of the used inputs under CRS and VRS specification respectively. Average scale efficiency, which can be calculated as the ratio between CRS and VRS efficiencies, is around 86%. This measure indicates that many farms are not operating at an efficient scale and that adjusting the scale of operation could improve the efficiency.

Table 2. Overall technical and water-subvector efficiencies under constant and variable returns to scale specifications.

Efficiency score	Tech CRS		Tech VRS		Water subvec CRS		Water subvec VRS	
	N° Farms	% of farms	N° Farms	% of farms	N° Farms	% of farms	N° Farms	% of farms
0-10	0	0	0	0	4	8	0	0
10-20	0	0	0	0	11	22	3	6
20-30	0	0	0	0	7	14	3	6
30-40	4	8	0	0	1	2	6	12
40-50	8	16	3	6	3	6	7	14
50-60	5	10	5	10	5	10	2	4
60-70	5	10	3	6	1	2	3	6
70-80	6	12	6	12	1	2	1	2
80-90	5	10	5	10	0	0	1	2
90-100	1	2	5	10	1	2	1	2
100	16	32	23	46	16	32	23	46
Average	0.74		0.86		0.52		0.69	
Scale Efficiency	0.86				0.75			

The sub-vector efficiencies for water demonstrated even larger inefficiencies. Average water efficiency was only 0.52 under CRS and 0.69 under VRS. Figure 1 gives a graphical representation of the cumulative efficiency distributions for the different measures. Again it is clear that under both returns to scale specifications more farms were highly inefficient in the use of water compared to overall technical efficiency.

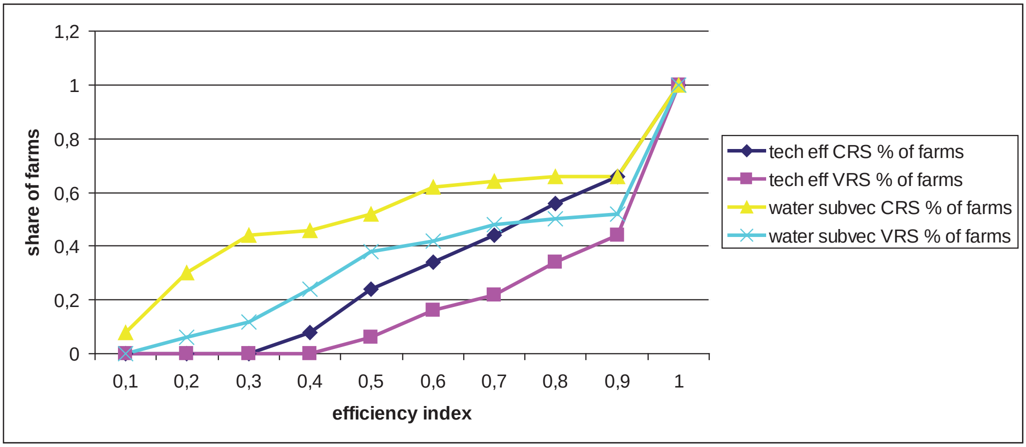

Figure 1. Cumulative efficiency distribution for technical and subvector efficiency for water under VRS and CRS specification.

Table 3 gives the correlation statistics between sub-vector efficiency for water and the overall technical efficiency, which help us to determine the relationship between the two efficiency measures. Technical efficiency and sub-vector efficiency were highly positively correlated both under CRS and VRS specification.

Table 3. Pearson correlations between efficiency measures

	CRS	VRS	SubCRS	SubVRS
CRS	1			
VRS	0,67**	1		
Sub CRS	0,85**	0,69**	1	
Sub VRS	0,609**	0,875**	0,79**	1

Note: ** indicates a 99% significance level

A paired sample t-test to analyse the equality between sub-vector efficiencies and overall efficiencies was statistically significant. Furthermore, sub-vector efficiencies for water were significantly lower than overall technical efficiency measures, both under CRS and VRS specification (table 4).

Table 4. Paired samples t-tests demonstrating the difference between overall technical efficiency and sub-vector efficiency

	Mean difference	Std dev.	t-statistic
CRS: subvector-overall technical efficiency	-0,21	0,21	-7,24**
VRS: subvector-overall technical efficiency	-0,16	0,19	-6,21**

Note: ** indicates a 99% significance level

2. Farm specific factors related to farm inefficiency

The second part of the analysis consists of identifying the characteristics that determine the sub-vector efficiencies for water of these private irrigated farms based on surface wells. Two separate Tobit regressions for CRS and VRS specifications were estimated using the Shazam's Tobit estimation procedure. The results are presented in table 5.

Table 5. Tobit regression coefficients (n=50).

Variable	Sub-vector CRS efficiency	Sub-vector VRS efficiency
Constant	0,907c	2,06a
Age (FA)	- 2,01	-2,52 b
Education (EDU)	1,5c	1,42b
Agricultural training (AGT)	-0,32	-0,44c
Age2 (FSA)	0,025	0,03b
Share of family labour (FL)	0,01	0,08
Size of a farm (FS)	-0,005c	-0,006b
Equipped irrigated area (EIA)	0,495a	0,56a
Log likelihood	-123,19	- 134,7

a Significant at 1% level

b Significant at 5% level

c Significant at 10% level

The estimated coefficients in the technical inefficiency model are also as expected. The farm size, agricultural training and age negatively influenced water efficiency, while the other significant variables had a positive effect on the efficiency measures.

The results in table 5 showed that the farmer's age has a negative, but a positive quadratic effect on all efficiency measures. However, the parameters are only significant for Sub-vector VRS efficiency at the 5 per cent significance level. This suggests that younger farmers are more likely to be inefficient than their older counterparts. The quadratic age variable has a positive coefficient indicating that inefficiency drops with age, perhaps because of the experience.

Farm size has a negative and significant effect on inefficiency levels, with suggests that, on average, large farms operate at higher efficiency levels than small farms.

Concerning the farmer training (AGT), variable of particular interest to policy maker, had a negative effect under both specifications, but were only significant under the VRS specification. Consequently, the negative and statistically significant at 10% level coefficient suggests that an increase in the training programs related to the irrigated agricultural contributes to higher technical efficiency levels of surface wells production on these farms.

Education (EDU) also has a positive impact on technical efficiency. Schooling helps farmers to use information efficiently since a better educated farmer acquires more information and is able to produce from a given input vector.

In addition, the results reveal statistically insignificant but consistently positive relationships between the share of family labour (FL) and all efficiency measures under both specifications.

Finally, the equipped irrigated area (EIA) was highly significant and had a positive effect on the sub-vector efficiency for water under both specifications at 5 per cent significance level.

IV – Conclusions and Policy Implications

The study used a DEA approach to measure the technical and sub-vector efficiency for water of irrigated private schemes based on surface wells in Smar watershed in south-eastern Tunisia.

Detailed survey data collected in 2008 on 50 sampled farmers were used to compute the efficiency measures. The results indicate that the mean technical efficiency under the CRS and VRS is 74% and 86%, respectively. This suggests that, on average, private irrigated farmers could increase their production by as much as 26% through more efficient use of production inputs. This result implies that improvement of technical efficiency should be the first logical step for considerably increasing irrigated production in the study region. Furthermore, considering that international competition is increasing and environment regulations are being tightened, the potential for increasing production by using more traditional inputs is limited.

The sub-vector efficiencies for water are with 52% (CRS) and 69% (VRS), even lower than the overall technical efficiencies. This might be an indication that farmers have little incentives to use water in an efficient manner, in the absence of a water price.

On the other hand, these low efficiencies suggest that substantial decreases in water use can be attained given existing technology, without compromising the key role in rural development played by small-scale irrigation. In this way there is room for lifting part of the increasing pressure on water resources by reallocating a fraction of the irrigation water elsewhere.

In a second step, the relationship between the sub-vector efficiency for water and various attributes of the farm and farmer was examined. The results of the Tobit models can help policy makers or extension services to better aim efforts to improve water use efficiency.

Estimation results from the technical inefficiency effects model suggest that the share of family labour (FL), the agricultural training (AGT), the equipped irrigated area (EIA), the education level (EDU) of the farmer and the square age of the farmer (FSA) variables have a significant and positive relationship with technical efficiency.

Furthermore, education level (EDU) and agricultural training (AGT) particularly used for pruning are associated with higher levels of technical efficiency. This highlights the need for government policies, through extension activities, to set up training programs on irrigated crops in arid zone

More research would also be needed to generalise the results. This paper builds on information of 50 farmers, spread over a significant number of irrigation schemes, but a similar approach in other irrigation schemes in rural areas could provide an interesting comparison.

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Water rationalization in Egypt from the perspective of the virtual water concept

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Abstract. Egypt is located in the hyper arid climatic zone, where rainfall is scarce and the desert covers most of the land. The available water resources in Egypt are restricted to a fixed Nile quota (i.e. 55.5 billion cubic meters) in addition to a deep non-renewable groundwater reservoir and a total annually torrent water of 1.5 BCM. Water demands were multiplied in recent decades as a result of overpopulation, agriculture expansion and industrial and living standard progress. The water shortage is the main constraint and a major limiting factor facing the implementation of the country future economy in industry, several actions are required to rationalize water uses. Recycling of agriculture wastewater and trapping water losses are satisfying the Egyptian water needs, which are 25% higher than the available water resources. Municipal water distribution networks in Egypt have witnessed great expansions during the last three decades in order to cope with the rapid urbanization projects and increased population. In this paper, a vision for the future water status in Egypt is presented. This vision is based on a perception of the current available water resources status. The topics of water usage, water use efficiency, the institutional and legislative frameworks of water management, and the strategies and policies to rationalize water use and to augment water supply are discussed. It was concluded that virtual water concept is an essential tool in calculating the real water use of a country, or its water footprint. Water losses in Egyptian agriculture sector are very large compared with these losses in industrial and domestic uses. So it is very important to take the concept of virtual water in consideration when the issue of water rationalization is discussed.

Keywords. Egypt – Water rationalization – Virtual water – Water use efficiency.

Rationalisation de l'eau en Egypte du point de vue du concept de l'eau virtuelle

Résumé. *L'Egypte est située dans une zone climatique hyper-aride, où les précipitations sont très faibles et le désert couvre la grande partie du territoire. Les ressources en eau disponibles en Egypte sont limitées à une quote-part du Nil établie (à savoir, 55,5 milliards de mètres cubes) en plus d'un réservoir d'eaux souterraines non-renouvelables profondes et d' une quantité d'eau torrentielle annuelle de 1.5 milliards de mètres cubes. Ces dernières décennies, la demande d'eau s'est multipliée à cause du surpeuplement, de l'expansion de l'agriculture et de l'accroissement de l'industrie et de l'élévation du niveau de vie. La pénurie d'eau représente la contrainte majeure et le principal facteur limitant pour le développement de l'économie industrielle du pays. Des actions différentes sont donc nécessaires pour rationaliser l'utilisation de l'eau. Le recyclage des eaux usées en agriculture et la réduction des pertes d'eau contribuent à satisfaire les besoins en eau dans le pays, qui dépassent de 25% les ressources en eau disponibles. En Egypte, les réseaux municipaux de distribution de l'eau ont connu une expansion considérable ces trois dernières décennies afin de faire face aux projets d'urbanisation rapide et à l'accroissement de la population. Dans ce travail, nous allons présenter une vision du statut de l'eau futur en Egypte. Cette vision repose sur une perception du statut actuel des ressources en eau disponibles. L'accent est mis sur des thèmes tels l'utilisation de l'eau, l'efficience d'utilisation de l'eau, le cadre institutionnel et réglementaire de la gestion de l'eau et les stratégies et les politiques pour rationaliser l'utilisation de l'eau et augmenter l'approvisionnement. On en conclut que le concept d'eau virtuelle est un outil essentiel pour le calcul de l'utilisation réelle de l'eau d'un pays ou de son empreinte sur l'eau. Dans le secteur agricole, les pertes d'eau sont très significatives par rapport aux pertes pour l'usage industriel et ménager. Par conséquent, il est très important de considérer le concept d'eau virtuelle dans la débat sur les enjeux de la rationalisation de l'eau.*

Mots-clés. *Egypte – Rationalisation de l'eau – Eau virtuelle – Efficience d'utilisation de l'eau.*

I – Introduction

Egypt is located in the hyper arid climatic zone, where rainfall is scarce and the desert covers most of the land. In addition to its fixed Nile quota, a deep non-renewable groundwater reservoir may be utilized with a rate of 2.7 BCM/year over a period of 100 years. The higher the exploitation rate, the shorter the period of use will be. Egypt is now capable of satisfying its water needs, which are 25% higher than the available water resources, through recycling of agriculture wastewater and trapping water losses. The water shortage is the main constraint and a major limiting factor facing the implementation of the country future economy.

The water demands were multiplied as a result of population growth, agricultural expansion, industrial development and rising of living standards. In this paper, a vision for the future water status in Egypt is presented. This vision is based on a perception of the current available water resources status. The topics of water usage, water use efficiency, the institutional and legislative frameworks of water management, and the strategies and policies to rationalize water use and to augment water supply are discussed.

Renewable water resources in Egypt are confined to the withdrawal quota from the Nile, the limited amount of rainfall, the shallow groundwater reservoirs in the Nile Valley and Delta and the coastal strip. The deep groundwater in the eastern desert, the western desert and Sinai, are almost non-renewable resources. The non-traditional water resources include reuse of agricultural drainage water and treated wastewater, as well as the desalination of seawater and brackish groundwater. Agriculture in Egypt, as in most developing countries, represents the main usage of water, followed by the residential, industrial and tourist uses. It is worth to mention that these sectors are users, as well as consumers of water, while other sectors like river transport and hydropower generation only use water without real consumption. Most data available on water uses in Egypt are approximate and are not based on field measurement, because there are no measuring devices with acceptable accuracy for the water uses for either irrigation or the municipal and industrial sectors.

II – Water supply in Egypt

There is no effective rainfall in Egypt except on a narrow strip located along the northern coast; agriculture is almost totally dependent on irrigation. The total water resources currently available in Egypt are totally estimated as 73.8 billion cubic meters (BCM) per annum, including the natural and non-traditional resources. Table (1) shows that the present annual use of water is 62.6 BCM. Table (2) shows the distribution of water consumption between the various sectors. The agricultural sector consumes about 81 percent of the total water available. The total torrent water is estimated at 1.5 BCM annually. The Nile is the major source of water in Egypt and agricultural development is closely linked to the Nile River and its management.

A major component of the strategy for agricultural development is the improvement of the efficiency of Nile water use, increasing the productivity per water unit. Total water consumption in the year 1995 was approximately 49 BCM. Water consumption for the proposed cropping pattern for the year 2017 should amount to around 67 BCM for the cultivation of about 9.2 million ha. The additional water is expected to result from reducing the area under rice to 420 000 ha and the cultivation of new varieties with a shorter growth duration and lower water consumption. This should reduce the consumption of irrigation water for rice cultivation by four BCM. A saving in the consumption of water on sugar cane is expected to be almost 0.5 BCM as a result of improving water use efficiency and land leveling by laser of about 42 000 ha. A further saving is expected to result from improving the use of drainage water and the use of nonconventional water resources. The Government has indicated its intent to shift emphasis from its role as the central (or sole) actor in developing and managing water supply systems, towards promoting participatory approaches in which water users will play an active role in the management of irrigation systems and cost sharing. Important institutional and legislative measures have been taken recently to promote the establishment of sustainable participatory irrigation management (PIM) associations. However, despite these measures, the development of water users associations (WUA's) as effective partners in irrigation management remains at an early stage. In the new lands, the concept of PIM is not yet effectively operational for a variety of economic, financial and institutional reasons. While most settlers recognize the importance of WUA's in the equitable distribution of available water, uneven water availability, either due to design shortcomings or to lax enforcement of rules against excess abstraction by front-end water users, has acted as a disincentive to the successful operation of WUAs in many instances (FAO, 2000).

Table 1. Availability and current use of water.

Source	Availability BCM/annum	Percent	Current use BCM/annum	Percent
Nile	55.5	75.2	51.7	82.6
Underground	11.3	15.3	5.2	8.3
Agriculture*	5.0	6.8	3.7	5.9
Waste water	1.5	2.03	1.5	2.4
Rainfall	0.5	0.67	0.5	0.8
Total	73.8	100	62.6	100

*Re-use of drainage water
(Source: FAO, 2003)

Table 2. Distribution of water use by sector.

Sector	Consumption BCM/annum	Percent
Agriculture	50.8	81.1
Industrial and municipal	8.8	14.1
Electricity	2.0	3.2
Navigation & winter closure	1.0	1.6
Total	62.6	100

(Source: FAO, 2003)

III – Policy of water resources in Egypt

In 1929, an agreement between Egypt and the United Kingdom, on behalf of the Sudan, was signed to ratify the historical Nile water rights for each country. The recorded water rights were 48 billion cubic meters (BCM) for Egypt and four BCM for Sudan. In 1933, the Government of Egypt implemented a water policy designed to benefit from the extra storage of the Nile water upstream from the old Aswan reservoir after its second elevation. That policy aimed at cultivating additional 160,000 ha in Lower Egypt and converting 208,000 ha from basin to permanent irrigation, along with the establishment of public open drains in the permanent irrigation areas. In 1948, the Egyptian Government presented a memorandum to the cabinet showing that after 1950 there would be a pressing need to find extra water resources. The memorandum recommended several Upper Nile projects to increase the river flow and to avoid flood hazards. After the 1952 revolution, the High Aswan Dam (HAD) project was presented to the Government and was approved. Its construction was planned for inside Egypt, as compared to the Upper Nile projects.

In 1959, an agreement between Egypt and the Sudan had been reached for the optimal use of Nile Water as an integral part of 1929 agreement. According to the agreement, the quota for Egypt and the Sudan had been increased by 7.5 and 14.5 BCM, respectively. These values were calculated according to the mean annual natural Nile flow at Aswan, Egypt, from the recorded inflows for 70 consecutive years, (i.e. 84 BCM/year). Moreover, it was recommended to trap the Upper Nile water losses and optimally utilize those losses in equal shares. The new quota allowed Egypt to increase its cultivated area to reach 2.4 million ha. In 1975, the Ministry of irrigation established a policy aiming at rebalancing the water status. Rebalancing was proposed through the rationalization of crop water applications, on basis of scientific studies and field experiments. The additional demands were to be satisfied by the reuse of drainage water, expansion of groundwater utilization especially in the Nile Delta region and the optimal use of rainfall on the Northern coast. In 1977, the Ministry of Irrigation began preparing the National Water Master Plan (NWMP) in collaboration with the German Development Bank (KFW) and UNDP. The NWMP aimed at setting plans to satisfy water demands over a period of 20 years (1980–2000). In 1982, the Ministry of irrigation reset its water policy according to the results of the NMWP; the new policy showed that 11.7 BCM of extra water was needed to satisfy future water demands. The policy showed that this additional water could be secured through Egypt share in the first phase of the Jonglie canal (2.0 BCM/year), which was designed to trap a small port on of Nile water losses in the Sudd region, southwest of the Sudan. Ultimately, this plan was intended to increase groundwater utilization up to 4.9 BCM/year and to expand drainage water reuse practices up to 10 BCM/year. In 1994, Ministry of Water resources and irrigation (MWRI) and the General Authority for Land Reclamation prepared a comprehensive and ambitious plan intended to expand the country's agricultural horizon by 1.28 million ha up to the year 2025. This would be achievable by limiting the rice area to 280,000 ha; improving surface irrigation projects; maximizing the drainage water reuse, treated wastewater recycling, and optimizing groundwater utilization, as well as the completion of the first phase of the Jonglie canal. In October 1997, MWRI prepared a draft of "Water resources Strategy of Egypt Until 2017" The strategy also analyzed the projected water balance in the year 2017 for three scenarios: the first is for reclaiming 612,000 ha, the second is for reclaiming 0.9 million ha, and the third for reclaiming 1.36 million ha. Securing the required extra water (about 24 BCM) has to be accomplished through the completion of the first phase of Jonglie canal, an increase in groundwater utilization, water reuse practices, and a reduction of the areas of high water requirement crops (MWRI, 1997).

IV – Water management practices in Egypt

Since the 1970's, water uses in Egypt have exceeded the available resources. Accordingly, the Government has provided additional resources by recycling drainage and wastewater, trapping water losses, and with water use rationalization practices. At present, municipal and industrial uses involve many negative aspects. These include high losses in the distribution networks, misuse of clean drinking water in small factories, workshops, car washing, and in irrigating backyards and public gardens. Other irrational uses include the absence of long-term technical or financial plans for preventive maintenance; and inadequate tariff policy.

Municipal water distribution networks in Egypt have witnessed great expansions during the last three decades in order to cope with the rapid urbanization projects and increased population. The irrigation improvement Project (IIP) in Egypt was launched due to the impetus of a leading research project executed by the National Water Research Center (NWRC) in 1977-1984. The project examined various alternatives capable of improving the on farm water management practices, including laser land leveling, developing mesqa (tertiary canal) and water distribution structures, and forming water users associations (WUAs). This project provided the following benefits;

1. Land saving due to the construction of the improved mesqas and saving about 2% of the total command area of the mesqa for agriculture.
2. Increase of crop yield due to the better conditions of water availability.
3. Equity of water distribution by improving the water allocation between the head and tail of the mesqa.
4. Reduction of 50-60% of irrigation time due to improving the conveyance efficiency and irrigation scheduling.
5. Using the findings of that research project in a large improvement program (1984-1996) implemented by MWRI on an area of 156,000 ha in five Governorates.

Another irrigation improvement project started in 1997 over an area of 100,000 ha. The irrigation and drainage law No. 12 for the year 1984 was amended to recover the relevant improvement cost from farmers at installments over twenty years without interest. There were also pilot projects to establish federations of WUA's and to form water boards to take part in Operation and Maintenance of branch canals. On one hand, the various irrigation improvement projects have several positive impacts (Allam, 1995). On the other hand, there were various difficulties like the slow rate of implementation, high cost of improvement, weak monitoring and follow-up programs, and funding problems for the pumping units for the raised mesqa (MWRI, 1998). The government has imposed modern irrigation methods in the new lands, however the relatively high maintenance costs caused the farmers to remove drippers or sprays and thus convert modern irrigation methods into surface ones. The government is planning to switch the orchards and other fruits farms into drip irrigation to save about 0.75 BCM/year. The main obstacle that faces this program was providing the funds needed for modernization. Farmers have no significant incentive to share the cost, as long as the government provides their water requirements free of charge. The crops of high water requirements are mainly sugarcane, banana and rice. Sugarcane is cultivated in Upper Egypt with a total area of less than 200,000 ha. Although one ha of sugarcane consumes triple the amount of water required for one ha of sugar beets, it is difficult to convert sugarcane agriculture into sugar beets. Firstly, because most of the existing sugar mills are sugarcane mills. Secondly, sugar beet is a winter crop and may not be suitable for the relatively hot climate of Upper Egypt. The solution may be the improvement of the irrigation methods for sugarcane to decrease the losses, as well as a gradual reduction of sugarcane areas. In light of the deregulation of crops prices, rice became one of the most important lucrative crops for farmers. Its grown areas gradually increased from about 280,000 ha by the mid-70's to about 0.8 million ha in 2000. Rice has become one of the most important Egyptian exports in the agricultural sector. The real intentions of the government towards this crop are not yet clear. The banana farms, on the other hand, consume a lot of water; most farms are in the newly reclaimed sandy soils which area characterized by excessive natural drainage.

V – Virtual water concept

Virtual water is the amount of water that is embedded in food or other products needed for its production. For example, to produce one kilogram of wheat we need about 1,000 liters of water (i.e. the virtual water of this kilogram of wheat is 1,000 liters), meat needs about five to ten times more. The per capita consumption of virtual water contained in our diets varies according to the type of diets, from 1m3/day for a survival diet, to 2.6m3/day for a vegetarian diet and over 5m3 for a USA style meat based diet. It is clear that moderating our diets especially in the developed world could make much water available for other purposes.

With the trade of food crops or any commodity, there is a virtual flow of water from producing and exporting countries to countries that consume and import those commodities. At the global level, virtual water trade has geo-political implications: it induces dependencies between countries. Therefore, it can be regarded either as a stimulant for co-operation and peace or a reason for potential conflict. The water consumed in the production process of an agricultural or industrial product has been called the 'virtual water' contained in the product (Allan, 1998). If one country exports a water intensive product to another country, it exports water in virtual form. In this way some countries support other countries in their water needs. For water-scarce countries it could be attractive to achieve water security by importing water-intensive products instead of producing all water demanding products domestically. Reversibly, water-rich countries could profit from their abundance of water resources by producing water-intensive products for export. Trade of real water between water-rich and water-poor regions is generally impossible due to the large distances and associated costs, but trade in water-intensive products (virtual water trade) is realistic (Hoekstra and Hung, 2002).

Virtual water trade between nations and even continents could thus ideally be used as an instrument to improve global water use efficiency, to achieve water security in water-poor regions of the world and to alleviate the constraints on the environment by using best suited production sites (Turton, 2000).

VI – Planning water policy using virtual water concept

Virtual water is an essential tool in calculating the real water use of a country, or its water footprint, which is equal to the total domestic use, plus the virtual water import, minus the virtual water export of a country. A nation's water footprint is a useful indicator of the demand it places on global water resources. At the individual level, the water footprint is equal to the total virtual water content of all products consumed. A meat diet implies a much larger water footprint than a vegetarian one, at an average of 4,000 liters of water per day versus 1,500. Being aware of our individual water footprint can help us to use water more carefully. Virtual Water for Crops (tables 3 & 4); water lost along with loss of different types of food (table 5), Agriculture crop trade balance (table 6 & 7), irrigation efficiency (table 8) and cropping pattern table 8) are the most important elements for obtaining the best water schedule and rationalization.

This information reveals the following:

- Crops are differing widely in their water use efficiency; some crops have low (need more than 2000 m^3/ ton), moderate (need more than 750 m^3/ ton) and high efficiency (need less than 500 m^3/ ton).
- The production of 1 liter from sunflower oil needs to 8000 liter of water, while production of 1 Kg vegetables require only 250 liter of water.
- The crops or food lost means the lost of water, this lost is very high in the case of low water efficiency crops (sugar and oil crops and rice), whereas it is low in the case of high efficiency crops (fruits and vegetables).

Table 3. Virtual Water for Certain Crops in Egypt.

Virtual Water m³/ton	Crop
Low Efficiency Crops	
10000	Soya bean
8000	Sun flower
3500	Cotton
2700	Sugar Cane
2300	Peanuts
2000	Rice
Medium Efficiency Crops	
1330	Banana
1300	Sugar beet
1080	Faba bean
960	Corn
750	Wheat
High Efficiency Crops	
600	Olive
500	Grape
440	Citrus
480	Bean
250	Potato
225	Melons
200	Tomato
130	Onion

Calculated and modified after FAO (2005) and MALR (1994).

Table 4. Virtual water content of certain crops in Egypt and the world.

Virtual water m³ / ton		Crop
World range	**Egypt**	
1000-1700	2700	Sugar cane
900-1450	2000	Rice
700-1100	1300	Sugar beet
250-400	1300	Banana
200-500	500	Citrus
80-100	200	Tomato

Calculated and modified after FAO (2005) and MALR (1994).

The data in table (5) refer the following:

- The loss of one loaf of bread means the loss of 75 liters of water
- The loss of a cup of tea (three cubes of sugar) means the loss of 40 liters of water
- The loss of cup of rice means the loss of 200 liters of water
- The loss of one spoon of sunflower oil means the loss of 80 liters of water

Table 5. Volume of water lost along with loss of different types of food.

Water (liter)	Type & Quantity
75	Loaf of Bread (100gr.Wheat)
54	Broad Bean (50gr)
38	One Potato (150gr)
30	One Tomato (150gr)
66	One Orange (150gr)
400	Cup of Rice (200gr)
200	One Banana (150gr)
13	Cube of Sugar (5gr)
80	Spoon of Sun Flower oil (10ml)

Calculated and modified after FAO (2005) and MALR (1994).

Table 6. Agriculture crop trade balance in Egypt.

Crop	Production $10^9 m^3$	Exports $10^9 m^3$	Imports $10^9 m^3$
Wheat	4.7		4.5
Corn	5.9		4.3
Pulses	0.4		0.3
Sugar	3.8		1.3
Plant oils	0.8		7.2
Meat	10.9		1.6
total	26.5		19.2
Cotton	3.5	0.35	
Rice	7.8	0.80	
Potatoes	0.6	0.08	
Vegetables	3.5	0.09	
Fruits	3.5	0.06	
total	18.9	1.38	

Calculated and modified after FAO (2005) and MALR (1994).

Table 7. Virtual water trade balance in Egypt.

Crop	Production 10^6 ton	Exports 10^6 ton	Imports 10^6 ton
Wheat	6.3		6.0
Corn	6.1		4.5
Sugar	1.4		1.0
Vegetables oils	0.1		0.9
Meat	1.3		0.12
total	15.6		12.82
Cotton	1.0	0.10	
Rice	3.9	0.40	
Potatoes	2.2	0.30	
Vegetables	14.0	0.35	
Fruits	7.0	0.12	
total	28.1	1.27	

Calculated and modified after FAO (2005) and MALR (1994).

The daily Food & water consumption of Egyptian family (5 persons) represented in table (8) show that a loss of 5% means the loss of 2.4 BCM /year (this amount of water is sufficient to cultivate 100,000 ha / year.

Table 8. The Daily Food & water Consumption of Egyptian Family (5 persons).

Water) Liter)	Quantity gr./day	Type
1500	2000	Wheat
770	800	Corn
1110	550	Rice
990	410	Sugar
75	292	Potatoes
120	112	Pulses
250	114	Oil Seeds
1200	150	Vegetable Oil
480	2400	Vegetables
540	1200	Fruits
	310	Meat
	27	Offal
	653	Milk
	29	Egg
	32	Animal Fat
1785	1051	Total (animal Products)
	136	Fish
8820	9215	Total

Calculated and modified after FAO (2005) and MALR (1994).

Table (9) represents the annual loss of water along with the post harvesting processes. The data indicate that the total value of the loss water is satisfied to cultivate 125,000 ha/year also this amount representing 75% of the domestic use of water in Egypt. The data refer to the importance of the use of the virtual water concept in the issue of water rationalization.

Table 9. Quantity of water lost along with post harvest losses.

Wasted Water	Post Harvest Losses		Crop
Mm^3	% from Production	1000 Ton	
905	19	1207	Wheat
448	6	224	Rice
809	14	843	Sorghum
71	8	74	Starchy Roots
54	10	214	Sugar Crops
44	1	145	Legumes
37	9	1344	Vegetables
269	10	663	Fruits
47	2.5	21	Oil crops
2976	-	4769	Total

Calculated and modified after FAO (2005) and MALR (1994).

VII – Conclusion

Virtual water (impeded water) is an essential tool in calculating the real water use of a country, or its water footprint, which is equal to the total domestic use, plus the virtual water import, minus the virtual water export of a country. A nation's water footprint is a useful indicator of the demand it places on global water resources. At the individual level, the water footprint is equal to the total virtual water content of all products consumed. A meat diet implies a much larger water footprint than a vegetarian one, at an average of 4,000 liters of water per day versus 1,500. Being aware of our individual water footprint can help us use water more carefully.

In Egypt the water losses in the agriculture sector is very large compared with these losses in industrial and domestic uses. So it is very important to take the concept of virtual water in consideration when the issue of water rationalization is discussed.

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Innovative Approach for Efficient Management of Ein Sultan Spring in Jericho

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Abstract. Ein Sultan natural spring is a unique water source in Jericho for all uses. It has a water discharge ranging from 550 to 720 cubic meters per hour with highs during summer and lows in winter. It has unexpectedly positive trend of water discharge over the studied period (1960-2008). Only 48% of the springs' water is allocated to agriculture, much below its formal quote, but still subject to mounting pressures from non-agricultural competing sectors such as domestic, industrial and ecotourism. The time-share water right adds to the uncertainty of farmers' water security and induces inefficiency in allocating this valuable resource. The study is based on secondary data covering hydrology indicators of the spring system and primary data via interviewing farmers and agricultural extension agents. Despite the limited research inputs, the study gave a hint about the situation and enabled thoughtful discussion and extraction of useful suggestions. It showed possible causes of water use inefficiency, among which is the water supply driven irrigation (linked to water rights) rather than decisions based on crop water requirements, and lack of informed decisions at farm and policy making levels. The study emphasizes the need for institutional reform particularly reinforcing Ein Sultan Irrigation Water Cooperative as a water user association, and the need for information-based integrated irrigation water management strategy that tackle the spring as a unique socio-economic system, maintain water-rights and introduce water pricing policy which recognize water as valuable economic good. The study stresses the importance of active participation of farmers in designing and implementing such policies and measures.

Keywords. Spring System **–** Water-rights – Cropping Pattern – Water Users Association – Informed Decisions – Allocation efficiency.

Approche innovante pour une gestion efficiente de la source d'eau d'Ein Sultan Spring à Jéricho

Résumé. *A Jéricho, la source naturelle d'Ein Sultan constitue une source unique, exploitée pour tout type d'usage. Le débit est compris entre 550 et 720 mètres cubes par heure avec des pics en été et une réduction en hiver. Pendant la période à l'étude (1960-2008), le débit a connu une évolution positive imprévue. Seulement 48% de l'eau de source est alloué à l'agriculture, un pourcentage bien en dessous de sa quote-part formelle, mais on enregistre encore une pression croissante exercée par les secteurs non-agricoles concurrents, à savoir le secteur ménager, industriel et l'écotourisme. Le droit d'accès à l'eau en partage contribue à augmenter l'incertitude de la sécurité hydrique des exploitants et cause une allocation inefficace de cette ressource précieuse. Des données secondaires sur les indicateurs hydrologiques du système d'eau de source et des données primaires obtenues en interviewant les exploitants et les vulgarisateurs sont passées en revue. Malgré les résultas limités de la recherche, cette étude propose un état des lieux, des pistes de réflexion et des suggestions utiles. On met en évidence les causes possibles de l'inefficience d'utilisation de l'eau, parmi lesquelles l'irrigation basée sur l'approvisionnement en eau (corrélé au droit à l'eau) au lieu d'une prise de décisions considérant les besoins en eau des cultures, et l'insuffisance des decisions informées au niveau de l'exploitation et au niveau politique. Par ailleurs, on souligne la nécessité d'une réforme institutionnelle en particulier, par le renforcement de la Coopérative de l'eau d'irrigation Ein Sultan comme association des usagers de l'eau, et aussi la nécessité de mettre au point une stratégie de gestion intégreé de l'eau d'irrigation basée sur l'information, considérant la source comme un système socio-économique unique, de maintenir le droit à l'eau et d'introduire une politique de tarification de l'eau reconnaissant l'eau comme un bien économique précieux. L'accent est enfin mis sur l' importance de la participation active des exploitants dans la conception et la mise en oeuvre de ces politiques et ces mesures.*

Mots-clés. *Système de source – Droit à l'eau – Modèle de culture – Association des usagers de l'eau – Décisions informées – Efficience d'allocation.*

I – Introduction

Around 53,000 dunums[1] in the West Jordan valley WJV are under irrigation. They comprise almost 52% of irrigated areas in the West Bank (ARIJ, 1998). Quite significant especially when off-season production, productivity and production costs are considered. Area under cultivation comprises only a fraction of the arable area. In Jericho Governorate, for example, only 4% of the total area is under cultivation, compared to 24% plus for the West Bank and 31-35% for Gaza Strip (PCBS, 2004). Around 23% is under permanent crops and the rest (or 77%) under temporary crops (PCBS, 2004). There is obvious decline in areas allocated to permanent crops with areas partially transferred to temporary crop cultivation (PCBS, 2004). Reasons behind this failure to efficiently use available lands are mostly due to the military occupation and its political, security and military measures.

Agriculture consumes in the average 60-70% of water, especially in the developing countries. Agricultural activities are, for several reasons, the least efficient in using this resource. This gives priority to be geared towards improving the water use efficiency, especially in agriculture and more precisely in developing countries, if conflicts at local, regional and global to be avoided.

This study has the intention to tackle the crucial issue of efficient allocation of irrigation water at farm (micro-) and spring (meso-) levels and on attempts to contribute to setting up a framework for a tangible and practical experimentation, researching and studying.

Resources (time and material) are neither available nor allocated to conduct an ambitious research and data gathering. Instead, a rapid research approach is used to investigate and test certain hypothesis respect irrigation water use efficiency in specific and allocation of Ein Sultans' irrigation water in general.

II – Methodology

Land, in the form of territory, is a pre-requisite for a state's existence while freshwater is a pre-requisite for life (FAO 2004). So, water, not land, is now the limiting factor for improving agriculture production. Therefore, maximizing water productivity, not yield per unit area, is the strategy for water management.

The importance of this study lies in tackling the spring in a holistic approach as a unique socio-economic and technical system and hence better understanding of its components (elements or sub-systems) and better foundation to working out sound solutions or decisions.

The study will indirectly contribute to the assessment of and setting objectives of water rights reforms based on the so-called "Dublin Principles". These are: 1. Freshwater is a finite and vulnerable resource; 2. Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels; 3. Women play a central part in the provision, management, and safeguarding of water; 4. Water has an economic value and should be recognized as an economic good (FAO, 2004).

A combination of quantitative and qualitative data was used to generate a blend of different types of policy-relevant information and ideas. Data used for the analysis came from secondary sources such as reports and previous studies; administrative records especially respect water discharges and water-rights and primary data through interviewing farmers and extension agents.

Although a few numbers of farms and extension agents were interviewed to study the Ein Sultan spring system, still these findings gave a hint about the situation and enabled extraction of useful suggestions and recommendation.

III – Results and Analysis

1. Ein Sultan spring system

A. Springs' hydro-geological features

West Jordan valley, particularly, the southern part (Jericho-Auja area) comprises an important outlet of underground water cached somewhere in the higher plateau, example is Auja, Nweimeh, Deyouk, Ein Sultan, Qilt, Ein Fashkha, Ein Gedi and others. These springs differ sometimes significantly in their hydrological, physical and chemical characteristics/indicators (ARIJ, 1998; Zayed *et al.*, 2005), which simply mean that each should be considered separately as a unique water system with much in common and other features such as technical and socio-economic vary widely.

Ein Sultan spring is considered by ARIJ, 1998 as a member of the Wadi el Qilt spring system. Its hydrological parameters used in vulnerability assessment (Table 1) shows a quite difference between Ein Sultan and other springs in the Valley or even in the neighborhood. The vulnerability index for Ein Sultan is low (Zayed *et al.,* 2005).

Table 1. Hydrological Parameters for Vulnerability assessment of Ein Sultan.

	rating for DtW	**rating for Recharge**	**rating AM**	**rating of Soils**	**rating for Top. slope**	**rating for aquitar**	**Rating for Karst**	**Result**
	D	R	A	S	T	I	C	
Rate	3	10	10	6	7	6	10	
Weight	5	4	3	2	1	5	3	
Computed Vulnerability index = ∑ Rate * Weight								164

Key to Table (1) above

Aquifer pumped	Lower
(DtW) Depth to Water	…
(DtA) Depth to Aquifer	…
Rainfall over Recharge area (mm/yr)	700 mm/year
(AM) Aquifer Media	Massive bedded limestone
Sig. area of Soil cover (>2m) within inferred flow path	Partly w irrigated and irrigable areas
Topography/slope in direct recharge area	lower-moderate
Protective aquitards in subsurface	yes
Karst observed along flow path	Yes

Source: extracted from (Zayed *et al.,* 2005)

B. Water discharges

The spring has an average discharge of 650 cubic meters (cbm) per hour with significant monthly and annual fluctuations (Figure 1). The flow discharge of the spring has apparently a positive trend. Note that discharges are much higher in the summer months compared to winter months. Water demand for irrigation is the opposite, i.e. more water is required in winter for the off-season production.

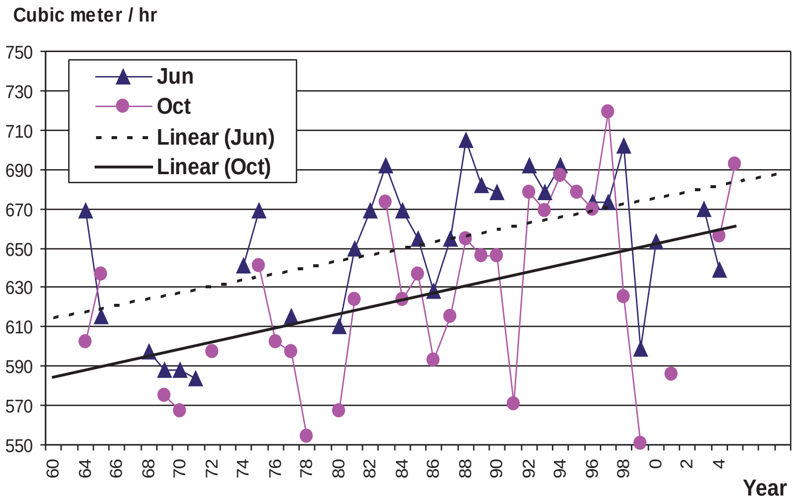

Figure 1. Monthly flow discharge of Ein Sultan spring and trend (1960-2008)

Water discharges of the different springs in the vicinity of Ein Sultan (s) such as Nweimeh (n), Auja (a) and Duyouk (d) are somehow correlated with the exception of Duyouk spring which has a very low correlation (r) with Auja (ra.d) of only 0.28 and even negative correlation with Nweimeh (rn.d) and Ein Sultan (rs.d) of - 0.31 and -0.17 respectively. The other springs are either highly correlated such as rs.a of 0.63**, rs.n of 0.84**, or moderately correlated such as ra.n of 0.42* (where * and ** mean significant statistics at $\alpha \leq 0.05$ and $\alpha \leq 0.01$ respectively).

All these seemingly adjacent natural springs have positive trend of the annual discharges except for Duyouk which has a diminishing trend. Discharge figures need further analysis and investigation since the hypothesis of diminishing flow discharges of the springs can not be proved true.

2. Water rights and water use efficiency

According to Van Aken *et al.,* 2008, Islam recognizes two rights related to water:

1. Shefa, the right of thirst, as universal right for human to quench all their thirst and that of their animals;
2. Shirb, the right of irrigation, which gives all users the right to water their crops in case of need.

Ein sultans' irrigation water flows into 4 canals (A, B, C and D). Water rights are based on time-share and weekly basis. Ein Sultan spring's water is divided into 672 hours, i.e. 4 canals times 168 hours per week, while Ein Auja is divided into a 5-day rotation (120 hours) (Sbeih, 2005).

Ein Sultans' water is divided into two (2) categories: The Bustani (Garden) and Felha (Agricultural) waters. The Bustani water is thought of as water for gardens and domestic use. It comprises one third of the springs water with 15 minutes per dunum[2] with time share identical with real time, i.e. 1 hour means 1 hour. The felha water is inherited and can be sold but not attached to land. The Bustani water is linked to the land. Here, the water time-share is sold or rented with the land but can not be exchanged from channel A to B …etc. The Felha water comprises 2 thirds of the springs water. 1 hour of the Felha water comprises only 23 minutes of real time and can be sold or rented.

Many jurisdictions do not permit the trade in water rights separately to the land to which they have been issued indicating that such a right is not personal but incidental to his ownership (FAO, 2004). This is also the case in Ein Sultans' water, where time-share system is made flexible to meet local needs and future needs with less social conflict. Selling the water rights was strictly linked to land for Orchards' water (Bustan).

The water rights were changed in 2006 from time-share system to cubic meter after converting canal conveyance system into pressurized pipes. It is controlled by the Jericho Municipality (JM) officials. With the volumetric water rights, compared to time-share, farmers would became more secure from the water flow perspective which positively affects the utility and thus the value of any land tenure rights they hold (FAO, 2004).

Sharing water between farmers on time-share rights is, more or less, a zero-sum game in that the gain of one farmer (beneficiary) is the loss of another (see Fisher et al., 2002) depending on the opportunity cost of water (productivity) at the different farms, which is different depending on technique, production pattern, and many other administrative and farm-specific factor.

Efficient water allocation/water use efficiency suggests the transition from a concept of water allocation based on household heads towards a water allocation according to the crops in the fields. It requires allocation of water, or calculates water to be allocated, at farm level according to what is planted and not according to 'water rights'. Setting water rights as upper limit (ceiling for water consumption at farm level) is another measure towards improving water use efficiency and decision making in that respect. Better if linked to a water price discrimination, with favored prices for the water quote and normal price (water value) for the water consumption above the quote.

Around 734 farmers are dependent on the springs' water to irrigate their lands. The water-rights differ significantly. Rough estimates show that around 180 farmers get only 1-12 minuets; 200 farmers get 13-30 minuets; and around 354 farmers get more than 30 minuets, of which only 6 farmers have water-rights of more than 40 hours each, or 1/3 the agricultural water. Farmers get nowadays 75 cubic meters per hour compared to 100 cubic meters per hour earlier.

Area cultivated depends on the water-rights of availability of water as indicated in table (2) below. Crop density increases with the increase in water rights or cbm per dunum. It increased from 138% under shortage of water (13 cbm per dunum) up to 180 to 190% under better water security situation, i.e. 22 to 25 cbm per dunum. This relationship needs further investigation and in-depth analysis. Implications of water rights on inefficiency is expected to increase in the light of the fact that Water rights of the bustan water is inheritable as well as lands, which means fragmentation of water rights and land parcels and ultimately contributing to inefficiency in the allocation of spring's water unless arrangements were reached between new owners to consolidate their time-shares and land parcels.

Table 2. Land use and water-rights relation.

	Area (%)	Crop Area (%)	Crop density	Quota cbm/du
Case 1	27.3	22.5	138	13
Case 2	2.3	2.6	190	15
Case 3	45.5	48.8	180	25
Case 4	25.0	26.0	175	22
Total	100.0	99.9	171	20

3. Water uses

The spring's water is privately owned. Jericho Municipality (JM) owns only 14-15 hours, which were bought some years ago. Water allocated for agriculture is potentially 3.5 MCM (or 400 cubic meter times 24 hrs a day times 365 days) but the actually received by farmers is around 2.6 MCM, i.e. only 74% of the farmers' aggregate water-rights.

Historically, the spring suffices for the irrigation of 4000 dunums (400 ha) of vegetables, citrus, banana and date palm…etc. The area under cultivation dropped to around 2,500 dunum (250 ha) due water shortage and domestic pressure put on the spring's water.

A. Prevailing cropping pattern

Out of the 2,600 dunum irrigated by Ein-Sultan, only 100 dunum are allocated to Banan, 500 du under citrus orchards and the rest, or 2,000 du are under temporary cultivation, either vegetables or cereals. A dramatic drop from previous years due to several reasons among which is the water shortage and inequitable distribution, in terms of needs and rights.

The prevailing cropping pattern (Table 3) shows the pivotal importance of September as the cropping in the Valley, confirmed by the work load and demand on irrigation water. Almost 73% of cultivated area is planted in September. The figures are identical with results of optimizing the cropping pattern in the Esat Jordan Valley (Musa, 1992) which shows that water available in September is the most active production constraint and have the highest shadow price (value). The whole area is put under cultivation in early winter (table 3) indicating the importance of off-season production in the Valley.

Certain crops are cultivated under plastic cover (shaded figures in table 3), particularly cucumber, pepper and tomato. Tomatoes, for example, can be cultivated under open farming conditions if planted earlier, others (cucumber and pepper) are not. A third category of crops like eggplant, squash, cabbage and cauliflower can be planted in the cold months (October-Dec.) without cover.

It seems that Jews Mallows are the most important crop in summer months occupying 50% of the cropped areas (Table 3). It needs plastic cover if to b produced earlier, i.e. in February. Allocating most of the area to Jews Mallow was not expected but indicates the willingness of farmers to use their water quote during summer months irrespective of expected economic returns. This phenomenon is widespread after diminishing of fruit trees plantation. This is another sign of water inefficiency. There is a need to make better use of water available in summer, which is more than water available in winter (Figure 1 above).

Figures in table (3) show that the land unit is used on the average 1.7 times, i.e. the cropped area = 1.7 times the agricultural area. Squash and Jews Mallows are more frequently cultivated. Tomatoes is the most important single crop occupying 8% of the cultivated are and planted under plastic cover (shaded) and 37% of the total cropped area followed by squash.

Another important phenomenon is cultivation of Sweet Corn, occupying 2% of the cropped area but with promising future if feed crisis continued and opportunity cost of available water is better utilized. Further investigation and research is needed in this respect.

Table 3. Land allocated to different crops, production techniques by planting date (%).

Crop	Aug.	E.Sept.	L.Sept	Oct.	Nov.	Dec.	Jan.	Feb.	E.April	L.April	May	June	Total
Squash	15	9			5	9							37
Tomato		25	1	8			4						37
G. beans		2											2
Pepper		3		2									5
Cabbage		2	1		5								8
cauliflower	2	2	1				2						8
J. Mallows								5	14	3	17	13	50
Sweet Corn		2											2
Egg plant		7		4	7								17
Cucumber				4									4
Grand Total	17	53	4	17	16	9	6	5	14	3	17	13	171
Accumulated	17	70	73	90	106	115	121	126	139	142	159	171	

B. Recommended production plans (Extension agents)

The extension agents were different opinion. They suggested to allocate more areas fruit trees (Table 4), particularly date palm (scored 18% of opinion) followed by open farming, particularly medicinal herbs (scored 9% of opinions) and only 2-4% of opinions for cultivation under plastic cover. Extension agents took these allocation decisions based on the market (56%) followed by the comparative advantage of the valley (40%).

Table 4. Crops suggested extension agents.

Fruit trees		Open Farming		Plastic-culture	
Crop	**%**	**Crop**	**%**	**Crop**	**%**
Date Palm	18	Squash	4	Cucumber	4
Citrus	9	Eggplant	9	G. Beans	2
Grapes	13	Tomatoes	4	Tomatoes	4
Banana	9	Melon	2	Pepper	2
		Med. Herbs	9		

The dispersion of agriculture engineers' opinions is either due to sampling error or due to the uncertainty of extension agents respects optimal agricultural uses particularly in cases were opinion change with time.

Extension agents are not always the same opinions, same suggestions. They seem not determined in their extension massages. Being so is more acceptable than changing conditions or sampling error. Reading in the opinions of agricultural engineers shows:

1. Asymmetry of available information to the different extension agents,
2. Inconsistency of information, ideas and extension massages,
3. Lack of clear and sound analytical capabilities of extracting relevant suggestions and to support decision making at central, spring and farm levels,
4. Weak communication and outreach of extension services,

C. Water uses and allocation efficiency

On the one hand, crops are very often crops over irrigated; the amount of water should be decided according to the crop effective potential, which also depends on levels of other inputs, e.g. fertilizer…etc. There is no point in allocating the maximum of water to a crop that is constrained by other input. World-wide used formulas for water requirement calculation are not applicable to all situations; they need adjustment to local production functions and factors.

On the other hand, farmers do not pay the actual cost of water (indicating inefficient water market). They use more water than needed, many areas were left without irrigation as there is not enough water and that the over all irrigation efficiency is less than 50% and the application efficiency is also less than 50% (Sbieh, 2005).

Some farmers may face deficit of water supply (water insecure), others may have surplus of water supply (over-watered) either at certain time interval or for a long lasting period depending how efficient they were in adjusting their cropping pattern and crop requirements to their water time-shares. Recalling the zero-sum role shows that the water-insecure farmer (low water quote per dunum) may lose some cropping opportunities and over-watered farmers (high water quote per dunum) may waste some water (see table 4 above). Both are subject to inefficient allocation of irrigation water and hence escalating the aggregate water allocation efficiency.

Ahmad, M. (1994) referred to the lack of demand-management practices in the irrigated farming and its contribution to low efficiency in water use and consequent waste. Matching the needs for water to water supply (water right) and optimizing the water demand of crops is complex. It requires a flexible, transparent and collective water management system. Irrespective of complexity, it is nevertheless crucial to work out and implement water management policy that consider compensating farmers for water surplus and supply other who face water shortage, a quasi-market for Ein-Sultan water (to be discussed later).

4. Water organizations and stakeholders

Several organizations (at central and local levels) are involved in the springs water management of have a role to plan in that respect. These are: Palestinian water authority (PWA), Ministry of Agriculture (MOA), Local government or Jericho Municipality (JM), and Ein-Sultan Irrigation Cooperative (ESIC) representing the riparian farmers.

ESIC was established in 1999 to manage distribution of Ein Sultan irrigation water and represent ASF and to defend their water rights. It was established in response to donors precondition (1996) to finance the conversion of the open canal conveyance system into pressurized pipes. The ESICs' general assembly includes 359 farmers out of the 734 beneficiaries.

There is no water mediator with a clear mandate and by laws who solves the disputes around water. JM assumes this job in the meantime but negotiations are undergoing to transfer part of that authority to ESIC. Agreement is reached with JM to allocate 58% of the springs' water for agricultural uses[3], which is neither respected by JM nor possible to monitor. It seems that JM is reluctant to implement already signed agreements, which adds to the already uncertain water availability to farmers (water security), which might have drastic and long term implication on the economic performance of the spring, particularly its overall socio-economic dividends.

These are perhaps some features of less efficient governing system and institutional failure in allocating Ein Sultans water. Institutional failure include markets, policies, political and administrative factors (FAO 2004, P40), while political failure occurs through lack of government intervention, insufficient integration between agencies and departments; inadequate availability of information for policy-makers; poor communication between stakeholders at all levels (FAO, 2004).

It is imperative to empower local organizations, example ESIC, to improve their water-security situation, i.e. long-term access, availability, stability, utilization and safety of water by local communities and farmers (Laban, 2005).

5. Challenges ahead

The future demand for the Ein Sultan springs' water is a function of the growth in population, agricultural production, productivity and water quality of other water sources (springs and wells), and future growth in other economic productive sectors.

- Domestic demand for water (drinking, industrial, eco-tourism…etc.) increases according to JM at 19% per annum, constituting a real challenge to agriculture production and hence livelihood and sustainable development of the whole region.
- Productivity and water quality of other water sources (springs and wells), which deteriorate due to over exploitation and deepening water table. Water sources are subject to intense pressure and yet, the pressure is likely to be aggravated in the coming years (Isaac, 1994).
- Future prospects and growth in agriculture activity, which is supposed to grow as a result of development initiatives. Important to emphasis here that as long as value of marginal productivity of water is much higher in productive sectors other than agriculture (Shetty, 2006). This will no doubt be increasing pressure to allocate water away from agriculture to industrial and other productive uses as well as to increase irrigation efficiency in terms of more crop per drop.

6. Efficient allocation of irrigation water is possible with proper planning

Efficiency and equity of the different water allocation systems can be judged according to certain criteria such as: Flexibility between uses; security of tenure for users; payment of real opportunity costs to internalize external effects; Predictability of outcomes; equity; political and public acceptability; efficacy in achieving policy goals; Administrative feasibility and sustainability (FAO, 2004). These principles need to be observed by the different actors and particularly by the policy makers at central level and decision takers at farm level.

Water allocation efficiency is not the responsibility of the farmers at farm level alone, but more crucial is actions and decisions prior to the inflow of water into the farm. (Mattiuzzi, 1994) put it nicely in saying "…its (waters') usefulness has to be implemented by a mix of different actions that have to start well before the mere irrigation activity.

Imperative is to work out a balanced and sustainable water use plan based on the value of water over time and to increase water use efficiency, productivity and improve farmers' well-being. Three issues are of crucial importance, namely Governance, institutional reform and integrated irrigation water management strategy.

A. Governance conducive to sound, responsible and knowledge-based decisions

Strategic water planning must be done in full recognition of the political and economic realities of the region, and must progress in concert with the implementation of well conceived plans for economic development, environmental protection, and, with the careful resolution of the political uncertainties (McKee, 2005).

Agriculture water management must recognize the political sensitivities relating to water access and use and other competing allocation opportunities as well. Many factors need to be integrated to achieve efficient outcomes respect springs' water management.

B. Institutional reform

Water institutions are not just Regulatory Agencies (McKee, 2005). They have a dynamic and crucial roe to play. Sustainable water management improvements require significant adjustment in institutional arrangements. Little has done to restructure irrigation agencies or expend private sector participation (World Bank, 2006). Institutional reform involves redefining responsibilities and core activities of relevant organizations to create a clear and viable focus on important issues including pricing, distribution, capacity building, monitoring …etc..

An integrated water management system is possible only with active involvement and participation of springs' riparian, which indicates the pivotal importance of Building and empowering ESIC as Water Users Association WUA.

WUA (ESIC) needs to be recognized as a legal entity that can enter into contract and have power to enforce rules and regulations for the sake of its members, i.e. the time-share holders. WUA can assume the responsibility of water distribution, fee collection, maintenance, conflict resolution, and representing farmers.

Transfer responsibility for the operation and maintenance of irrigation scheme from governmental agencies to farmer/irrigator operated "Water User Association", the so called "Irrigation Management Transfer" IMT (FAO, 2004) can not be successful in the absence of secure rights both to water and land (FAO, 2004). But, a transfer of water rights management to WUA would be very helpful and effective, and may soon require an additional by law in order to better define these transfers of responsibility (Van Aken, 2007).

C. Integrated Irrigation Water Management Strategy

a. *Dispatching water use from water rights*: or depersonalizing the water distribution and keeping the water rights is possible and will certainly have significant impact on the water use efficiency at (micro-) farm level and more obviously on the aggregate spring system. One way of doing this is through creation of a special fund (*sundouk*) run by the ESIC to mange the financial part of the agreement. A sort of group agricultural insurance for the spring partners is a further improvement and guarantee for proper implementation.

b. *Deal with water as an economic good:* Proposed water management arrangements, the market-based, must seek to satisfy the two goals, i.e. water use efficiency and financial soundness. Recognizing water as an economic good requires a well-informed water pricing system and perhaps the establishment of a quasi-market for water. Economic theory argues that water is allocated efficiently if the true price is paid. Implementation of a quasi-market mechanism, such as permit trading, can establish a win-win situation wherein all parties (water insecure farmers and over-watered farmers) benefit economically more than they otherwise might from the allocation of a rigidly fixed quantity of resource. Important here is to distribute based on demand and not incinerating irrigation decisions based on water supply (quote).

c. Transparency and farmers' participation: A more integrated approach to Water Resources Management requires enhancing stakeholder integration and involvement, improving access to and use of quality information and mainstreaming information and knowledge-based decision taking and policy making. This involves the active participation and interaction of farmers in decision making, monitoring and sanctioning.

IV – Conclusions

Spring peculiarities are not well-considered in decision making, particularly in allocation of water among different uses and different crops, including springs discharges overtime, quality of water …etc. The gathered data illustrate that extension massages are not based on farm specific.

Imperative is to tackle the spring as a unique system with interrelated ecological (water), technical (distribution), and socio-economic dimensions.

Less efficient water uses prevailed and carried out by individuals with no or very little planning. As a consequence, a series of socio-economic problems have risen and subject to escalate. These can, and must, be solved to achieve a sustainable and efficient water use of the spring system, particularly for irrigation purposes.

The study shows that the problem is not simply technical one and associated with the spring or the water conveyance system but more softer and linked to the socio-economic context and institutional arrangements which has much to do with the water rights, distribution and management of the spring system. Even at the farm level, there is much to be done with empowering the farmers and their collective work and strengthen their bargaining power.

The need for a strategic plan as a dynamic tool which identifies, defines, and describes the implementation process. It should be written to provide a vision, clear objectives, and clear activities to achieve these objectives and need to be worked out in full participation, involvement and backing of all stakeholders, particularly the farmers.

The water management and pricing policies must recognize the critical and crucial points such as to maintain the water rights of the beneficial farmers as a top priority of any induced water management strategy and policy; less drop per crop, i.e. efficient water use at farm level depending on crops technical water requirements, balanced agriculture inputs, and less water losses; water prices to promote adoption of water saving techniques and technologies and improve availability and stability of water supply (water safety); a proper pricing of water and security of tenure for users (water rights) is a challenge to be taken seriously if sustainability of the system is sought, not only the water per se.

Research and training is the key to form the knowledge-base and sharpen capacities to develop models, policies, programs impinge to irrigation management.

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1. Dunum (du) =0.1 ha or 1000 square meters.
2. Indicating that when the time-share principle was introduced (around 1930s), agricultural production was the only thoughtful water use.
3. he municipality extracts 60-62% of springs' water not 48% as agreed upon.

Sixth part

Conlusion

Approach to a conceptual frame of technological perspectives for water resources management in the Mediterranean Region

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Abstract. In most Mediterranean countries the availability of fresh water supply is increasingly reduced due to the growing demand. This often creates conflicts among the various sectors and places great pressure on the ecosystems supporting these resources. Therefore, the challenge of water use and allocation is now a major political concern in the Mediterranean Basin and is likely to become even more serious in the next years. This is why integrated water resources management (IWRM) and the search for appropriate technology are high on the policy agenda. Technology development will be aimed at managing both supply and demand and tackling problems relating to water quantity and quality. Therefore the 2nd Melia project workshop, held in Marrakech in November 2008, was intended to face most of these issues and discuss the technological perspectives of sustainable integrated water resources management in the Mediterranean region, focussing on the technology used to enhance water supply, the preservation of resources quality, the social and cultural aspects of water management, the institutional, governance and policy aspects and emphasizing the importance of available technical tools to improve management (GIS and remote sensing). The debate also addressed the various regulations and directives in the field of resources management and the new challenges posed, particularly, by global and climate change, the changing world economy and social and economic disparity between southern and northern Mediterranean countries and the need for bridging this gap in order to promote sustainable management of resources in the Mediterranean Basin. As a result, some key concepts were defined and the final recommendations outlined a number of criteria to tailor technology to the sustainable management of scarce water resources in the Mediterranean region.

Keywords. Appropriate Water Technology – Integrated Water management – Stakeholder involvement – Initial stage – Mature stage – Demand management – Criteria – Water Scarcity.

Approche a un cadre conceptuel des perspectives technologiques pour la gestion des ressources en eau en region Mediterraneenne

Résumé. *Dans les pays méditerranéens, on constate une réduction considérable de la disponibilité d'eau douce face à une demande croissante, ce qui génère des conflits dans les différents secteurs et une pression importante sur les écosystèmes qui soutiennent ces ressource. Par conséquent, le défi de l'utilisation et de la distribution de l'eau représente une préoccupation politique majeure dans le bassin méditerranéen qui risque de s'aggraver dans les années à venir. C'est pourquoi la gestion intégrée des ressources en eau (IWRM) et la recherché de technologies appropriées constituent actuellement une priorité dans l'agenda politique. Les technologies seront développées en vue de gérer tous les aspectes concernant la demande et l'offre et faire face aux problèmes relatifs à l'eau sur le plan de la quantité et de la qualité. Le deuxième séminaire du projet Melia, organisé à Marrakech en novembre 2008, avait donc pour objectif d'aborder ces problématiques et de débattre les perspectives technologiques d'une gestion intégrée durable des ressources en eau en Méditerranée, en parcourant différents thèmes, depuis les technologies utilisées pour améliorer l'offre d'eau à la préservation de la qualité des ressources, en passant par les aspects sociaux et culturaux de la gestion de l'eau, les aspects institutionnels, politiques et de gouvernance et l'importance des outils techniques mis au point pour faciliter la gestion (SIG et télédétection). Le débat a aussi été focalisé sur les différents règlements et directives concernant la gestion des ressources et les nouveaux défis de la gestion et notamment, le* *changement planétaire et climatique, l'évolution de l'économie mondiale, la disparité sociale et économique entre les pays du sud et du nord de la Méditerranée, et sur la possibilité de réduire cet écart pour gérer les ressources d'une manière raisonnée dans le bassin méditerranéen. Le débat a permis d'identifier des concepts clés et de formuler des recommandations sur les critères à satisfaire pour employer les technologies appropriées en vue d'une gestion durable des ressources en eau limitées de la région.*

Mots-clés. *Technologies de l'eau appropriées – Gestion intégrée de l'Eau – Participation des acteurs – Stade initial – Stade avancé – Gestion de la demande – Critères – Pénurie d'eau.*

I – Introduction

Most of the Mediterranean countries in North Africa, the Middle East and Southern Europe display many similarities in terms of growing water shortage, increased drought events, increased pollution threats, increased overexploitation of groundwater resources and increased threat of sea water intrusion, rapid population growth and rapid tourism growth. In addition, natural surface and groundwater resources do not recognize frontiers, and many of them are shared by more than one country, thus complicating more water sustainable management. The common feature in the Mediterranean area is that water is one of the limiting factors for sustainable development, increased quality of life, and peace.

The regional average annual per capita renewable water has significantly fallen over the last 40 years from 3,300 m^3 in 1960 to 1,250 m^3 in 1995 and is estimated to drop to 650 m^3 by 2025. Estimates of the World Resources Institute (1996) suggest that by 2025 some EMR countries will be among the 45 countries worldwide which will suffer from chronic water stress. An increasing proportion of surface and groundwater resources in the region are polluted mainly due to inappropriate disposal of municipal wastewater, infiltration from onsite sanitation facilities, and excessive use of fertilizers and pesticides in agriculture. Due to a severe shortage in agricultural water, reuse of wastewater has become unavoidable in many countries such as Jordan and Syria. Untreated wastewater was and is still used sometimes in agriculture without adequate health safeguards.

Trends in most European countries indicate that water supply to the population is threatened by man-made pressure and that water ecosystems are undergoing severe processes of quality deterioration (Berbel *et al.,* 2004). About 20% of the whole surface water in the European Union is seriously threatened by pollution. Groundwater supplies around 65% of all Europe's drinking water, and 60% of European cities overexploit their groundwater resources. Furthermore, 50% of Europe's wetlands are identified as "endangered" due to groundwater over-exploitation and the area of irrigated land in Southern Europe has increased by 20% since 1985 (European Commission, 2002). In recent years, there has been a growing concern throughout the EU regarding drought events leading to water scarcity problems, especially in the Mediterranean countries. The competition between various uses, especially agriculture and tourism, which are major components of this area's economy, very often make trade-off allocation decisions too difficult. Hence, conflicts over water are increasing and they are becoming more complex, involving competition among alternative uses, among geographical regions with disparate water endowments, and between water resources development and other natural resources lost due to that development.

The challenge of water use and allocation is now a major political concern in the Mediterranean Basin and is likely to become even more serious in the next years. This is why integrated water resources management (IWRM) and the search for appropriate technology are high on the policy agenda. Technology development will be aimed at managing both supply and demand and tackling problems relating to water quantity and quality. The identified relevant technology shall enhance supply through the use and reuse of available resources in the most efficient way and lead to integrated and comprehensive management. The legal and institutional aspects are also an integral part of the countries' efforts toward overcoming their water problems and helping reduce poverty, attaining food security and economic growth, while maintaining sustainable ecological systems and their services. (Gbadegesin, 2008).

Over the last decade of the 20th century, new strategies for water resources management have been promoted. These strategies are recommended in several chapters of Agenda 21 and they are also confirmed in the First Paragraph of the UN Program on Integrated Water Resources Development and Management, which states that the "development of appropriate water management requires the application of new sustainable technology both in terms of analysis and of engineering".

II – Water Management Techniques and Technology

The rapid advancement in developing water technology related to large pumping equipment, drilling technology and the ability to tap very deep aquifers, filtration and treatment technology, has allowed easier access to water resources and increased the pressure over the sustainable utilization of these resources. In many northern countries the overutilization and the unsustainable use of resources during the forties have left large rivers and lakes heavily polluted and some aquifers extremely overexploited during the sixties in some southern areas of the Mediterranean. These alarming incidents and many similar ones worldwide have drawn the attention of water scientists leading them to consider the need for using resources in a sustainable way. The Mar del Plata conference in 1977 was the first to address this issue. Then the famous Dublin principles came in 1992 during the preparation of the UN conference on the concept of sustainability that was organized in 1992 in Rio de Janeiro. After that, the IWRM concept has become the rule in water resources management in general and accordingly, emphasis has increasingly been laid on the need for developing more efficient technology to ensure the sustainable use of resources, while achieving the goal of social, economic and environmental benefits. Moreover, it is clear that at this point in time, where demand exceeds supply, the available water resources cannot be managed and utilised as they were in the past, when the resources capacity was much higher than the demand and the inter-sectoral conflict over the use of resources hardly existed.

Randall (1981) distinguished two stages in the development and management of resources, the initial or expansive stage, and the maturity stage. During the initial stage of resources development, the volume of economically and technically available natural resources exceeded the demand. Accordingly, the competition was low and the engineering works were designed to allocate water in the areas where water rights were established. He also summarized the characteristics of water resources development and management during the two stages as shown in Table 1.

Table1. Major Water Resources Development Stages.

Aspect	Stage	
	Initial	**Maturity**
Increasing long-term supply by exploiting new natural resources	Mostly possible	Extremely difficult
Water Demand	Low and expanding High elasticity at low price and inelastic at high price	Strong and expanding Medium elasticity at low price and inelastic at high price
Physical conditions of engineering infrastructure	Most of them are almost new and in good condition	A large part is old and expensive to repair and renew
Competition for water among different users.	Minimal	Intense
Socio-economic and environmental problems	Minimal, competition for economic resources (public infrastructure)	Intense, competition for the resource itself
Social cost stemming from subsidised water, especially for agricultural purposes	Very low, very low levels of cost recovery	High and expanding, increasing cost recovery schemes

Clearly, depending on the stage of water resources development and management (initial or mature stage), some solutions will be more successful than others. We can deduce that, during the initial stage, focus will be more on the supply side management and on actions aimed at increasing the supply, whilst during the maturity stage the demand side management of existing available resources is much more important. During this stage, water management has, on the one hand, an engineering dimension that aims at meeting demand with the most efficient water use possible and, on the other hand, it must address socioeconomic and environmental aspects that can even lead to the reallocation of the resources, provided that pre-existing rights are respected or duly compensated (López-Martos, 2008).

It was also clear that during the initial stage of water resources development, the main and almost only activity is to quantify and tap the available resources (surface and groundwater). The advances in developing sophisticated technologies and tools such as remote sensing, GIS, various quantity and quality modelling techniques, have fostered the level of understanding and improved the knowledge about physical as well as other characteristics of water resources. However, when pressure over resources increases, resources management in a conjunctive and efficient way becomes a necessity in order to ensure the sustainability of these resources in terms of quantity and quality. This implies that the technology should focus on all possible demand management aspects. Such aspects may vary from improving the main water transmission networks and water supply systems (reducing losses), adopting low flow appliances at household and farm level (efficient irrigation techniques) to developing proper pricing policies that capture the true value of the supplied water as well as developing regulations that support efficient and proper allocation among the different users. In the meantime, more attention is given to the development and utilization of the unconventional water resources or even to consider various other options such as virtual water. Furthermore, good water governance and efficient institutional setup becomes a must in order to ensure a balanced and participatory approach in managing these resources. Such an approach shall ensure the representation of all stakeholders' interests in a given watershed or a river basin or of those who benefit from the same resource in a given territorial unit. The importance of this approach is more challenging in areas where water is scarce. Spain, for instance, was the first country to introduce the notion of watershed or river basin as a legal concept for water management, and consequently, watershed was considered as the territorial unit for water resources planning and management. This concept has also been adopted by other countries including the USA and taken into account by the European Water Framework Directive (2000/60/EC).

During the mature stage, the development and utilization of unconventional water resources (wastewater reuse and/or desalination of seawater or brackish water) become an integral part of the overall resources management and they are considered as part of the water resources budget in a given watershed. This becomes especially significant in areas suffering from water shortage. Despite the fact that the development of these unconventional resources requires expensive and energy-intensive technologies, yet, the need for their integration within the overall resources budget is a must. Here, the relation between water production and energy requirement for the process becomes one of the key determining factors. However, the advancement in technology and engineering has so far led to develop these resources at a reasonable cost. Yet, if this achievement in technological advancement is not met through proper governance, institutional setup and regulatory structures, that can ensure the integration of these resources in the overall management policies, may become a burden and may cause the failure of the overall water management in a given area.

In addition, the stakeholders' involvement in the various phases of resources planning, adaptation and management is really crucial in order to ensure social and cultural acceptability of some of these resources (especially, the reuse of treated effluent). To support the stakeholders' involvement more awareness programmes on resources and advantages and disadvantages of their potential use are needed along with more capacity building programs, tailored to improve the stakeholders' knowledge of resources and technology used for their management.

Based on the above considerations, any technology used for water resources development and management, whether at the initial stage or mature stage, should fulfil the following requirements:

1. New and sustainable technology should have the capacity to address the challenges with we are facing, but fully respecting the ecological needs;
2. Technical skills and expertise necessary for technology implementation are available;
3. Public engagement in the technology development must be ensured; for example, technology developed though public- private partnership may be considered favourable;
4. Technology should be cost-effective;
5. To make sure that the new technology developed / adopted in agriculture is tailored to save more water and may include;
6. Efficient irrigation technology;
7. Possibility of planting earlier;
8. Shorter crops cycle;
9. Improved draught resistance capacity;
10. Salinity resisting crops.

The 2nd Melia project workshop, held in Marrakech in November 2008, was intended to face most of these issues and discuss the technological perspectives of sustainable integrated water resources management in the Mediterranean region, focussing on the technology used to enhance water supply, the preservation of resources quality, the social and cultural aspects of water management, the institutional, governance and policy aspects and emphasizing the importance of available technical tools to improve management (GIS and remote sensing). The debate also addressed the various regulations and directives in the field of resources management and the new challenges posed, particularly, by global and climate change, the changing world economy and social and economic disparity between southern and northern Mediterranean countries and the need for bridging this gap in order to promote sustainable management of resources in the Mediterranean Basin. . As a result, some key concepts were defined and the final recommendations outlined a number of criteria to tailor technology to the sustainable management of scarce water resources in the Mediterranean region.

The criteria for Appropriate Technology can be classified under several categories as follows:

1. Technical viability
   - Easy to be operated and maintained;
   - Technically efficient;
   - Capable of addressing real needs.
2. Economic Feasibility
   - Cost-effective in specific socio-economic conditions;
   - Affordable, i.e. people can afford its adaptation;

3. Environmentally Sound

- Producing no environmental harm;
- Appropriate, according to the local environmental conditions where it will be applied.

4. Socially and Culturally Acceptable

- Developed in a real participatory way by all actors (stakeholders).

5. In line with the national standards and regulations

6. Adequate Institutional setup for its accommodation and customization.

It is important to note that even when the above criteria are fulfilled, the implementation and adaptation of any new technology will face certain constraints.

Constraints to implement new and more efficient technology:

1. Large knowledge gap between scientists, practitioners, policy makers and the public about the different technologies applied;
2. The format and language that describes technology are too technical to be understood by the public and sometimes even by policy makers (lack of appropriate communication language);
3. Lack of mechanisms to create sufficient concerns about the problems and mechanisms to propose appropriate solutions;
4. Lack of people's capacity and reluctance to adopt new technology;
5. Bad experience of people in applying some technologies which affect their willingness to adopt other useful technologies. No public debate on different alternatives;
6. Lack of funds;
7. Lack of responsible and independent media coverage;
8. Poor governance conditions.

These constraints are commonly encountered and they hinder the possible adaptation of technology. However, mitigation measures can help overcome such constraints.

Mitigation Measures Needed to Overcome the Constraints Facing Technology Adaptation

1. A compulsory institutional involvement in costs & maintenance and especially, in staff training is needed;
2. Feasibility and Demonstration studies in local conditions are needed in order to assess their applicability according to the real needs and possibilities;
3. Dissemination and Communication Strategies to raise public awareness on the importance of treating wastewater must be elaborated;
4. North-South scientific collaboration and knowledge transfer in this field must be promoted;
5. Public participation in social aspects shall be enhanced through interaction with end users, administrators and stakeholders;
6. End users shall be regularly informed on the costs and difficulties encountered in handling new technology, if any.

III – The way forward

In order to overcome the constraints to develop new technologies and promote their public appropriation, the following measures can be proposed:

1. Select the technology that best fits the local conditions, and do not to consider that technologies successful somewhere are necessarily successful in another place.
2. Allow all actors being involved in the development of experimental platforms. Scientists and Administration have to work together. The public should be able to follow debates on technology adoption.
3. Promote broad dissemination of successful scientific results to the public, end users and all the actors concerned (translate scientific outputs into simple common language).
4. Promote the participatory approach in decision taking.
5. Increase training opportunities for technical and non-technical staff.
6. Need for institutional and economic support to enhance public awareness on a regular basis, and not on an ad-hoc basis.
7. Promote lobby groups to ensure that policy makers properly understand the problems IWRM, and adopt the appropriate means to handle it.
8. Use unconventional channels to convey the message to the public at large (e.g. use Football teams, actors, etc.).
9. Show the consequences of not taking any action.
10. Develop a communication strategy with media involvement.
11. Improve knowledge sharing among practitioners through the following actions:
    - Support their participation in different scientific events as well as in the experimental work;
    - Build their theoretical capacity to allow them coupling theory with practice;
    - Report on success and failure stories known and on the lessons learnt;
    - Provide communication venue;
    - Allow exchange of expertise (to overcome barriers such as funds, language, etc.)

IV – Key Recommendations

1. It is necessary to focus more on virtual water concept and consider it as a tool to raise awareness of water cost-effective use water, especially in water deficient regions. The import of a product or the production of a crop could be presented as virtual water Importation or exportation, respectively. Therefore, we can compare water use efficiency according to the crop type, the specific conditions, etc. Any option can be evaluated according to the virtual water needed, and its impact on the overall water budget. The term National Water Footprint reflects the National situation in terms of water balance.
2. Remote sensing is a useful scale-dependent tool which can never be used without ground truth. It is a complementary tool which can reduce the amount and costs of field validation in integrated water management. However, scale and both spatial and spectral resolution must be considered for each individual case. Active remote sensing (i.e. Radar and Interferometer) are additional remote sensing tools for the assessment of water quality and non traditional

water resources. Developing computer models and computation of indices as indicators for water quality and water balance is recommended. The Global Earth Observation System (GOES) provides short intervals of satellite imaging and therefore it can be used for remote sensing in agriculture and in water resources management.

3. More work should be done to enhance on-farm water use efficiency.
4. To Intensify the dialogue among partners is necessary to heighten awareness of the consequences of using fossil water to irrigate the oases.
5. More work shall be devoted to assess the possible impact of the climate and global change over the resources and adaptation measures that must be taken by the different Mediterranean countries.
6. More research is needed to explore the utilization of renewable energy as an important alternative in water management related technology throughout the Mediterranean Basin.
7. Policy alignment among the different countries in the basin is needed to ensure better integrated management of resources.
8. It is necessary to encourage technology preserving water and energy by providing incentives at local, national or regional levels to users and investors.

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