Economic evaluation of water demand management in the Mediterranean

Study report

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I. Context and aims of the study: an « economically » relevant Mediterranean water saving objective?

Water demand management (WDM) is a concept which has been developed since the 1990s in reaction to water supply development policies in the agricultural sector in particular, the economic and environmental cost of which was giving rise to increasing political opposition during the ‘80s.

WDM can be defined as a set of technical, political, institutional, economic, training, awareness-raising and communication tools intended to encourage better use of existing water supply before considering increasing supply. WDM thus encompasses measures intended to improve water use « efficiency »[1]in the various uses but also how water is allocated between uses. Over the past ten years or so it has become a key issue in water management in the Mediterranean.

According to studies conducted by the Plan Bleu, the volume of non-conventional water extracted and produced doubled over the second half of the 20th century. Prospective analyses also suggest that, following a trend scenario, the pressure exerted on resources will intensify by 2025. The introduction of WDM instruments against this backdrop is proving particularly useful in helping to mitigate such pressure.

Drawing on these analyses, the Mediterranean Strategy for Sustainable Development (MSSD) which was adopted in 2005 by the twenty one riparian states and the European Community set itself the target of stabilising water abstraction by 2025. The recommendations made by the regional workshop on « Water Demand Management in the Mediterranean, progress and policies » organised by the Plan Bleu in Zaragoza (Spain) in 2007, stressed the role of economic instruments in WDM. Finally, the Euro-Mediterranean water ministers, meeting in Amman in December 2008 and subsequently in Barcelona in April 2010, demanded that the future Strategy for Water in the Mediterranean set targets for water savings to be made by 2025 and examine the most appropriate tools to this end.

Using the latest available data on the state of water resources and abstraction trends, the Plan Bleu is seeking to study the potential for water savings by 2025 in the countries bordering the Mediterranean. The relevance of such potential water savings is addressed using an economic analysis of various water management options, taking account of the Mediterranean countries’ short and medium term environmental and social policies objectives.

The general aim is to assess and compare the following in financial and economic terms:

- The cost of water saved (WDM policies) and of water newly collected (Supply driven water policies),
- The benefits related to the redistribution of water saved and those of increasing water supply.

This report summarises a study conducted between July 2009 and February 2010 on the efficiency of water transport, supply and use in the Mediterranean region. Focusing on the analysis of domestic and agricultural use, it is part of a broader consideration of WDM measures and draws on a comparative analysis of the economic evaluation methods deployed in the case studies covered.

The activities conducted by the Plan Bleu were rolled out in three phases (2009-2010):

- State of play on work conducted throughout the Mediterranean (2009),
- Critical and comparative analysis of the methodological approaches applied in the available case studies on the economic evaluation of water saving measures in Mediterranean countries (2009),
- Summary and evaluation of results (2010).

They were conducted in partnership with scientists from the three banks of the Mediterranean and water and/or environmental economics experts.

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[1] The notion of « efficiency » could be translated as yield. It relates to achieving a result minimizing means to do so.

II. Methodological framework for the economic evaluation of water demand management (WDM) measures

Two approaches for the economic evaluation of water savings were used in the studies: a cost-benefit analysis (CBA) and a cost-effectiveness analysis (CEA). They involve specific ratios used to assess the economic and financial value of WDM measures. The results of the economic evaluation and the calculation of these ratios are necessarily situated in both space and time since the costs and benefits of the measures may vary significantly according to the scale of the study and the perspective for their evaluation. Such evaluations are not only objectivation instruments. They also, by nature, embed political dimensions since they are deployed within specific problem framing with specific social, institutional "boundaries" and they suppose that all values can be commensurated.

1. The analysis of the effectiveness of WDM measures…

CBAs compare the overall benefits and costs of a project, without necessitating the examination of further options. If the benefit/cost ratio is higher than 1, the project is deemed to be of positive value to the community concerned.

CEAs calculate the direct financial cost involved in order to achieve a quantitative result, compared with some other option producing the same outcome. The CEA is based on the cost of producing one unit (in this case, one m^3 of water), over the volume of activities and results for calculating a cost-effectiveness ratio. It may, however, also include some features of the CBA, particularly when the evaluation is being conducted over an entire region. All the case studies analysed correspond to CEAs, even though some of them also include elements from the CBA.

The cost-effectiveness ratio may thus be calculated:

- Either using exclusively the financial costs of the measures and the volumes saved (FC ratio). Theoretically the financial costs includes the cost of investment as well as operation and maintenance costs;
- Or using financial and economic costs, including the cost of non-action to the beneficiary of the measure (EC_1 ratio) or the economic and environmental externalities and the opportunity cost of the measures for a given community as a whole (EC_2ratio).

It is expressed in Euros (or some other monetary unit) per m^3 and takes the following form:

$$Cost-effectiveness\ Ratio = \frac{Costs}{Volume\ saved}$$

Comment: Where it includes direct financial costs alone (FC) the ratio is always positive as it expresses the net cost of water savings. Where, on the contrary, it includes avoided costs (EC_1) or, more globally, externalities (EC_2), the ratio may be negative, thus indicating that the direct and indirect costs of the measure are lower than the cost of non-action and/or the benefits it produces.

When the costs of the measures on which an economic analysis is being conducted are staggered over time, discounting operations are needed in order to assess their cost effectiveness (Inset 1). Discounting makes it possible to compare economic values staggered over time by relating their future value to a current one. This is done by giving these monetised values a coefficient: the « discount rate». This is a rate of substitution between future and present, which translates the preference for the present (or the « cost of time »), risk aversion (or the « cost of risk ») and reflects the cost of capital. *The choice of discount rate is therefore a crucial element in the economic evaluation of a project.*

Another way of assessing how the investment costs of a measure are distributed over time is to estimate the payback period, which establishes as of which year it shows clear profit.

Inset 1: Discounting of investment costs

If the distribution of costs throughout the lifespan of the measure is known, it is possible to calculate the discounted value of the costs using the following formula *(Equation 1)*:

Equation 1: Discounted cost of a measure

$$Discounted\ cost = \sum_{t=0}^{T} \frac{C_t}{(1+a)^t}$$

Where: C_t : cost of the measure in year t - a : discount rate - T : lifespan of the measure

If the distribution of costs over time throughout the lifespan of the measure is not known and assuming that operation and maintenance costs and externalities remain unchanged from one year to the next, an attempt can be made to discount the investment costs alone(Aulong& al. 2008), (*Equation 2*) :

Equation 2: Discounted cost of a measure whose investment cost has been discounted

$$Annual\ discounted\ cost\ = \frac{a \times I_0 \times (1+a)^T}{(1+a)^T - 1} + annual\ Cost_{r\&M} + \ annual\ E$$

Where: a: discount rate. - T: lifespan of the measure.

Annual cost$_{r\&M}$: the operation and maintenance cost of the discounted measure, presumed to remain unchanged from one year to the next.

Annual E: discounted externality (which may be either positive or negative), presumed to remain unchanged from one year to the next.

Thus, the higher "a" (discount rate) and the lower "T" (equipment lifespan), the higher the annualised discounted cost for a given investment (I_0).

The cost-effectiveness ratio calculated is thus as follows:

$$EC = \frac{Annualised\ discounted\ cost}{Average\ annual\ volume\ of\ water\ produced\ or\ saved}$$

Source: Aulong& al. 2008

…is determined by the scale and perspective under consideration

In order to address the hydraulic efficiency issue and to compare WDM measures adopted in various contexts with each other, it is important as far as possible:

- To define the scale of analysis and the perspective being taken,
- To be aware of usage features and water demand functions: abstraction, consumption, « dry » losses, water supply management and sustainability, use-generated water pollution…

1.1. At Mediterranean level

Throughout the Mediterranean, irrigation accounts for almost 65% of anthropogenic abstraction. It may even exceed 80% in the countries to the south and east of the Mediterranean (*Table 1*).

Table 1: Relative share of anthropogenic abstraction in the Mediterranean

Territories considered		Total water abstraction	Breakdown by sector of use by volume and as a % of total abstractions							
			Drinking water		Irrigation		Industry not served by drinking water systems		Energy (cooling of nuclear plants)	
			Km^3/yr	%	Km^3/an	%	Km^3/an	%	Km^3/an	%
Entire countries	North	127,7	22,3	17	57,7	45	13,6	11	34,1	27
	East	60,4	8,7	14	47	78	2,2	4	2,5	4
	South	92,8	7,9	9	76,6	83	3,4	4	4,9	5
	TOTAL	208,9	38,9	14	181,3	65	19,2	7	41,5	15

Source: Plan Bleu, 2007

The seasonal nature of rainfall also plays a crucial role in the emergence of water stress when agronomic water demand of the crops selected coincides with the periods of lowest rainfall hence reduced flow in rivers and aquifers.

In certain areas, the share of abstractions being used to produce electricity through storage in hydroelectric dams or for cooling thermal power stations may also prove significant. Although only a tiny share of these abstractions is consumed, they nonetheless have a major impact on the hydrosystem quality by limiting sediment and fish transit, creating a pollution risk (thermal pollution for power stations, limiting the dilution or self- cleansing capacity of rivers for hydroelectric dams if releases do not coincide with periods of low flows, etc.).

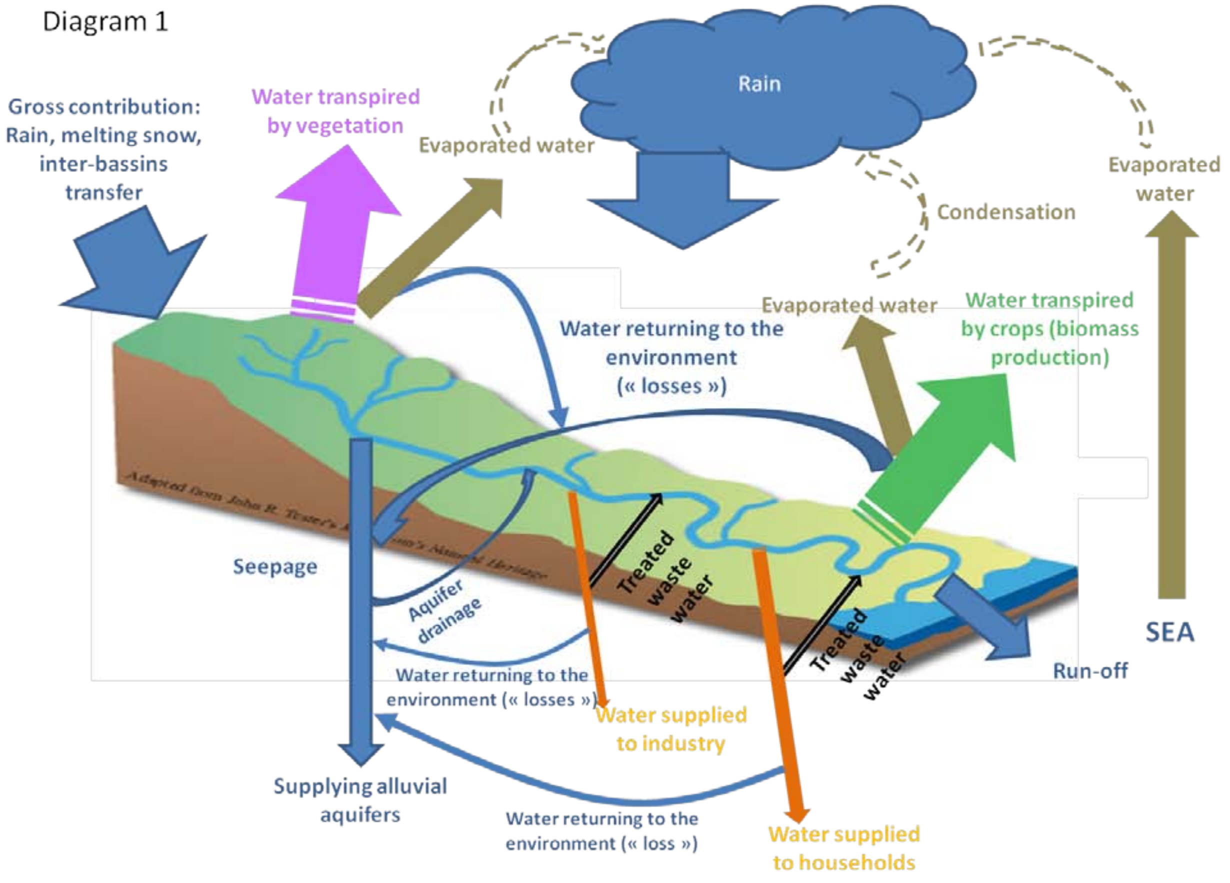
For domestic water too final consumption levels are low. Most of the water used returns to the environment with a decline in its quality, more or less important according to the treatment applied.

In 2007 the Plan Bleu estimated that total water use efficiency for the Mediterranean countries stood at between 50 and 85% (Thivet&Blinda 2007).

1.2. Within the catchment basin

Apparent « losses » tend to return to the environment and may be available for downstream users provided that the quality of the water has not been overly impaired (*Figure 1*). Some extreme cases known as « closed basins » exist, however, for which any decision to abstract further water from the system will almost certainly affect other users (Seckler 1996). In such cases, « losses » systematically meet user demand, through replenishing an aquifer, for example. As agriculture accounts for most use in quantitative terms this positive role may be significant. Thus the « loss » has a cost attached but it is also put to good use. Taking into account this use into the economic evaluation of WDM measures will produce a more precise analysis of the costs and benefits of reducing water losses.

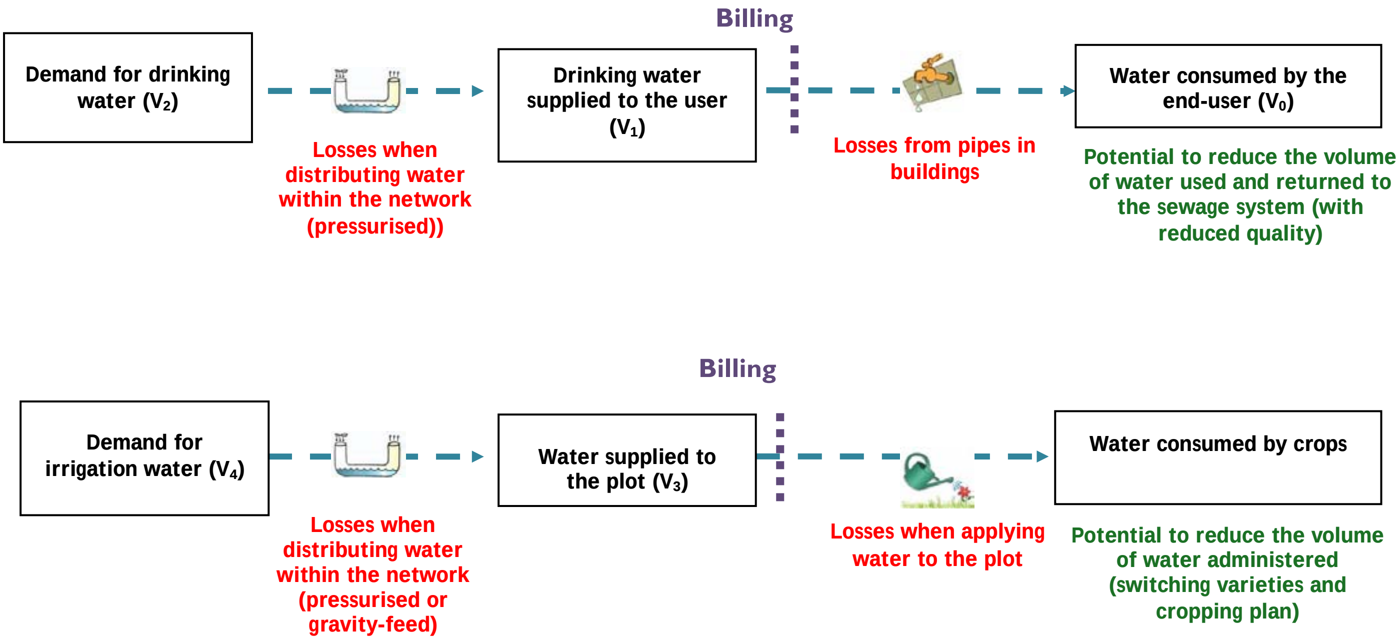
Figure 1: Diagram of the water cycle within a catchment basin



1.3. At service level (supply system and users)

The « hydraulic » efficiency of the water supply service for domestic and agricultural purposes can be broken down into: (i) the efficiency in collecting and distributing water and (ii) the efficiency of the use of water at the scale of the end-user (*Figure 2*).

Figure 2: Efficiency in water conveyance, distribution and end-use in the drinking water and agricultural water (blue water) sectors.



Source: Modified from (Thivet&Blinda 2007)

1.4. Scale and perspective chosen for the analysis

The analysis covers the two types of hydraulic efficiency within the water service (supply system and use) according to:

- three perspectives : the water service provider[2], the user and a local government, governing an area which extends beyond the service,
- Two levels: the drinking or irrigation water service (supply system and use) and a governed area or catchment basin.

It also covers the results of studies conducted on various areas within the Mediterranean on the effectiveness of water supply or demand-based measures in dealing with pressure on the resource.

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[2] Initially no distinction was drawn between the service provider and the authority responsible for providing the service, even though their strategies may differ where they are separate entities (when for instance the service is "delegated" to a private company).

III. Economic and financial evaluation of drinking water demand management

The study initially considers the quantification and monitoring of « losses » before subsequently addressing the benefits attached to the implementation of water saving measures for the service provider, the final user and the community. It sets out an analysis framework for drinking water services for both the collective supply system (section 1) and the end-user (section 2). It is subsequently illustrated by five case studies (section 3).

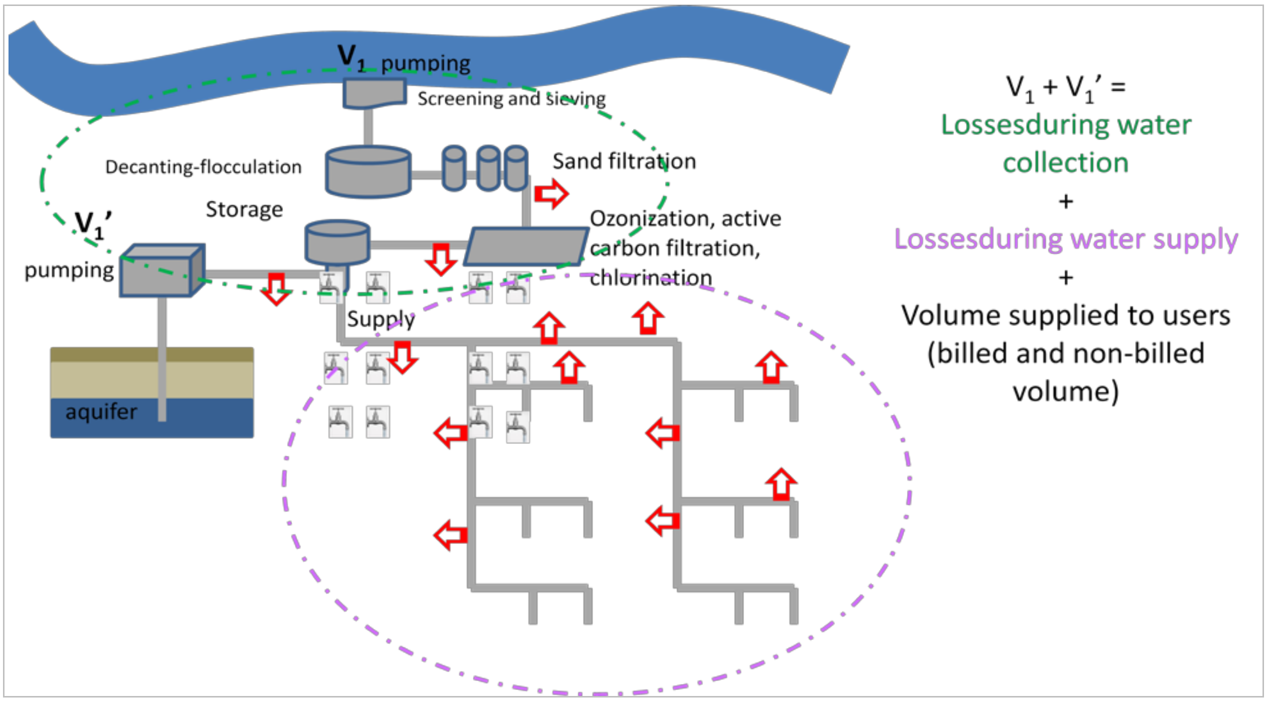
1. Reducing loss in the collective drinking water system

1.1. Quantification et suivi des pertes dans le réseau Quantification and monitoring of supply system losses

Within the supply system, « losses » during drinking water supply (*Figure 3*) can be ascribed:

- Either to physical and financial losses within the supply system: leaks in the system or water treated to become drinkable but not used (therefore not charged for).
- Or purely to financial losses: amounts of water diverted elsewhere (« illicit users ») or metering defects[3].

Figure 3: Losses within the drinking water supply system



Attempting to reduce loss first and foremost being able to quantify the loss, define its explaining variables and modelling it.

- The most widespread water « loss » indicators, listed in Annex 1, are:
  - Potential drinking water supply efficiency as defined by the Plan Bleu and used for MSSD monitoring. It represents the share of drinking water produced and supplied which is effectively paid for by the user.
  - Supply system yield, the indicator most widely-used by drinking water service providers.

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[3] Volumes supplied but not billed for social and political reasons can hardly be considered as « losses », as was envisaged by the Plan Bleu for defining water use efficiency indicators, since they are the result of a conscious political choices.

  - Linear loss index constituting an indicator of the system's physical performance, relating the volume of losses to the length of the network.

- The most widespread economic « loss » indicator is the « Economic Level of Leakage », ELL. The ELL (*Equation*3) is defined as the threshold level of leakage above which attempting to reduce loss would prove more expensive than providing water from another source(Pearson &Trow 2005), (Fantozzi& al. 2005), (Brothers 2005). It is such that:

Equation 3: Economic Level of Leakage (ELL)

$$Marginal\ cost\ of\ reducing\ leakage = Marginal\ cost\ of\ supplying\ water$$

Indeed, the technical complexity and the cost of leakage reduction increase in line with the scale of repairs to the network, the cost of repairs being correlated to the network's initial yield. For the service provider, ELL corresponds to an optimum defined according to the marginal cost of the water supplied and compared with the cost of mobilizing new water resources. It results from a « balance » being struck between system maintenance, water savings and the mobilization of new resources.

1.2. Economic and financial evaluation of loss reduction during water supply through the collective system

« Loss » (leaks, metering errors, illicit users) during the supply of drinking water represents a financial cost for the service provider, linked to the conveyance, treatment and distribution of unsold water. Thus the main issue for the service provider as far as leak reduction measures are concerned lies in better controlling production costs (largely determined by the cost of energy and capital), whilst taking into account additional distribution costs they generate (largely determined by the cost of labour). Economic analyses have shown, however, that costs are not the only reason for the high levels of loss and have suggested the importance of the informational rent in the case of public service delegation, for example. Leaks also entail the risk of disrupted service, which may in turn give rise to health hazards.

The significance of « loss » reduction also depends on the use made of the water saved (*Figure 4*):

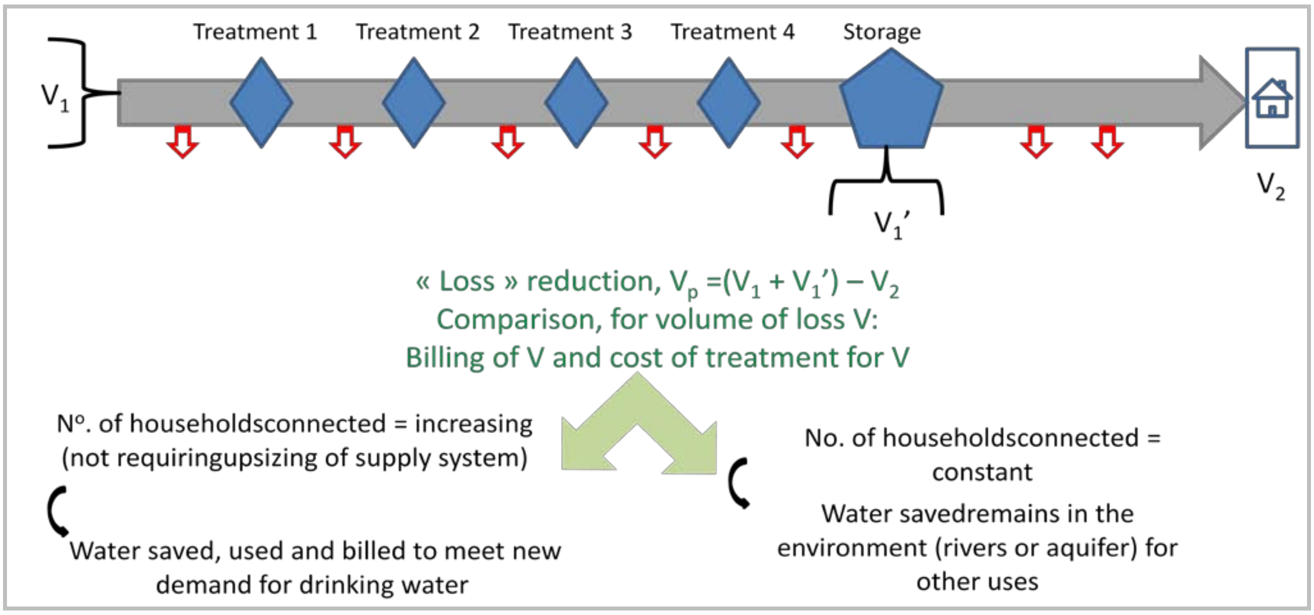
- If the demand which could be met by the supply system is under stress and increasing (at network constant size), any water saved could be resupplied and charged for, thus becoming a source of revenue for the service provider or prompting the redistribution of fixed costs on a greater billed water volume.
- If demand is satisfied and constant, the water saved will remain in the environment (it will be neither collected nor treated), and can be available for other uses. There will thus be a slight fall in production costs. The service provider will have to compare this fall with the cost of reducing leakage in order to establish whether leakage reduction within the network is worthwhile. For the community, water saved and valued by other users must also be factored in.

Consequently, for the service provider:

- It is advantageous to track down leaks as long as the optimum is not exceeded (ELL).
- Saved water is better valued when drinking water demand is increasing and can be met without resizing the network.

From the user perspective, such a water saving measure will have an effect if the fall in costs is reflected in the water bill. For the community, the benefits also depend on how the water made available is valued by other users.

Figure 4: Valuing water savings in drinking water supply systems



2. Reducing the volumes consumed by drinking water end-users

2.1. Quantification and monitoring of end-user-level losses

The issue concerns:

- Either loss from pipes in buildings i.e. billed water which returns to the environment.
- Or poor water use efficiency (or « over-use »), i.e. water used by households, not consumed, and which feeds back into the sewage system where it is treated before being returned to the environment (rivers).

The second type of « losses » is often the largest in quantitative terms. It can often be curbed by replacing domestic apparatus with more water efficient versions: up-dating air-conditioning and toilets, abolishing ground source cold chains, installing economisers, replacing washing machines, washing-up machines and taps… According to several studies, apparatus replacement can reduce specific consumption by as much as 35%, particularly for public establishments.

For the user, whether or not it is worthwhile installing water-efficient apparatus at home or in public buildings depends on their payback period and savings on water and energy bills. The payback period is a function of the cost of water and the market cost of the apparatus. It tends to be less than 5 months for simple equipments such as tap aerators and about 2 years for heavier apparatus such as flushes.

2.2. Economic and financial evaluation of loss reduction in the user’s home

As far as the user is concerned, the main reason for curbing loss is to reduce the water bill.

For the service provider too the relevance of curbing water « loss » and « over-use » by the consumer also depends on how the water thus saved is valued (*Figure 5*):

- If demand is increasing, any water saved could be resupplied and charged for. This could lead to a drop in the overall unit price for water if the service provider redistributes the fixed costs of the service across the newly supplied volume.

- If demand is constant and met, the water saved will remain in the environment: it will not be collected, treated or charged for. If large volumes are involved, this will be reflected in the fixed costs being distributed over a smaller billed volume and thus an increase in the overall unit price of water charged to the user. This explains why several municipalities in France are no longer willing to encourage users to cut down their water consumption. (*Inset 2*).

Consequently, water saved is better valued by the service provider and the user when demand is rising and can be met without resizing the network.

Where demand is constant or falling, curbing « loss » within the system or at end-user level generates significant extra cost for managing the water service. However, the water thus released can also be of benefit to the environment or to other downstream users.

Inset 2: Per unit consumption and water price in the Mediterranean

The use of drinking water and the related issues vary considerably within the Mediterranean region. The factors which determine drinking water demand are "situated" and of complex analysis.

In France and in Europe more generally, over the past 20 years, drinking water use per household has been on a downward trend. Per unit consumption in Paris fell by an average of 2.2% between 1991 and 1998. This drop has particularly affected major water consumers, albeit not them alone. Usually, however, water price is not the factor prompting households to replace their apparatus with more water-efficient versions. Instead, the major urban drinking water consumers (apartment blocks, offices, industry and public services) rather tend to combine renovation work with reducing leakage and replacing their appliances (Barraqué&Nercessian 2008).

Since the early 90s', a tendency towards stagnation and falling per unit consumption has also been observed in the major cities in some countries of the south of the Mediterranean, such as Tunisia (Bennasr&Verdeil 2009) and Morocco (Maria & Giraud 2008). Analysing these mean trends, their causes and the effect they have on service management and on overall water use for domestic purposes is a complex exercise. Indeed, averages mask major disparities between consumers (poorest households, middle classes, hotels, offices and administrations, industry, etc.).

In Morocco and Tunisia, the downward trend of drinking water per household has been related to an increase in the price of the water provided through collective networks, leading to the redistribution of the water saved, by limiting network resizing and operation costs. However, the most significant drop in unit consumption has come from the major consumers (industry, shared buildings…).

This can be ascribed to several factors: replacement of apparatus, price incentives, alternative resources…

In Casablanca (Morocco), Lydec[4] has noted a significant increase in the amount of water being abstracted from aquifers by hammams, industry and major residential consumers, due to a notable price hike of the water provided by the collective network. Similarly, in Sfax (Tunisia), industries are increasingly resorting to drilling or reusing treated wastewater. In Tunisia, the Sonede[5] is thus currently facing major transition stakes in order to keep the financial balance of the service. The equalization pricing measures between major and minor consumers or between urban and rural areas were implemented in order to allow service financial equilibrium while also reaching specific social and political objectives. However, the current downwards consumption trend amongst « major » consumers, either due to a more efficient water distribution or end-use, or to the increased cost of water provided by the collective network rendering off-network practices more attractive, are undermining the networks' long-term financial sustainability.

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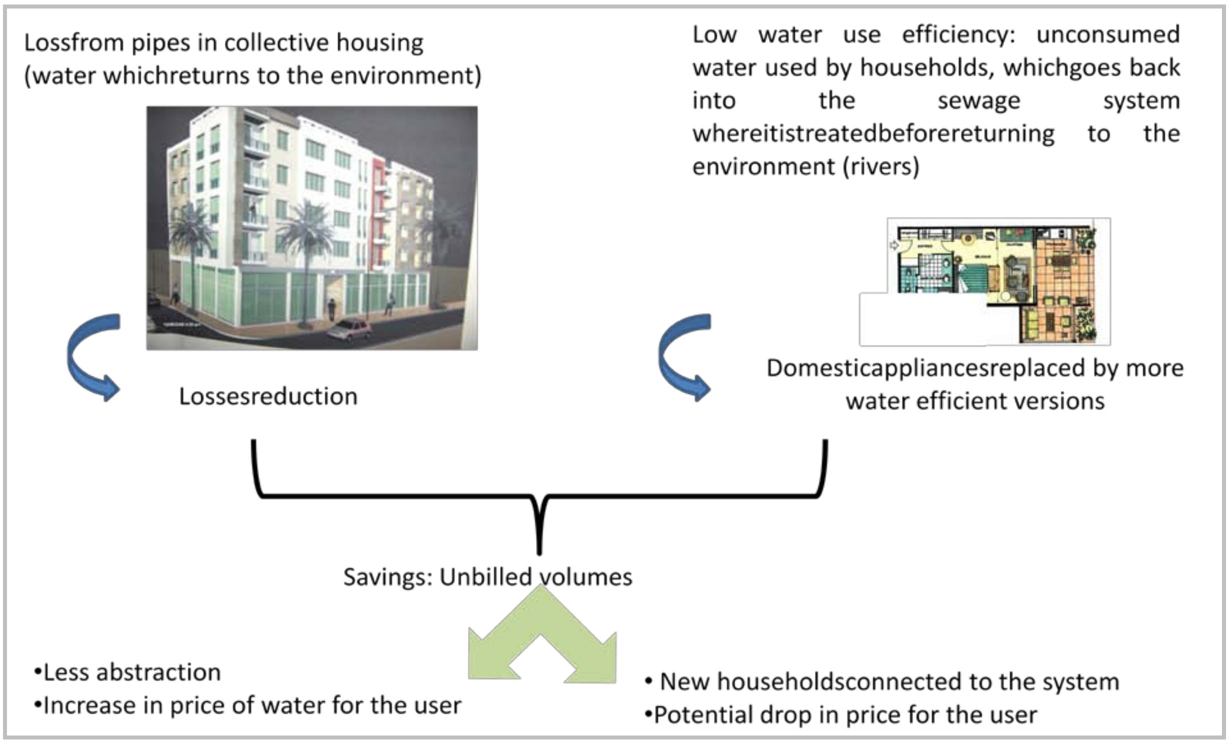
[4] The *Lyonnaise de Casablanca* is a private company, whose capital stock includes shareholders such as *Suez Environnement, Elyo, Endesar Europa and Aguas de Barcelona.* Since 1997, management of the electricity, drinking water and sewage services in Casablanca has been delegated to the Lydec for a period of 30 years. The concession covers Casablanca urban community, i.e. some 4 million people.

[5] The Sonede was set up in 1968. It is a non-administrative public body under the authority of the Ministry of Agriculture and Water Resources. It is in charge of the drinking water service throughout Tunisia (production, treatment, transport, water delivery, studies and projects)

Figure 5: Valuing water savings at the level of the drinking water end-user (household)



3. Analysing the results of the case studies conducted in the Mediterranean

Five studies from the set analysed are presented hereafter *(*Table 2): Tensift basin (French Development Agency 2008), the Hérault region (Rinaudo 2008), the Ardèche basin, Karditsa region (Strosser& al. 2007) and the IPEST university establishment (Khrouf 2001):

Three of these studies comprise an economic evaluation of efficiency gains at network and/or user level, whilst the remaining two provide the same evaluation at a larger territorial level. They are all based on a « cost-effectiveness » type of analysis. The cost-effectiveness ratios of the various studies do not, however, all cover the same elements:

- The costs either include the financial cost of the measure and the cost of non-action for the beneficiary of the measure (EC1),
- Or the costs include the financial cost of the measure and its economic and environmental externalities for the beneficiary and the community as a whole (EC2),
- Or the costs are limited to the financial cost of the measure (FC).

The methodological framework described in sections 1 and 2 has been applied to the case studies analysis (*Table 3*) in order to establish the effectiveness of the WDM measures analysed, according to the perspective and timeframe considered.

Table 2: The case studies chosen for the drinking water sector

Area covered by the case study	Objective	Measures taken	Type of economic evaluation	Scale of analysis
Region of Karditsa (Greece)	To assess the measures for addressing expected water deficit by 2030, in a context of competition between uses for over-exploited groundwater resources.	✓ At water distribution networks scale: Reduction of leakage within the networks. ✓ At user level Installation of water saving appliances ✓ Reduction of leakage in shared and individual housing	Indirect Costs evaluation including the avoided financial costs (payback)	Drinking water Service
Ardèche catchment basin (France)	To assess the measures for addressing seasonal water shortages (peak periods) within a context of increasing demand.		Costs evaluation including the financial costs of the measure (FC and payback)	
IPEST University Establishment(Tunisia)	To assess measures for reducing water leakage and wastage by collective users.	✓ At user level: Installation of water saving appliances Reduction of leakage in the network between buildings		
Tensift catchment basin (Morocco)	To consider various solutions for providing Marrakech with additional drinking water, by analysing possible water reallocations between uses and its consequences.	✓ Water distribution networks rehabilitation ✓ Reallocation of the water stored in existing reservoirs ✓ New reservoirs, ✓ Inter-basins water transfers, ✓ Seawater desalination	Comparing various alternatives according to cost-effectiveness ratios that vary according to the type of costs, financial and/or economic, included in the calculation: FC, EC1 or EC2.	Area
Hérault area (France)	To assess measures for creating consistent programmes in order to meet the objectives of the European Water Framework Directive (WFD).	✓ Water distribution networks rehabilitation, ✓ Reducing drinking water use (leaks in collective housing, water saving appliances, pricing), ✓ Rainwater recovery, ✓ Reallocation of water from existing reservoirs, ✓ Water transfers from the Rhône, ✓ Seawater desalination.		

3.1. Within the drinking water service

The analysis draws on the studies conducted in the Ardèche (France),the region of Karditsa (Greece), (Strosser& al. 2007), and for the IPEST university establishment (Tunisia), (Khrouf 2001). The Ardèche and IPEST studies only consider financial costs, whereas the region of Karditsa study also covers the avoided cost compared with a reference situation without project.

It is not possible to calculate the cost-effectiveness ratios for the region of Karditsa case study as there is no information on the cost of the measures.

For the Ardèche basin study these ratios can be calculated using the information provided and hypotheses on the discount rate and the lifespan of the apparatus for the various measures affecting the efficiency of the water delivery network and household water use.

The annualised discounted cost was calculated for each measure using the formula of the Equation 2 (*Table*5).

The results suggest that (*Table 4, Table 5*):

- Payback periods widely vary between the case studied,
- For the same volume saved, measures concerning the network efficiency seem more cost-effective (from a strictly financial point of view) than user-targeted measures,
- The efficiency of measures increases with their lifespan.

Table 3: Features of measures, their benefits and beneficiaries (Ardèche basin, France, IPEST, Tunisia, and region of Karditsa, Greece)

Case	Measure	Benefits	Perspective
ARDÈCHE BASIN	Improving supply system efficiency	In the short term: ✓ At water service level: Smaller volumes abstracted but not billed ✓ At river level: Contributes to low water flows, water system quality, spare-time activities (swimming, canoe-kayak) ✓ At aquifer level: Limits the drop in aquifer levels. In the medium term: Contributes to meeting new demand	Service provider Catchment basin users, environment
	Water saving appliances	Lower consumption. Smaller water and energy bills.	Drinking water supply system users
IPEST	Enhancing the efficiency of waterend-use	✓ In the short term, at user level: Lower consumption. Smaller water bill. ✓ In the medium and long term, at service and user level: Less need to upsize water supply and distribution system. No increase in water bills (fixed costs)	New and established users of the drinking water system Service provider (this programme is encouraged by the National Water Exploitation and Supply Company)
	Water saving appliances		
REGION OF KARDITSA	Improving supply system efficiency	✓ In the short term, at service level: Lower volumes abstracted but not billed ✓ In the medium and long term, at service and user level: Less need to upsize water supply and distribution systemand no increase in water bills (fixed costs)	Service provider
	Water saving appliances	✓ In the short term, at user level: Lower consumption. Smaller water and energy bills ✓ In the medium and long term, at service and user level: Less need to upsize supply system and no increase in water bills (fixed costs)	New and established users servedService provider

Table 4: Cost of water savings (Ardèche Basin -France, region of Karditsa-Greece and IPEST-Tunisia)

Case	Quantitative water savings and quantified benefits	Cost of water saved	Financial and economic indicators used in the study
ARDÈCHE BASIN	Networks efficiency: 2.4 Mm³/yr. Water saving appliances: 2.46 Mm³/yr (30% of water used by households). Overall reduction of household water bills between 7 and 12 M€/yr. (average water price: 2.79 €/m³).	✓ Cost to the service provider: 0.23 M€ (improved efficiency of water distribution) ✓ Cost to households: 1. 51 M€ (installation of water saving appliances)	Payback (households) < 1 yr (3 months)
REGION OF KARDITSA	Networks efficiency: 2.3 Mm³/yr (10% of demand). Water saving appliances: 2.3 Mm³/yr (10% of water used by households). Overall reduction of household water bills: 3.2 M€/yr. (water price for the municipality of Karditsa: 1.35 €/m³).	No information available	Payback (households) = [7 yrs, 8 yrs]. Payback (supply system) = 10 yrs
IPEST	Networks efficiency: 10 000 m³/yr (33% of average annual consumption) Water saving appliances: 3200 m³/yr (11% of consumption) Overall reduction of water bill (supply system): 15 000 DT in 2000 (7900 € today)	✓ Cost of renovating the network: 12 000 DT in 2000 (6300 € today) ✓ Cost of installing water efficient appliances: 78 000 DT in 2000 (41 100 € today) Overall cost: 90 000 DT (47 400 € today)	FC of overall project = 0.4 €/m³ (costs discounted over 30 years, with a discount rate of 10%) Savings on water bills estimated at 60% Payback (system within the building) < 1 yr (10 months)

Source: Ratios calculated based on data from (Strosser& al. 2007), (Khrouf 2001)

Table 5: Estimate of the cost-effectiveness ratios of the measures planned for the Ardèche basin (France)

Ardèche basin (France)	Volumes / year (mcm)	Investment cost (M€)	Cost-effectiveness ratio (T=2 yrs) (€/m³)		Cost-effectiveness ratio(T=5 yrs) (€/m³)		Cost-effectiveness ratio(T=10 yrs) (€/m³)		Cost-effectiveness ratio(T=20 yrs) (€/m³)	
			a=4%	a=10%	a=4%	a=10%	A=4%	A=10%	A=4%	A=10%
Supply system efficiency	2,4	0,23	0,051	0,055	0,022	0,025	0,012	0,015	0,007	0,011
Household water use	2,46	1,51	0,325	0,354	0,138	0,163	0,076	0,100	0,045	0,072

Source: Ratios calculated based on data from(Strosser& al. 2007)

The chosen hypotheses are as follows:

Discount rate (a): 4% rate set by the General Planning Commission in 2005 (Lebègue report) for public investment projects – 10% rate set for the Tunisian case study (IPEST). Lifespan of appliances (T): The proposed measures cover appliances whose lifespan varies widely. We have attempted to test the sensitivity of the ratios for the time span over which the cost of the measure is distributed (T = 2 years, 5 years, 10 years or 20 years).

3.2. At a territorial level

The two studies considered are the one conducted in the Tensift basin (French Development Agency 2008) and the other in the Hérault(Rinaudo 2008). They fit into a broader water scarcity management perspective at a territorial level, using an inter-sector approach.

Table 6: Cost-effectiveness evaluation of various water demand management options in 2 areas (Western Hérault in France and the Tensift basin in Morocco)

Measure			Case	Volumes saved – Additional water provision (Mm^3) and their allocation	Cost-effectiveness analysis (EC$_1$ or EC$_2$, €/m^3) Or average annualised cost of the measure (FC, €/m^3)
WATER DEMAND MANAGEMENT MEASURES	Drinking water supply system	Reducing leakage in the network	« Western-Hérault »	Volume: 1.345 Mm^3 at peak periods, 3.45 Mm^3/yr. Objective: Supplying drinking water without upsizing the system	FC (peak period) = 0.53 €/m^3 26% of municipalities: EC$_1$=- 0.026€/m^3, 74% of municipalities: EC$_1$ =[0.12€/m^3, 11.66€/m^3] Costs considered: the financial cost of the measure and the avoided cost of upsizing the system compared with the reference situation.
			Tensift basin	Volume: 7Mm^3/yr Objective: Supplying drinking water without upsizing the system	FC =0.08 €/m^3 (0.91 Dh/m^3) Costs considered: the capital and operating costs of leakage management.
	Drinking water end-use	Reducing leakage in collective housing	« Western-Hérault »	Plumbing contracts Volume: 0.194 to 0.224 Mm^3/yr Objective: Supplying drinking water without upsizing the system	FC (peak period)=7.6 €/m^3 EC$_1$ (peak period) = [6.62€/m^3, 6.70€/m^3] Costs considered: the direct cost of the measure and the avoided cost of upsizing the system and for energy compared with the reference situation.
		Reducing unit consumption in private homes	« Western-Hérault »	Installation of water efficient appliances in all municipalities with a take-up rate of 30%. Volume: 3.63 Mm^3/yr (i.e. 36 m^3/yr per average household), of which 1.45 Mm^3 during peak period (40%). Objective: Supplying drinking water without upsizing the system	FC (peak period) =0.382 €/m^3 EC$_1$ peak period = [-1.2 €/m^3, -1.9 €/m^3], EC$_1$ average= -1.58 €/m^3 Costs considered: the financial cost of the measure and the avoided cost of upsizing the system and for energy compared with the reference situation.
		Reducing consumption via price incentives	« Western-Hérault »	Introduction of seasonal pricing. Volume: 3.468 Mm^3/yr (1. 387 Mm^3 during peak period) Objective: Supplying drinking water without upsizing the system	FC (peak period) =[0.2 €/m^3, 0.9 €/m^3] 4% of municipalities: EC$_1$ (peak period) < 0, 96% of municipalities: EC$_1$ peak period=[0 €/m^3; 0.7 €/m^3] Costs considered: the direct cost of the measure and the avoided cost of upsizing the system and for energy compared with the reference situation.
	Rendering usage of water from existing reservoirs more flexible (Reallocation of water from existing reservoirs)		« Western-Hérault »	Increased abstraction from Salagou lake. Volume: from 3 to 15.5 Mm^3 during peak period Objective: Drinking water supply, improving the self-cleaning capacity of rivers.	Coastline dropped by 50 m: EC$_2$ (peak period) =0.436 €/m^3 Drop ruling out all tourist activity on the lake: EC$_2$ (peak period) =0.56 €/m^3 Costs considered: the costs associated with the loss of tourist activity on the lake.
	Restoring water quality in the aquifers		« Western-Hérault »	Change in farming practices regarding inputs and pesticides in the catchment areas and grassing over of vineyards. Volume: 0.127 Mm^3 during peak period Objective: Drinking water supply, improving aquifer quality	FC = 0.70 €/m^3 Costs considered: the cost of grassing over and switching practices, cost subsidised in order to limit its impact on agricultural income.

Source: Ratios calculatedbased on data from(Agence française de développement 2008), (Rinaudo 2008)

Table 7: Cost-effectiveness evaluation of various supply management options for 2 areas (Western Hérault in France and Tensift basin in Morocco)

Measure		Case	Volumes saved- additional water provision (Mm^3) and how it is attributed	Cost-effectiveness analysis (EC$_1$ or EC$_2$, €/m^3) or average annualised cost of the measure (FC, €/m^3)
SUPPLY MANAGEEMENT MEASURE	NEW RESERVOIRS	Tensift basin	Volume: 17 M m^3(for Wirgane dam with a capacity of 70 M m^3) Objective: Drinking water supply (Marrakech)	FC =0.21 €/m^3(2.3 Dh/m^3) Costs considered: financial investment and operating costs.
		« Western-Hérault »	Rainwater collection by private individuals: 500 litre capacity drums: Volume: 0.033 Mm^3 Objective: Watering private gardens (Supplying drinking water without upsizing the system)	FC =9.53 €/m^3 EC$_1$= 8.96 €/m^3 Costs considered: the direct cost of the measure and the avoided cost of upsizing the system compared with the reference situation.
			Rainwater collection by private individuals: Large capacity system: underground tank (9 m3 capacity). Volume: 0.18 Mm^3 Objective: Watering gardens and supplying flushes (Supplying drinking water without upsizing the system)	EC$_1$=17 €/m^3 Costs considered: the direct cost of the measure and the avoided cost of upsizing the system compared with the reference situation.
	TRANSFERS	« Western-Hérault »	Transfer of water from the Rhône Volume: Between 3.33 Mm^3 and 7.793 Mm^3 (less abstraction in the Hérault, the Orb or the Astien aquifer at peak periods). Objective according to size of feeder channel: (1) Drinking water supply (with several alternatives according to the size of the geographic area in question), (2) Drinking water supply and irrigation, (3) Drinking water supply, irrigation and supplying the canal du Midi	EC$_2$ (peak period)=[1.14 €/m^3,2.03 €/m^3] (according to size of feeder channel). Costs considered: annualised investment costs, operation and maintenance costs for the pipes carrying untreated water, purification costs and CO$_2$ emission costs, which correspond to environmental externalities.
		Tensift basin	Transfer from reservoirs (Massira, Bin El Ouidane, Hassan 1st), via channels. Volume: Between 30 and 80 Mm^3 Objective: Drinking water supply (Marrakech)	EC$_2$ = [0.63 €/m^3, 1.23 €/m^3], [7 Dh/m^3 ; 13.5 Dh/m^3] Costs considered: the financial cost of transfer and the opportunity cost represented by agricultural losses linked to the reallocation of water from reservoirs.
	DESALINATION OF SEAWATER	Tensift basin	Volume: No information Objective : Drinking water supply (Marrakech), with network upsizing	FC = [0.5€/m^3, 0.85 €/m^3 ([5.5, 9.4 Dh/m^3]) Costs considered: the cost of collecting water, no transport.
		« Western-Hérault » Project	Coastal desalination plant (Agde region), plant capacity: 30 000 m^3/day. Volume: 4.05 Mm^3/yr of which 2.7 Mm^3 at peak periods. Objective: Drinking water supply, with networkupsizing and easing of the pressure exerted on the Astien aquifer.	EC$_2$ (peak period)=1.545 €/m^3 Costs considered: annualised investment costs, operation and maintenance costs and CO$_2$ emission costs. There is no avoided cost compared with the reference situation
			Coastal desalination plant (lower reaches of the Orb), plant capacity: 15 000 m^3/day Volume: 2.025 Mm^3 of which 1.35 Mm^3 during peak period. Objective: Drinking water supply, with system upsizing, easing of pressure on the Orb and the Astien aquifer.	EC$_2$ (peak period)= 2.06 €/m^3 Costs considered: annualised investment costs, operation and maintenance costs and CO$_2$ emission costs. There is no avoided cost compared with the reference situation.

Source: Ratios calculatedbased on data from(Agence française de développement 2008), (Rinaudo 2008)

4. Conclusion

The conclusions are based on an analysis of Table 4, Table 5, Table 6 and Table 7:

Compared measure-by-measure analysis of the unitary economic results:

- The most effective solutions entail the reduction of leakage from the water supply network where the network's initial yield is low.
- The installation of water efficient appliances is an effective solution for the user and service provider when demand which can be connected to a water supply networkof constant size is rising.
- Leakage reduction in communal housing as well as rainwater recovery would not appear to be effective measures.
- Solutions aimed at providing for the more flexible use of water from reservoirs may prove effective.
- Solutions aimed at limiting diffuse pollution are effective.
- The least effective solutions are those involving increased supply such as transfers or the desalination of seawater[6].

- **Overall analysis of the projects:**

The various measures analysed are not all comparable in terms of the total volumes saved as a result.

- ♦ According to the case studies, besides being the most cost-effective, measures reducing leakage in the network and the installation of water efficient appliances may make a significant contribution towards meeting future drinking water demand.

Besides the measure-by-measure evaluation, the studies also assess the cost-effectiveness ratios of various combinations of measures according to the objective of an available volume of water to be reached, intended either to ease pressure on the environment or to meet new anthropogenic demand.

The case studies also suggest:

- Wide spatial variation in the effectiveness of certain measures, to be taken into account in project design.
- The significance of seasonal variability in the water supply/demand relationship to the effectiveness of measures. On the whole the peak period calculation produces lower cost-effectiveness ratios.

Finally, only measures with a negative ratio are likely to be spontaneously implemented, since they represent a clearly identified net profit for the beneficiary of the measure. Measures with low but positive ratios, on the other hand, generally demand collective financing (public, international…), particularly ones which are related to indivisible investments with high fixed costs.

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[6] Desalination appears to be less expensive in the Moroccan case, most probably because conveyance costs have not been factored in and possibly due to different technical options.

IV. Economic and financial evaluation of irrigation water demand management

This chapter addresses irrigation ("blue water") services and the productivity of agricultural water (blue and green water). As for the economic evaluation of drinking water demand management, the analysis discusses the measuring, monitoring and management of irrigation water efficiency at plot level and within the irrigation network.

The cost of irrigation depends on topography and distance to the resource. Irrigation on the banks of a river or an aquifer is the least expensive. A distinction is usually drawn between "individual" and "collective" irrigation. Indeed, they differ in the way they foster stakeholders' organisation for the management of irrigation and sharing water with other uses. However, this distinction does not always correctly portray the reality of irrigated systems, which may well combine both types of irrigation.

Assessing efficiency gains in the agricultural water use sector is a particularly complex operation, since the causal factors behind agricultural water management mostly lie outside the "water world", within territorial or agricultural policies, for instance.

Irrigation water efficiency can be subdivided into « hydrological », « hydraulic », « agronomic » and « economic » efficiency (Bouaziz&Belabbes 2002), (*Annex 2*).

1. Reducing loss in the irrigation water service (hydraulic efficiency)

1.1. Quantifying and monitoring loss within the network and in the application of water to the plot

« Losses » during the collection and supply of irrigation water through individual or collective channels may stem from (*Figure 6*):

- leakage: water collected and supplied, lost when transported through the network and which returns to the environment,
- misappropriated water (« illicit users ») or metering defects[7],
- water evaporating during transport through open networks (rainwater which evaporates and subsequently condenses into clouds).

The main indicators of hydraulic efficiency are described in Annex 2.1: efficiency of the water conveyance, supply and application. Irrigation techniques contribute to the efficiency of irrigation water application to the plot. Irrigation technique options are also driven by various constraints (*Table 13*, Annex 2.1) such as:

- physical constraints: climate, topography,
- agronomic constraints : cultural practices, global constraints on the farming system,
- economic, human and organisational constraints: manpower-energy ratio, availability of manpower (paid, family), level of development of industries producing the techniques, farmers' overall technical skills, labour organisation, organisation of the allocation and distribution of water (overhead irrigation tower, on request, regularity of flow...).

Choosing an irrigation technique is part of wider production system profitability logic, within which the utilisation of the « water » factor is only one dimension.

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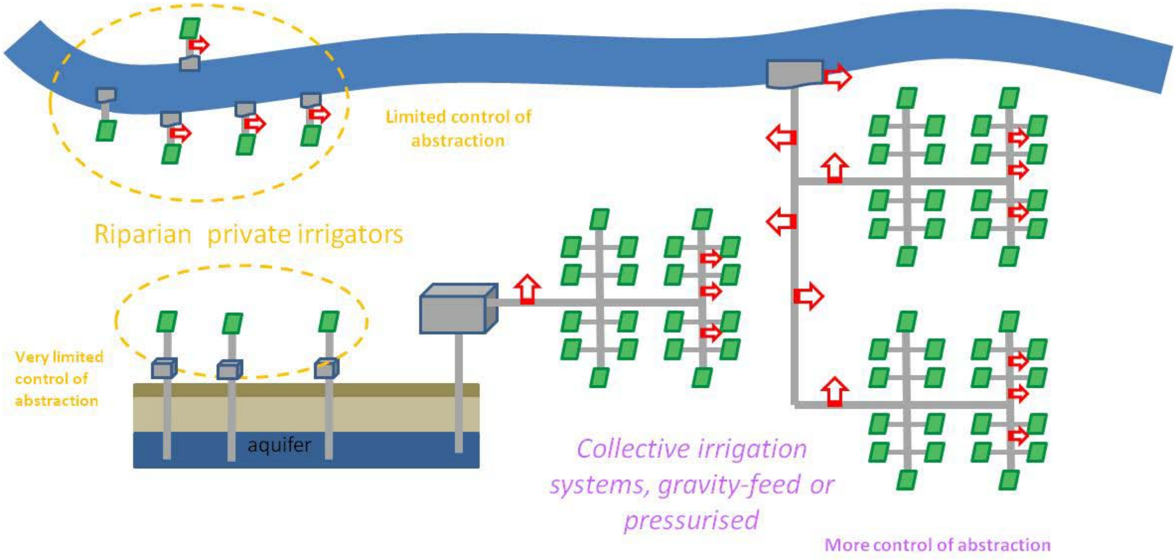
[7] As with drinking water, it is not convenient to class amounts of water distributed but not billed for social and political reasons as « losses ».

Figure 6 : Losses within the irrigation water service



1.2. Economic and financial evaluation of loss reduction within the irrigation water service

As far as water loss during collection and distribution due to hydraulic inefficiency is concerned:

- With individual irrigation, water losses represent a financial cost (collection and distribution) for the irrigator:

Thus for the irrigator, the financial analysis includes:

- The financial cost of collecting and distributing the « lost » water,
- The financial cost of rehabilitating the supply system or hillside lakes,
- The benefits attached to the water saved: depending on the irrigator's water demand features and his water rights, the water saved can be used to intensify or extend irrigation or will not be picked up and will then remain potentially available for downstream users or for the aquatic environment.

At a territorial level (community) the economic analysis will weigh up these results against the benefits of the water saved for potential downstream users or for the aquatic environment.

- With collective irrigation, water loss represents a financial cost (collection and supply) for the service provider.

For the service provider and the irrigator:

The service provider weighs up the financial cost of collecting and supplying « lost » water against the cost of rehabilitating the network. It is also weighed up against the benefits, which are positive if demand for irrigation water in the network is stressed compared with available supply, thus potentially allowing the fixed costs to be redistributed over a larger supplied volume.

At a territorial level (community) the economic analysis will weigh up these results against the benefits of water saved for potential downstream users or for the environment.

The main indicators of economic efficiency are described in Annex 2.3: Irrigation water use indicators, gross product, added value and per hectare revenue, compared water value between crops, and the strategic value of irrigation water.

In so far as water use is part of a productive activity, making best use of the m^3 of water abstracted and consumed for irrigation is also an element of water use efficiency. The corresponding indicators are those which allow the wealth produced per m^3 of water consumed to be assessed (added value/m^3 consumed at the scale of the farm, of the sector-based network, gross margin/m^3 consumed...).

Consequently:

- For the service provider (different to the irrigator), the water saved is better valued when it can respond to constrained demand within the network,
- For the irrigator, the water saved may be a source of additional income if it is used to extend or intensify irrigation, depending on the added value of the irrigated crops; otherwise, the amounts saved will be reflected in a smaller water bill.
- For the community, if the water saved remains within the environment, it can be picked up by downstream users or by the aquatic environment.

2. Loss reduction on the plot and in crops (agronomic efficiency)

2.1. Quantification and monitoring of loss in crops

« Loss » during the application of irrigation water or when using rainwater may be ascribed to:

- Water evaporation which subsequently condenses into clouds,
- Water seepage phenomena, where the water is not absorbed by crop root systems.

The agronomic efficiency of a given crop also depends on irrigation and land management practices. The main indicators of agronomic efficiency are described in Annex 2.2: efficiency in the application of irrigation water, « real » efficiency in the application of irrigation water, irrigation water use efficiency compared with agronomic yield.

Potential water savings within an irrigated production system stem from various strategies, as follows (Amigues& al. 2006), (Mediterra 2009):

- Strategies which essentially concern the physiological features or the crop behaviour of a given plant: reducing the risk of lower yield by accepting a reduction in the maximum attainable yield (evasion, avoidance and improvement of water efficiency) or maintaining the maximum attainable yield by accepting an increased risk of loss of yield (tolerance),
- Strategies which concern the organisation of agricultural production: choice of cropping plan, which has a significant effect on the amount of water abstracted from the environment.

2.2. Economic and financial evaluation of loss reduction in the plant

Agronomic efficiency gains bring with them the same type of benefits as hydraulic efficiency.

Hydraulic or agronomic efficiency gains are intended to increase the share of water effectively used compared with the water abstracted. The issue at stake from an economic point of view is to assess the creation of value linked to the improvement in agronomic or hydraulic efficiency. Whilst from an agronomic point of view the aim is usually to maximise constrained yield, economic efficiency is generally based on maximising constrained revenue. The increased value created when water is reallocated towards other users also influences water economic efficiency.

3. Results of the case studies conducted in the Mediterranean

Eight case studies were considered: Tensift Basin (French Development Agency 2008), the Hérault area (Maton 2008), (Rinaudo 2008), the Ardèche catchment basin, the region of Karditsa and the Guadalquivir basin (Strosser& al. 2007), Amman-Zarqa basin (Aulong& al. 2008) and the Gabès oasis (Louhichi& al. 2000) (*Table 8*).

As far as water saving measures are concerned, the case studies largely focus on measures for improving hydraulic efficiency within the supply system at plot level. Some case studies also analyse the impact on water savings:

- Of economic instruments such as pricing,
- Of switching cropping plans towards more water efficient crops.

The case studies also consider measures for increasing water supply: reservoir construction, using alternative resources to surface water such as aquifers, inter-basin water transfers.

They are essentially based on the calculation of FC type ratios, with the Western Hérault study being the only one to analyse EC2 type ratios.

The methodological approach set out in sections 1 and 2 has been applied to the case studies analysis (*Table*9) in order to identify the benefits associated with irrigation water demand management measures according to a given perspective and type of efficiency.

3.1. Within the irrigation networks

It is based on the studies conducted in the Ardèche (France), the region of Karditsa (Greece), the Guadalquivir basin (Spain), the Gabes oasis (Tunisia) and the Amman-Zarqa basin (Jordan).

They all address the financial costs alone (FC).

For the Ardèche basin study, cost-effectiveness ratios were calculated using the information provided as well as hypotheses concerning the discount rate and the life span of the apparatus linked to the various measures[8]. The discounted cost was calculated for each measure using the formula of the Equation 2.

The case study analysis suggests that (*Table 10, Table 11, Table12*):

1) Water demand management measures

- Measures at network level

  Measures to make networks watertight and those involving a change in canals type (from open, gravity-feed canals to pressurised pipes) produce cost-effectiveness ratios of the same order of magnitude. The ratios established largely depend:

  - On the type of cost considered, even when the perspective is a purely financial one; each type of cost may show major spatial variability.
  - On the life-span of the apparatus considered for the calculation, whether this be during comparison of various measures at system level or of system-level versus plot-level measures (*Table 12*).[9]

- Measures at plot level

  The lower the initial yield, the more cost-effective the improvement of yield (hydraulic efficiency) on the plot. Switching from sprinklers to micro-sprinklers thus produces a higher cost-effectiveness ratio, in other words it is less effective than switching from gravity-feed to sprinklers or to a drip system. However, reference costs may vary widely from one case study to another for the same change of technique.

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[8] For the region of Karditsa study, the cost-effectiveness ratio cannot be calculated in the absence of information on the cost of the measures.

[9] For the losses reduction measures, the studies do not specify the periods over which water saving costs are discounted, nor the discount rates applied. Hypotheses have been established (discount rate, life-span of apparatus) but more detailed studies will be required in order to confirm the results.

No economic evaluation was made of the switch in cropping plan. These are, however, some of the most significant measures in terms of potential water savings. Assessing the impact of a change in cropping plan and whether or not it is worthwhile requires a specific agro-economic analysis. Indeed, whether a switch is worthwhile and feasible mainly depends on the features of the production environment (soil type, temperature, etc.), on farm constraints (investment capacity, amortization of past investment) and product enhanced value.

- Pricing measures

  According to two of the case studies, pricing measures would lead to significant water savings with a good cost-effectiveness ratio. Thus for the Guadalquivir river basin, a pricing measure would appear to be more cost-effective and would lead to greater amounts of water being saved than would a measure combining a change from collective channels to pressurised ones and conversion to a drip irrigation system.

  More in-depth analysis, combining qualitative and quantitative approaches, is needed, however, in order to isolate the impact on water consumption of a change in pricing policy compared with that of other measures.

- Regulatory measure: Enforcement of abstraction regulations

  Enforcement of abstraction regulationsis one of the water demand management measures with the best cost-effectiveness ratio. Only one of the seven studies analyses it, however.

2) Measures towards increasing water supply

   Three of the case studies also analyse supply-based management measures, whose cost-effectiveness ratios are relatively low when compared with the measures studied as a whole.

   The case studies show that cost-effectiveness ratios largely depend on:

- The period over which costs are discounted:

  According to the case study under consideration, the cost-effectiveness ratio of a new dam may turn out to be lower (Amman-Zarqa case, Jordan) or higher (Gabès oasis in Tunisia and the Tensift basin in Morocco when the impact of the infrastructure silting up is taken into account) than that of demand-based management measures. It is worth emphasising, however, that in the Amman-Zarqa basin study the cost-effectiveness ratio of the enforcement of abstraction regulationsmeasure is calculated on the basis of a total cost annualised over 5 years, whereas the cost of building the Al-Wahdah dam is annualised over the entire working life of the dam, i.e. 80 years. If, on the contrary, costs are discounted taking into account their real distribution in time, the cost-effectiveness ratio obtained will thus reflect the high annualised cost of capital for the initial volumes of water produced. On that basis, enforcing abstraction regulationsbecomes more worthwhile than constructing a new dam.

- Costs included in the economic evaluation:

  The cost-effectiveness ratio for the construction of the Wirgane dam (Tensift basin in Morocco) is virtually tripled when the effect of silting is factored into the cost. Thus environmental externalities have a noticeable effect on the ratio.

- Size of the infrastructure built:

  Further analyses conducted within the Mediterranean region also suggest economies of scale: the greater the storage capacity, the lower the cost-effectiveness ratio, as is the case with the twenty or so dams assessed under the Decennial Strategic Plan drawn up by the Lebanese Directorate General for water and electricity resources (Comair 2008), with cost-effectiveness ratios ranging from 0.33 to 14.55 €/m3 for structures with a capacity of between 300 000 m^3 and 120 Mm^3.

- Geographical context:

  For a given storage capacity, the cost also depends on the features of the site where the infrastructure is to be built (spatial variability).

Table 8: The case studies chosen for the agricultural water sector

Location of case study	Objective	Measures introduced	Type of economic evaluation	Scale of analysis
Ardèche basin (France)	To meet seasonal shortages (peak periods), within a context of water stress.	✓ At collective network level: Switch from gravity-feed to pressurised pipes ✓ At irrigator level: Switch from surface to sprinkler irrigation, Switch from sprinklers to micro-sprinklers, Conversion of surfaces sown with wheat to vineyards, Increase in water price.	Evaluation of financial costs (FC)	Irrigation water Service
Karditsa Region (Greece)	Secure irrigation when facing growing demand and forecasting deficit leading to a drop in farming revenue.	✓ Within the collective network: Reducing leakage in supply systems ✓ At irrigator level: Switch from surface to sprinkler irrigation	Evaluation of financial costs (FC) and analysis of the drop in farming revenue avoided	
Gabès Oasis (Tunisia)	Improving irrigation water use, within a context of water scarcity and poor resource management.	✓ Within the collective network: Reducing networks leakage Construction of new reservoirs ✓ At irrigator level: Abstraction from aquifers using surface wells or deep drilling	Evaluation of financial costs (FC)	
Guadalquivir basin(Spain)	Compensating the current water deficit and meeting growing demand, with a limited number of options for increasing supply.	✓ Within the collective network: Switch from gravity-feed to pressurised pipes ✓ At irrigator level: Switch from surface to localised irrigation Introduction of volumetric pricing and increase in the price of water	Evaluation of financial costs (FC)	
Amman-Zarqa basin(Jordan)	Reducing a forecasted deficit towards 2030 within the current context of overexploited resources.	✓ Within the collective network: Enforcement of abstraction regulations Construction of a new reservoir	Evaluation of total annualised financial costs (FC)	
Tensift Basin (Morocco)	Securing irrigation (agricultural water provision), within a context of conflicts over use of overexploited resources.	✓ Within the collective network: Reducing leakage in supply networks ✓ At irrigator level: Converting from gravity-feed to localised irrigation Construction of a new reservoir	Comparison of the various alternatives according to cost-effectiveness ratios which vary according to the type of cost (financial and/or economic) included in the calculation (FC or EC_2)	Area
The Hérault Area (France)	Assessing measures leading to a reduction of agricultural water withdrawals at the lowest possible cost, in order to curb the demand trend.	✓ Within the collective network: Reducing leakage in supply systems Switching from gravity-feed to pressurised channels ✓ At irrigator level : Conversion from surface to localised irrigation Transfers from the Rhône		

Table 9: Features of the measures, their benefits and beneficiaries

Efficiency targeted by the measure	Measure	Future of the volumes saved	Benefits/Costs	Perspective
Hydraulic efficiency	Within the collective network: ✓ Optimisation of existing networks: reduction of leakage within supply systems ✓ Switch from gravity-feed to pressurised mode ✓ Water PolicingOn the plot: ✓ Techniques improvements ✓ Change of irrigation technique	Non-abstracted volumes	Smaller volumes abstracted and charged for (cheaper collection and distribution), financial sustainability risk due to service cost structure and water pricing	Water service provider
			Contribution to low water flows, to water quality (dilution/self cleaning capacity)	Environment, downstream users
			Possible reduction in water bill	Irrigator
		Extension of irrigated area or intensification or safeguarding of water administered	Zero effect	Water service provider
			No release of the pressure on the resource	Environment, downstream users
			Action within the collective network : Where water acted as a constraint on maximising revenue: - Increased revenue, - Increased economic efficiency Action at plot level: Increased agronomic and economic efficiency if the change (or improvement) in technique is reflected in better irrigation management.	Irrigator
Agronomic and economic efficiency	Change in cropping pattern	Volumes not abstracted(trend towards more water friendly crops)	Smallervolumes abstracted and charged for (cheaper collection and distribution), financial sustainability risk due to service cost structureand water pricing	Water service provider
			Contribution to low water flows, to water quality (dilution/self-cleaning capacity)	Environment, downstream users
			Possible reduction in water bill. Increased revenue and economic efficiency if the new crop has higher added value, drop in economic efficiency otherwise.	Irrigator
		Extension of irrigated area or intensification /safeguarding of irrigation	Zero effect	Water service provider
			No release of the pressure on the resource (counter-productive measure if the objective is to mitigate tensions on water resources)	Environment, downstream users
			Increased revenue and economic efficiency if the new crop has higher added value, drop in economic efficiency otherwise.	Irrigator
Economic efficiency	Pricing measures, water sharing control (licences, Enforcement of abstraction regulations, etc.)	Volumes not abstracted (for pricing only applies if there is high price flexibility)	Smaller amounts abstracted and charged for (cheaper collection and distribution), financial sustainability risk due to service cost structure and water pricing. This phenomenon is mitigated if this is a pricing instrument and the price of water balances out the losses, whilst not totally cancelling out demand for agricultural water.	Water service provider
			Contribution to low water flows, water quality (dilution/self-cleaning capacity) « Pareto-improvement »[10] mechanism for water allocation	Environment, downstream users, community
			Incentive towards hydraulic efficiency improvement measures at plot level (for the pricing instrument only if there is high price elasticity). Changes the constraint linked to maximising the utility function (either directly through a licence on the resource or indirectly through pricing if there is high price elasticity).	Irrigator
		Same volumes (measure has no incentive effect or lack of control over quotas, water policies, or illicit abstraction)	Zero effect	Water service provider
			Zero effect for the aquatic environment or downstream users Cost for the community due to the introduction of the measure	Environment, downstream users, community
			Pricing measure: Higher water bills and lower economic efficiency. Water licences orenforcement of abstraction and dischargeregulations : zero effect	Irrigator

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[10] A *Pareto-improvement mechanism leads to the enhanced well-being of certain actors with no negative impact on that of other actors: collective well-being is enhanced following implementation of the mechanism.*

Table 10: Cost-effectiveness ratio (FC) of the measures assessed under the case studies for the agricultural water sector (demand and supply-based management measures)

Measure			Case	Volumes saved/Additional water provision (Mm^3)	Cost-effectiveness analysis (FC)
WATER DEMAND MANAGEMENT MEASURES	Collective system	Switch from gravity-feed to pressurised pipes	Ardèche basin	Volume: 0.11 Mm^3 (76 ha, i.e.: 1447 m^3/ha)	FC = [0.22 ; 1.73] €/m^3 The results are shown in Table 10 (produced by a calculation conducted on the basis of a set hypotheses and data from the studies). Costs considered: investment cost (4 342 €/ha)
		Reducing loss in collective networks	Region of Karditsa	Volume: 4.8 Mm^3 (20% of irrigation water abstractions)	FC = 0.05 €/m^3 Costs considered: Unit investment cost extrapolated from available data forFrance
			« Western-Hérault » (gravity-feed)	Volume: 3.55 Mm^3/yr (30% reduction in abstractions depending on the initial state of the system)	FC = 0.55 €/m^3. Costs considered: technical investment costs (1 000 to 5 500 €/ha depending on the initial state of the canals),administrative costs and technicians salaries
			Tensift Basin (gravity-feed)	Volume: 59 Mm^3/yr	FC = 0.31 €/m^3 Costs considered: investment costs
	System and on the plot	Switching from gravity-feed to pressurised pipes and switching from surface to drip irrigation	Guadalquivir Basin	Volume: 429 Mm^3 (375 000 ha, i.e. 1144 m^3/ha) (375 000 ha, of which 278 000 ha affected by the switch to drip irrigation)	FC = 0.38 €/m^3 Costs considered: investment costs (5 000 €/ha for the switch from gravity-feed to pressurised pipes and 3 000 €/ha for the switch from surface to drip irrigation)
			« Western-Hérault » (switch to low pressure channels)	Volume: 5.54 Mm^3/yr (30% gains in conveyance and 40% on the plot)	FC = 0.71 €/m^3 Costs considered:investment costs (pipes and pumping station: from 4500 to 11 300 €/ha), drip irrigation system: from 650 to 1500 €/ha), study and management costs (operation and maintenance).
		Reducing loss intertiary canals (off the farm) and quaternary canals on farms	Gabès Oasis	Volume: 0. 014 Mm^3 for 400 m of equipped system	FC = 0.002 €/m^3 Costs considered: investment costs
	Plot	Switch from sprinklers to micro-sprinklers	Ardèche basin	Volume: 0.14 Mm^3 (435 ha i.e. 322 m^3/ha)	FC= [0.36 ; 2.07] €/m^3 The results are shown in Table 10 (produced by a calculation based on set of hypotheses and data from the studies). Costs considered: investment costs (1500 €/ha)
		Switch from surface irrigation to sprinklers		Volume: 0.08 Mm^3 (87 ha i.e.920 m^3/ha)	FC = [0.05 ; 0.37] €/m^3 The results are shown in Table 10 (produced by a calculation based on set of hypotheses and data from the studies). Costs considered: investment costs (600 €/ha)
			Region of Karditsa	Volume: 0.292 Mm^3 (35 000 ha, i.e. 8m^3/ha)	FC=1.32 €/m^3 Costs considered:investment costs (250 €/ha)
		Switch fromgravity-feed to drip irrigation system	Tensift Basin	Volume: [11.5 ; 29] Mm^3/yr	FC = [0.26 ; 0.65] €/m^3 Costs considered: investment costs (between 3500 and 4500 €/ha)
		Switch from maize to vine	Ardèche basin	Volume: 0.35 Mm^3 (320 ha), 1094 m^3/ha	Not defined Impact of production changeon farmers revenue(not calculated)
		6% increase inthe variable part of the water price	Ardèche basin	Volume: [0.09 ; 0.17] Mm^3 (1600 ha, i.e. between 56 and 106 m^3/ha)	FC = [0.8 ; 1.5] €/m^3 Costs considered: cost to the irrigator of an increase in the price of water (+ 0.04€/m^3)
		Volumetric pricing and 100% increase in water price.	Guadalquivir basin	Volume: 695 Mm^3	FC = 0.24 €/m^3 Costs considered:Management cost by the administration linked to a change in pricing structure + cost to the irrigator of an increase in the water price (+ 0.012 €/m^3)

Measure				Case	Volumes saved/Additional water provision (Mm^3)	Cost-effectiveness analysis (FC)
		Enforcement of abstraction regulations		Amman-Zarqa Basin	Volume: 60 Mm^3 reduction of private abstractions	FC = 0.069 €/m^3 (1st type of ratio: calculated using the annualised discounted cost) FC = 0.034 €/m^3 (2nd type of ratio: calculated using the discounted cost) Costs considered: investment costs + management
SUPPLY MANAGEMENT MEASURES		New reservoirs		Amman-Zarqa Basin	Volume: 110 Mm^3	FC = 0.051 €/m^3 (1st type of ratio: calculated using the annualised discounted cost) FC = 0.101 €/m^3 (2nd type of ratio: calculated using the discounted cost) Costs considered: investment + operation costs
				Gabès Oasis	Volume: [100 ; 500] Mm^3 depending on the dam	FC = 0.0376 €/m^3 Costs considered: investment and operation costs (obtained from the study of 18 dams currently in operation)
				Tensift Basin (Wirgane dam)	Volume: 17 Mm^3/yr (for a capacity of70 Mm^3)	FC = 0.22 €/m^3 Costs considered:financial cost (investment and operation) FC = 0.57 €/m^3 factoring in the effect of silting up (calculated over a working life of 30 rather than 50 years). Considering opportunity costs, economic and environmental externalities
		Aquifer abstractions	Shallow wells	Gabès Oasis	Volume: 0.011 Mm^3/yr (0.22 Mm^3 over 20 yrs)	FC = 0.0698 €/m^3 Costs considered: Wells construction costs, purchase of motor-pump + operation costs
			Deep drilling	Gabès Oasis	Volume: not defined	FC = 0.04 €/m^3 Costs considered:investment and operation costs
		Evaluation of the average cost of supply-based management measures		Gabès Oasis	Volume: not defined	FC = 0.049 €/m^3 Costs considered:investment and operation costs FC = 0.22 €/m^3 Costs considered: investment and operation costs and average cost of transfer and supply

Source :Ratios calculated based on data from (Agencefrançaise de développement 2008), (Rinaudo 2008), (Strosser& al. 2007), (Aulong& al. 2008), (Louhichi& al. 2000)

Table 11:Evaluation of the cost-effectiveness ratios of the measures planned for the Ardèche basin (France), variable according to (i) working life considered for the apparatus and (ii) discount rate (a = 4% or a = 10%)

'Ardèche Basin (France)	Volume Mm^3/yr	Investment cost (M€)	Cost-effectiveness ratio (T = 2 yrs) (€/m^3)		Cost-effectiveness ratio (T = 5 yrs) (€/m^3)		Cost-effectiveness ratio (T = 10 yrs) (€/m^3)		Cost-effectiveness ratio (T = 20 yrs) (€/m^3)	
			a = 4%	a = 10%	a = 4%	a = 10%	a = 4%	a = 10%	a = 4%	a = 10%
Collective network: Switch from gravity-feed to pressurised canals	0.11	0.33	1.591	1.727	0.673	0.791	0.373	0.491	0.218	0.355
Plot: Switch from sprinklers to micro-sprinklers	0.14	0.6525	2.471	2.686	1.043	1.229	0.571	0.757	0.357	0.550
Plot: Switch from surface irrigation to sprinkler system	0.08	0.0522	0.350	0.375	0.150	0.175	0.080	0.106	0.050	0.075

Source: Ratios calculated based on datafrom (Strosser& al. 2007)

The following hypotheses were chosen:

Discount rate (a): 4% rate. Rate established by the General Planning Commission in 2005 (Lebègue report) for public investment projects,

10% rate. Rate established for the Tunisian case study (IPEST). Working life of apparatus (T): The proposed measures cover apparatus with very different working lives. We strove to test the sensitivity of the ratios for the time span over which the cost of the measure is distributed (T = 2 yrs, 5 yrs, 10 yrs or 20 yrs).

3.2. At a territorial level

The results in Table 12 were compared with those in Table 10 and Table 11.

- Significantly higher costs are not produced when external effects (here CO_2 emissions) are factored into the evaluation of the cost-effectiveness ratio for networks losses reduction or for measures combining network and plot losses.
- Overall, the results in Table 12confirm that the greater the yield differential between the two techniques, the more effective the switch in irrigation technique. The results for the same switch in technique largely depend on the costs considered (financial costs: investment, operation and maintenance, or environmental externalities).
- Inter-basins water transfers produce a particularly high cost-effectiveness ratio, which is thus of little interest. If these results are influenced by the factoring in of external costs, they are also definitely due to the importance of financial costs involved in this type of solution. The water transfer studied in the Western Hérault case corresponds to the construction of a feeder canal to extend the lower Rhône canal westwards. The objective is to allow water from the Rhône to be used for agricultural purposes instead of water from the Hérault, Orb and Astien. If the cost of such a solution were to be reflected in the water price charged to irrigators, it would lead to a significant drop in demand for agricultural water or would produce a shift to alternative water resources such as the mushrooming of private wells.

Table 12: Cost-effectiveness ratio (EC_2) of the measures assessed in the case studies for the agricultural water sector (demand and supply-based management measures)

Measure			Volumes saved/Additional water provision (Mm^3)	Cost-effectiveness analysis (EC_2, €/m^3)
WATER DEMAND MANAGEMENT MEASURES	Collective network	Loss reduction in existing pressurised networks	Volume: 5.3 Mm^3/yr (reduction of abstractions of about 20% depending on the initial state of the network)	$EC_2 = 0.7$ €/m^3 Costs considered:investment cost (1000 to 4000 € depending on the initial state of canals) + maintenance + study and administrative costs + energy costs (per m^3 saved and per m^3 of CO_2 emitted)
	Network and on the plot	Switch from gravity-feed to pressurised pipes with equipment on the plot for drip irrigation when possible	Volume: 5.47 Mm^3/yr (gains of 30% on conveyance and 40% on the plot)	$EC_2 = 0.89$ €/m^3 Costs considered:investment costs (7500 €/ha for pipes and 1700 €/ha for pumping station) + investment in drip irrigation system (650 to 1500 €/ha) + maintenance + study and administrative costs + energy costs (per m^3 saved and per m^3 of CO_2 emitted)
	Farm	Switch from sprinklers to drip irrigation in pressurised systems	Volume: 2.62 Mm^3/yr (gains of up to20% on the plot, effectiveness increasing the lower the system's initial yield at irrigator level)	$EC_2 = 0.77$ €/m^3 Costs considered: investment costs (650 to 1500 €/ha) + maintenance + energy costs (per m^3 saved and per m^3 of CO_2 emitted)

Measure		Volumes saved/Additional water provision (Mm^3)	Cost-effectiveness analysis (EC_2, €/m^3)
SUPPLY MANAGEMENT MEASURES	Transfers from the Rhône	Volume:[5.79 ; 7.793] Mm^3/yr depending on the size of conveyance channel (abstractions avoided)	EC_2 (peak period)= [1.72 ; 1.79]€/m^3depending on size of conveyance channel Costs considered:investment costs (94 M€ for the 2nd section and 110 M€ for the 3rd section + operation and maintenance + CO_2 emission costs (environmental externalities) + untreated water transport costs and purification costs

Source :Ratios calculated based on data from (Rinaudo 2008)

4. Conclusion

- At network level, optimising the operation of existing distribution canals (gravity-feed or pressurised) would appear to be as cost-effective a solution as switching collective canals (from gravity-feed to pressurised). Moreover, significant volumes can be saved by renovating/waterproofing the supply system: they may represent 30% of abstractions for the resource.
- The effectiveness of measures to improve hydraulic efficiency within the collective supply system and on the plot largely depends on the systems' initial hydraulic yield and/or irrigation techniques. By way of example, according to the Western Hérault study, the unit cost may triple (from 4 000 to almost 12 000 €/ha) depending on the given irrigation system.

The case studies also reveal major spatial variability in cost-effectiveness ratios, particularly in the case of conversion to localised irrigation techniques. Under the Syrian National Programme for Converting to Modern Irrigation, for example, although the per hectare cost of converting to sprinkler and enhanced gravity-feed systems are rather similar over all projects, they vary from simple to double in the case of conversion to localised irrigation(Al-Azmeth 2008).

Moreover, analyses conducted in the agricultural water field tend to be limited to financial costs, without factoring in economic and environmental externalities. Of these financial costs, only investment costs are more often than not included, with operational and maintenance costs tending to be ignored. However, the various irrigation techniques also have different operation and maintenance costs: these costs also influence the attractiveness of a technical solution. Thus, for example, in the Guadalquivir basin, irrigators with pressurised systems spend on average 10.5% of their gross income on water, whilst for irrigators using gravity-feed systems the ratio is in the order of a mere 4% or thereabouts. Finally, none of the evaluations take account of the positive external effects which may stem from « losses » within networks (aquifer replenishment…).

For the irrigator, water demand management measures may be of economic interest, since they lead to securing their water supply, more efficient water use or even an increase in the volume allocated to agriculture if water is a limiting factor. In that case they do not release water for other uses or into the environment. The redistribution of water to other uses depends on the introduction of incentives, contractual or coercive measures, allowing for more flexible water rights. The results obtained from one of the case studies would appear to suggest that enforcing abstraction regulations may prove cost-effective. However, to conclude, a more detailed and comparative analysis of measures is required (contractual solutions were not assessed and the type of costs included for assessing enforcement of abstraction regulations need to be clarified).

V. General conclusion

For the domestic as for the agricultural sector, the analysis of the case studies shows that water demand management measures are often effective and may free up significant amounts of water.

This is mainly the case in the domestic sector for measures aimed at supply system efficiency and the installation of water efficient appliances at household levels. Measures aimed at safeguarding supply, such as diffuse pollution management are also effective. The results also suggest that the cost and effectiveness of measures largely depend on the initial state of supply systems and on urban water demand features.

In situations where the service is unreliable, intermittent, does not serve the entire population or does so in a very unequally manner, water savings take on another dimension and become a marked political concern: the enhanced value of the volumes saved thus becomes even more important.

Apart from the quantitative issues regarding water availability, in the countries of the south and east of the Mediterranean sanitation issues are also at stake, particularly when they are associated to the deterioration in the quality of water resources leading to tensions with downstream users.

In the agricultural sector, water demand management measures are economically worthwhile for the irrigator if they allow him to safeguard his water supply when it is a limiting factor of production. This, or even increasing them, is the aim of the measures assessed in the case studies on the Tensift basin and in the region of Karditsa. Significant annual volumes can be released (59 Mm^3 through reducing loss in collective supply systems, as opposed to 17 Mm^3 produced by the Wirgane dam in the Tensift basin). The economic evaluation must, however, be part of a more global logic, integrating constraints and opportunities within farming systems, revenue, risk aversion, quality of life etc. rather than simply limiting itself to a marginal approach alone. Promoting significant change in the pressure, which agriculture brings to bear on water resources, hinges on the introduction of incentives in support of certain types of agricultural production or effective systems for controlling withdrawals and sharing water. The market alone may well create a preference for crops which consume greater or lesser amounts of water. This is why incentives and regulatory measures are avenues to be explored.

The analysis of these case studies has revealed how exceedingly sensitive the results obtained are depending on the method applied, the type of cost considered, the working life considered for the appliances assessed, the discount rate… To give an example, taking account of spinoffs or even the type of financial cost factored in has a marked effect on the results. This variability reveals the necessarily « situatedness » nature of the economic analysis: its content, its thrust and the methods which underpin it are actually contingent upon the context within which it is conducted.

It provides an analysis grid which could be used to conduct further studies and which would allow solid comparisons to be drawn whilst highlighting the strategic and political nature of the economic evaluation and the need to clarify the methodological choices made.

Main messages

Relating to domestic and agricultural water demand management measures:

- Reducing leakage in drinking water supply systems and installing water efficient appliances for end-users are the most cost-effective measures which may, moreover, make a significant contribution towards meeting future drinking water demand,
- At supply system and end-users levels, the higher the unsatisfied demand which could be connected to the system, the more effective the water saving measures,
- Hydraulic efficiency improvement measures provide interesting cost-effectiveness ratios which depend, however, on the initial hydraulic yield of the networks and/or irrigation techniques,
- In the drinking water sector, leaks reduction in collective housing as well as rainwater collection are not particularly cost-effective measures,
- A distinction should be drawn between « dry » and « wet» savings when evaluating "losses" at a watershed level,
- Pricing and regulatory measures seem to be cost-effective, but their evaluation requires further analysis.

Relating to supply-based management measures:

- The evaluation of new infrastructure building largely depends on environmental and social externalities being factored in,
- Solutions based on increasing supply such as transfers between basins or seawater desalination are the least cost-effective,
- Solutions aimed at making more flexible the use of water from existing reservoirs may prove effective,
- Solutions aimed at managing diffuse pollution are effective.

Relating to the economic evaluation method:

- Cost-effectiveness ratios vary widely depending on the time and spatial scales chosen for the evaluation and the type of costs considered (financial, related costs, externalities),
- Only measures with a negative ratio are likely to be spontaneously implemented since they represent a net benefit for the beneficiary of the measure. Conversely, measures with low but positive ratios generally require collective financing (public, international...), particularly those relating to indivisible investments, with high fixed costs.

Annex 1: Domestic hydraulic efficiency indicators

The most widespread water « losses » indicators are:

Potential drinking water supply efficiency, as defined by the Plan Bleu and used for MSSD monitoring. It represents the share of drinking water produced and supplied which is actually paid for by the user:

Equation 4: Drinking water supply efficiency according to the Plan Bleu

$$DW = \frac{V_1}{V_2}$$

Where:
V1 = volume of drinking water billed to and paid for by the user in km^3/yr
V2 = total volume of drinking water produced and supplied in km^3/yr
This indicator, developed for national level analysis, combines physical efficiency dimensions linked to the state of the network and financial efficiency, since the evaluation is based on the volumes billed and paid for by the user. It is, however, impossible with this type of indicator to define the variables responsible for the state of the system to be evaluated and thus actions intended to improve efficiency of drinking water supply. It leaves no scope for recognition of the fact that non-billing of a certain volume of water may be the fruit of aware political choices;

- Network yield:

Equation 5: Drinking water system yield

$$Y = \frac{V_c}{V_c + V_l}$$

Where:
Y: yield (%),
Vc: volume used by households (m^3),
Vl: volume of leakage (m^3).

- This is the indicator most widely used by drinking water service providers. It does not actually show network efficiency as such. In fact, the volume of leakage (V_l) is not a function of the volume distributed (V_c+ V_l) but rather of pressure once the system is loaded. V_l, thus depends on the volume used by households (Vc) and system yield increases with Vc(Guérin-Schneider 2001).

- Loss volume (linear loss index):

Equation 6: Indicator of the physical performance of drinking water supply systems

$$I = \frac{V_l}{\text{Characteristic size}}$$

Where:
I: the indicator (m^3/ unit of characteristic size)
Vl: Leakage volume (m^3)
Characteristic size: for example the length of the system (m or km), for a comparison between systems.

Annex 2: Indicators of agricultural water efficiency

Typology of agricultural water efficiency

- Hydrologic efficiency, based on an analysis of the water cycle at catchment basin level.

  The evaluation of hydraulic efficiency is based on the idea that « losses » within irrigation networks often also helps meet users demand. This demand is produced by the very existence of the « losses » which helps satisfy it. Thus in the evaluation « losses » should be included both as a cost but also as a gain. Since agriculture accounts for the biggest use in quantitative terms, this positive role may be significant.

  - For the community (area, catchment basin), the value of this « loss » should be compared with the costs and benefits of the water saved.

- Hydraulic efficiency, within irrigation systems

  This amounts to measuring the yield of transport, distribution and application at the plot. These yields compare volumes of water between two points (entry and exit) along the length of the irrigation network.

- Agronomic efficiency, at the scale of the crop

  This involves measuring water use efficiency (blue and green water or only blue water) of a given crop. This efficiency is often defined as the relationship between potential yield and water used for biomass production per surface unit. For this type of indicator, the essential element in any strategy for rationalising the use of production factors is therefore being aware of crops' agronomic water « needs » based on water balances.

- Economic efficiency

  It reflects the economic value made out of water, often defined by a ratio between (i) the value of the agricultural product and (ii) the opportunity costs of the water used in the process of agricultural production.

  Hydraulic and agronomic efficiency (calculated from yield) are merely intermediate factors of economic efficiency, the purpose of which is **the optimal allocation of rare resources based on monetised value criteria**. Hydraulic or agronomic efficiency gains endeavour to increase the share of water which is effectively used compared with the water abstracted. Economically speaking, there is all the more reason for improving agronomic or hydraulic efficiency since the water thus saved creates value. Thus a marginal gain in hydraulic or agronomic efficiency is only effective from an economic point of view if it is greater than the marginal cost of the measure. Thus economic optimisation does not necessarily mean maximising indicators which count from a strictly hydraulic or agronomic point of view.

Annex 2.1: Hydraulic efficiency indicators

The most widely used indicators of losses are (Rao 1993):

- Water conveyance efficiency (*Equation 7*)

Equation 7: Irrigation water abstraction efficiency

$$E_m = \frac{(V_s + V_2)}{(V_p + V_1)}$$

Where:
Vp= Volume of water collected (abstracted or pumped) from a river or aquifer
Vs= Volume of water supplied to the primary system
V1= Volume of incoming water from other sources (rain)
V2= Volume of water supplied for non-agricultural use within the primary system

- Water deliveryefficiency (*Equation 8*)

Equation 8: Irrigation water supply efficiency

$$E_d = \frac{(V_f + V_3)}{V_s}$$

Where:
V_f= Volume of water supplied to plots
V_s= Volume of water supplied to the primary system
V_3= Volume of water supplied for non agricultural use within the secondary or tertiary system

- Efficiency of the water abstraction and delivery (*Equation 9*)

Equation 9: Efficiency of the irrigation water conveyance and delivery

$$E_r = E_m \times E_d = \frac{V_2 + V_3 + V_f}{V_1 + V_p}$$

- Efficiency of the water conveyance, delivery, and application (*Equation 10*)

In short, the Mediterranean Strategy for Sustainable Development (MSSD) proposes an indicator to reflect overall hydraulic water use efficiency from the point of withdrawal until it is applied to the plot (UNEP/MAP 2005):

$$E_{Irrigation} = E_{Supply} \times E_{Plot}$$

Where: $E_{Supply} = V_a/V_b$
E_{Supply}: ratio between the volume of water effectively supplied to the plot (V_a) and the total volume of water allocated to irrigation (or demand for irrigation) upstream of the systems, including losses within the system (V_b).
E_{Plot}: sum of efficiency on the plot for each irrigation mode (surface irrigation, sprinklers, micro-irrigation…), multiplied by the respective proportions of the various modes in the country and assessed as the ratio between the quantity of water actually consumed by the plants and the quantity supplied to the plot.

Equation 10: Irrigation water use efficiency according to the Plan Bleu

$$E_{Plot} = \sum_{m=1}^{n} \frac{S_m \times E_m}{S}$$

Where:
n: number of irrigation modes used
S_m: surface irrigated by mode m
E_m: efficiency of mode m
S: total area irrigated across all modes

Comments:

Numerous studies have shown that adopting more efficient irrigation techniques basically lead to changing constraints within farming systems, particularly in terms of manpower. In situations where availability of irrigable land is not a limiting factor, the switch in technique has led to increased abstractions per agriculture working unit. This has been observed in the Gabès region in Tunisia, the Niayes region in Senegal, in California and in North-eastern Brazil (Fernandez 2001), (Molle&Turral 2004).

The most determining factor is actually farmers' overall technical skills and reliable access to water resources. It has a significant influence on hydraulic productivity.

Generally speaking, gravity-feed irrigation is somewhat inflexible due to the technical constraints of water supply and the way in which water rights are defined. This can lead to a tendency to over-irrigate where crops have surface root systems and/or the soil has a low water retention capacity. Localised irrigation may provide for improved irrigation behaviour over time with tighter controls on the water administered (duration, frequency and quantity), which may potentially lead to increased hydraulic productivity and yields (Pereira 1999).

However, switching from one irrigation technique to another (with greater potential for uniform water supply, for example) is capital intensive and not always justified. It requires technical and industrial development to facilitate access to the components required for pressurised systems. Improving existing systems may provide the potential for greater efficiency gains (based on improved irrigation calendars, etc.) than would investment in new infrastructure.

Table 13: Cost comparison and overall productivity of irrigation techniques

Irrigation technique	Cost characteristics	Global productivity
Gravity-feed (furrow, channel, flood irrigation)	✓ Plots need to be levelled ✓ No operational energy costs ✓ Large workforce required ✓ Little technological development needed	Plus points: ✓ Low risk of crop disease (leaves are not wet) ✓ Irrigation is not affected by the wind Constraints: Topography
Sprinklers	✓ Technological development required ✓ High energy costs ✓ Relatively small workforce	Plus points: ✓ Few topographical constraints ✓ Fertirrigation possible ✓ Regular watering Constraints: ✓ Not possible to water in very windy conditions (uniformity of field application reduced) ✓ Risk of crop disease (because leaves are wet) ✓ Farming work hampered if sprinklers provide integral cover
Drip (localised irrigation, low pressure, channel may be covered over)	✓ Technological development required ✓ Lower energy costs ✓ Major upkeep, maintenance and regulation (fragile system)	Plus points: ✓ Few topographical constraints ✓ Fertirrigation ✓ Irrigation is not affected by the wind Constraints: ✓ Fragility of irrigation system ✓ Pressurisation required

Annex 2.2: Agronomic efficiency indicators

The main indicators available are:

- The classical indicators of irrigation water application efficiency (*Equation 11, Equation 16*):

Equation 11: Classical efficiency of irrigation application to the plot (1)

$$E_{a\,(1)} = \frac{Blue\ water\ transpired}{(1 - LR)\ \times V_{applied\ to\ the\ plot}}$$

Where:

$E_{a\,(1)}$: traditional irrigation water application efficiency (1),
LR: leaching demand,
$V_{\text{administered to the plot}}$ = Volume of water applied to the plot.

The challenge is to establish how much irrigation water (blue water) has been transpired.

Transpired water is the consumed water which contributes to the plant's biomass production. In practice, it is difficult to distinguish between evaporated and transpired water. The two tend to be assessed together and comprise evapo-transpiration.

Water which is evapo-transpired by an irrigated crop stems,both from (i) irrigation water (blue water) and (ii) rainwater, or more specifically from « effective » rain (green water), in other words the fraction of rainfall stored in the root zone and that can be used by the plants[11]:

$$RET = effective\ rainfall\ + evapotranspired\ irrigation\ water$$

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[11] The agronomist's « effective » rainfall is actually the hydrologist's « ineffective » rainfall. In fact, in the hydrological sense « effective » rainfall is defined as follows: "*Effective rainfall* represents the quantity of water provided by rainfall which remains available on the surface of the soil once losses through real evapo-transpiration have been subtracted. Effective rainfall is equal to the difference between rainfall and real evapo-transpiration".

Equation 12: Classical field application efficiency of irrigation (2)

The indicator then becomes:

$$E_{a\,(2)} = \frac{RET - (effective\ rainfall)}{(1 - LR)\ \times V_{administered\ to\ the\ plot}}$$

Where:

$E_{a\,(2)}$: classical irrigation water application efficiency (2)

RET = Real evapo-transpiration (function of the crop, the climate, practices and the features of the substrate) for crop c.

$V_{\text{administered to the plot}}$ = Volume of water application to the plot.

Real evapo-transpiration is, however, difficult to establish on a large scale. More often than not it is only assessed on experimental plots.

In practical terms, several authors have established approximations based on coefficients which are the product of experimentation and which are calculated using unconstrained ideal condition hypotheses. These approximations are useful for irrigation management. They do not, however, allow the real efficiency of irrigation water application to be assessed.

Maximum evapo-transpiration (MET) is thus defined for a given crop growing under optimal agronomic (water) conditions (*Equation 13*):

Equation 13: Maximum evapo-transpiration

$$MET = K_c\ \times ET_0$$

Where:

K_c = crop coefficient which varies according to the crop's level of development,

ET_0 = potential evapo-transpiration (this is maximum evapo-transpiration for a lawn, for which water is not a limiting factor), climate coefficient.

FAO has developed two methods of calculation, with one or two coefficients. With two coefficients, Kc is expressed as the sum of these two coefficients, one of which is linked to the evaporation process through the soil and the other to transpiration through crops (Allen & al. 1998).

The difference between water applied and water actually consumed depends on the irrigation technique, environmental conditions and the characteristics of the soil

- «Real » efficiency indicators for the application of irrigation water(*Equation 14*):

This involves producing an efficiency evaluation which takes account of possible reuse of water « lost » on a given plot (Wichelns 2002):

Equation 14: Effective efficiency of application of irrigation water to the plot

$$E_{a\ effective} = \frac{MET - (effective\ rainfall)}{F}$$

Where:

$E_{\text{aeffective}}$: effective efficiency of irrigation water application

F = effective use of irrigation water. F corresponds to the « effective » incoming flows minus the « effective » outgoing flows. Flows reused elsewhere are deducted from the outgoing flows. These flows thus only represent a loss, reducing the effective efficiency of irrigation water use, when not reused downstream or if their quality has deteriorated to such an extent that they cannot be reused downstream.

Thus, in the case of the Nile Valley in Egypt, indicators $E_{a\,(1)}$ or $E_{a(2)}$ give an efficiency of 40 or 50% whereas, on the contrary, indicator $E_{a\ \text{effective}}$ is very high, with values of around 80%, given the high level of water recycling (Wichelns 2002).

Indicator $E_{a\ \text{effective}}$ allows seepage or run-off water on the plot to be factored into the evaluation of the performance of irrigation water use, as well as the impact of irrigation on water quality, since potential reuse depends on the qualitative state in which the water returns to the environment.

This indicator allows hydraulic efficiency and thus the costs and benefits relating to the reallocation of water between uses to be assessed at catchment basin level.

Thus, if a basin is « closed », there are no potential efficiency gains from a hydraulic point of view. There are only potential agronomic and economic gains between uses or within the same use, depending on how the water is valued. These real efficiency gains stem from improved water productivity in crops, less diffuse agricultural pollution, cropping plan changes and mechanisms for reallocating water towards uses which make best use thereof.

- Irrigation water use efficiency compared with agronomic yield (*Equation 15, Equation 16*):

The yield gain provided by irrigation is assessed by comparing the agronomic performance of a given crop depending on whether or not it is irrigated(Howell 2001), (Crepin& al 2001).

Two types of indicators can be distinguished: those which take account of irrigation water applied (*Equation*15), and those which take account of irrigation water actually consumed (*Equation 16*):

Equation 15: Efficiency of irrigation water consumed in shaping agronomic yield

$$\boldsymbol{ET_{WUE}} = \frac{(\boldsymbol{Y_i} - \boldsymbol{Y_d})}{\boldsymbol{ET_i} - \boldsymbol{ET_d}}$$

Equation 16: Efficiency of irrigation water administered in shaping agronomic yield

$$I_{WUE} = \frac{(Y_i - Y_d)}{I_i}$$

Where:
Y_i = yield for level of irrigation i,
ET_i = evapo-transpiration for level of irrigation i,
Y_d = yield for an equivalent but not irrigated plot (green water alone or rainfed agriculture),
ET_d = evapo-transpiration for an equivalent but not irrigated plot (green water alone or rainfed agriculture),
I_i = quantity of irrigation water applied at level of irrigation i,
ET_{WUE} expresses the water productivity of the crop from an agronomic point of view. I_{WUE} provides information on the efficiency of irrigation techniques.

The two indicators are generally optimised for a slight water deficit, where this deficit allows water evaporation to be reduced without reducing water transpiration by the crop. In other words, the aim is to maximise the carbon gain (CO_2 assimilated by the plant cover) whilst minimising water loss.

For the same Y_i and Y_d, comparing ET_{WUE} with I_{WUE} allows the efficiency of the irrigation technique on the plot to be assessed.

For a given crop, these indicators feed discussion about the efficiency of irrigation compared with rainfall, depending not only on the irrigation technique but also on the agronomic characteristics of the crop and water-soil-plant relations. In other words, it allows the efficiency of blue water use in agricultural production to be compared with that of green water alone.

From the service provider's point of view, these indicators may provide him with a clearer picture of irrigation water demand and therefore allow him to better tailor his tactical management of water supply.

The indicators may also allow the provider or the irrigator to adopt a more reasoned approach to costly and structuring hydro-agricultural investment.

Comments:

Potential water savings in irrigated farming are driven by several strategies, which can be distinguished as follows (Amigues& al. 2006), (Mediterra 2009):

- **Strategies which essentially focus on the physiological features or crop management characteristics:**
  - Those which involve reducing the risk of drop in yield by accepting a drop in maximum attainable yield:

- ♦ **Dodging** which consists of shifting the crop growth cycle to rainy periods and/or periods of low climatic demand, or shortening the crop cycle.

  Changes in cropping practices affect the value of real evapo-transpiration (ETR) for the crops under consideration, compared with potential evapo-transpiration (ETP). Varietal changes also give rise to new ETP and ETR for the crops in question. It should be pointed out that climate change could well intensify the discrepancies between crop calendars and stress on water resource.

- ♦ **Avoidance,** which consists of rendering the crop more resistant to water stress (reducing stomatal conductance and foliar growth, reducing transpiration thereby saving water in the soil, increasing root growth, etc.).
- ♦ **Improving water efficiency** in other words the proportion of biomass produced to the quantity of water transpired. This proportion is particularly marked in C4 species such as maize or sorghum. It also depends on irrigation water application efficiency, a function of water-soil-plant relations.

– Those which involve maintaining the maximum attainable yield by accepting an increase in the risk of reduced yield. This is the tolerance which consists of maintaining the plant's functions (growth, number of organs, transpiration, photosynthesis).

- **Which focus on the organisation of agricultural production: choice of cropping plan**

  Inter-seasonal and inter-regional variations in reference evapo-transpiration (ET_0) are actually much more marked than variations in ETP between crops whose cycles cover the same seasons (Seckler 1996). Thus cropping plans significantly affect the quantity of water abstracted from the environment. Alternative crops must then be identified, which would meet food demand and be sufficiently economically viable, and which could be planned for periods when the resource is most abundant. In countries where the climate varies from one area to another, this might involve territorial planning taking account of ET_0.

Insofar as water use is part of a productive activity, how the m^3 of water abstracted and consumed for irrigation purposes is valued is also an element in water use efficiency. Corresponding indicators are those which allow the wealth produced per m^3 of water consumed to be assessed (added value / m^3 consumed either at farm scale or sector-based scale, gross margin/m^3 consumed, etc.).

Annex2.3:Economic efficiency indicators

Indicators intended to show the economic efficiency of water use by irrigated agriculture are generally based on the following type of ratio(Burke & al. 1999), (Cai& al. 2001), thus drawing on agronomic efficiency indicators (*Equation 17*):

Equation 17: Economic efficiency indicator for the use of irrigation water

$$Economic\ efficiency = \frac{Value\ (\$)/ha}{Volume\ of\ blue\ water\ consomed/ha}$$

The evaluation of the amount of blue water consumed is based on agronomic indicators as previously defined.

The monetised value created by the water being consumed is usually established:

- Either through the added value of agricultural production (which takes no account of subsidies),
- Or through the gross margin or even agricultural revenue (which takes account of subsidies).

The intermediate indicators used are (*Equation 18*):

Equation 18: Gross product, value added and revenue per hectare

$$GP/ha \quad = Y * unit\ sales\ price$$

$$VA/_{ha} \quad = GP/_{ha} - IC/_{ha} - \ Ed/_{ha}$$

$$GM_1/_{ha} \quad = VA/_{ha} - \ Red + Aid$$

$$GM/_{ha} \quad = R_1/_{ha} - MP\ family/_{ha}$$

Where:
GB: Gross product ($),
Y= yield (tonnes/hectares),
Unit sales price: $/tonnes,
VA: value added ($),
IC: intermediate consumption (expenses for inputs, rented equipment, insurance, equipment maintenance, electricity and water costs, etc.),
Ed: Economic depreciation,
Red : Redistribution : It represents the fact that the operator does not own all his production means (ground rent: farm rent, property tax, financial costs relating to loans, social contributions, salaries and the social costs relating to the employment of a salaried workforce,
Aid: subsidies,
MP_{family}: family manpower,
GM_1 (or R_1): gross margin or revenue,
GM_2 (or R_2): gross margin or revenue.

These various indicators can be related to the volume of water used, by establishing the volumes supplied, applied or consumed per hectare (hydraulic and agronomic indicators), in order to arrive at indicators of economic water productivity, expressed in $/m^3.

The evaluation may:

- Compare the value created per m^3 of water consumed (irrigation water alone or blue water and green water) for various possible alternative crops (*Equation 19*)

Equation 19: Value of water compared between crops

$$V_a \ = \frac{GM_a}{I} \text{Compared with} V_b \ = \frac{GM_b}{I}$$

Or:

$$V_a' = \frac{GM_a}{W} \text{Compared with} V_b' = \frac{GM_b}{W}$$

Where:
a, b : possible crops,
V: value of the water ($/m^3),
GM: gross margin ($/ha),
I: irrigation water supplied, administered or consumed (m^3/ha),
W: evapo-transpired blue and green water (m^3/ha).

- Compare the value of irrigation by comparing the value created by an irrigated crop with that of the same rainfed crop (*Equation 20*):

Equation 20: Strategic value of irrigation water, according to (Tardieu 1999) amended

$$\boldsymbol{Vs \ = \frac{GM_{irrigated} - GM_{rainfed}}{I}}$$

Where:
V_s: Strategic value of irrigation water ($/$m^3$),
$GM_{irrigated}$: Gross margin of the irrigated crop ($/ha),
$GM_{rainfed}$: Gross margin of the rainfed crop which can be done in substitution (either the same crop or another), ($/ha),
I: irrigation water supplied, administered or consumed (m^3/ha).

Commentary:

In the European or United States context, for example, most cereal production has a negative added value, with only revenue (or even the gross margin per hectare) being positive. Indeed, post-second world war agricultural policy sought to safeguard access to food and to avoid shortage, to free up as much manpower as possible for industry and services, to provide outlets for industry upstream and raw materials for the agri-food industry. Lowering food costs was an indirect way of making the industrial sector more competitive. In the cereal sector, added value is thus mainly created upstream and downstream of agricultural production, with a sector-based approach.

Neo-classical economic analysis is in turn based on seeking a Paretian equilibrium, which amounts to optimising the distribution of water (rare resource), under constraints, between different uses. The optimum is achieved when marginal costs and gains are equal, in other words when rights and duties are organised in such a way that it is impossible to change the rules and redefine the system of rights and duties to increase the expectations of a representative individual without at the same time decreasing those of another one.

The issue is thus to identify the economic and financial costs relating to changes in crops or practices.

VI. Bibliography

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VII. Table of illustrations