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Options to reduce unmet demand in the domestic and agricultural sectors

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DISCLAIMER:

ABBREVIATIONS

MCM	Million Cubic Meters
RWH	Rainwater Harvesting
GWR	Greywater Reuse
WWTP	Wastewater Treatment Plan

1. INTRODUCTION

A “Demand Management Policy” is typical based on a bundle of technological, management and regulatory measures which promote water saving and efficiency gains in different economic sectors (urban, agricultural, industrial sectors, etc.) while they can be combined with measures to increase the water supply (e.g. through water reuse, rainwater harvesting, etc.) which do not cause adverse environmental impacts. The current report elaborates on different options for the domestic and agricultural sectors.

Box 1. Basic Definitions

Demand management: adoption of interventions and measures (technological, legislative, regulatory, financial, etc.) to achieve efficient water use by all sectors of the community (urban/ domestic, agricultural, industrial, tourism, etc.)

Demand reduction/ water saving measures: Measures targeting to reduce demand and/or introduce water conservation *[For example: reduce leakage, install water saving fixtures, increase irrigation conveyance and field application efficiency, create incentives, water tariffs, water markets, taxes, etc.]*

Increase supply measures: Measures targeting to increase water supply and the water available for use. *[For example: greywater and wastewater reuse, water recycling, desalination, rainwater and stormwater harvesting, natural water retention measures].* Caution to potential adverse environmental impacts is important.

2. DEMAND MANAGEMENT MEASURES

2.1 MEASURES FOR THE URBAN SECTOR

There is a variety of available technologies designed to deliver domestic water saving targeting the different household water uses. These include a range of low water using appliances and retrofitting. On top of that, there are technologies and interventions that can increase the water supply. All these options are analytically presented below

- **Water saving measures**

Toilet flushes, usually accounting for one third of the domestic water use on average can deliver reductions up to 50% of the water used. Common options include the replacement of older style single-flush models (14 lt/flush) with low-flush gravity toilets (6 lt/flush), dual-flush valve operated toilets (4 lt/flush), air-assisted pressurised toilets (2 lt/flush). Evidence exists that flush volumes down to 4 lt do not cause any problems in the drains and sewers in terms of the waste disposal.

Taps and **Showerheads** can be adjusted and render saving by installing water saving devices and inexpensive retrofits. Various options are available for retrofitting kitchen and bathroom taps, which are estimated to account for more than 15% of domestic indoor use, with respective savings of 20-30% and less than 2 years paybacks: fitting of new water efficient tap-ware (spray taps, push taps, etc.), low-flow aerators, durable tap washers, flow restrictors and regulators, automatic shutoff. Showerheads are usually gravity fed, electric or pumped (power showers). The average consumption of showers ranges across the households as it depends on many interrelated factors: frequency of use (from 0.75-2.5 showers/day) average shower time duration (2-5 minutes), type of shower, flow rate (6-16 lt/minute), etc. Yet, evidence exists that showers and baths account for 20-35% of the household water consumption and installing water saving devices (flow restricting devices, low-flow showerheads - aerating or laminar-flow, cut-off valves, etc.) can secure around 30-40% water savings. It worth mentioning that the expected savings from the installation of smart water saving devices in taps and showerheads is also highly influenced by the use patterns and habits of the users.

Washing Machines and **Dishwashers** can be replaced with more efficient ones delivering water and energy savings. Washing of clothes is probably the third largest consumer of domestic water, around 20%. Installing high-efficient washing machines can save up to 40% of the volume need per cycle. Modern washing machines use about 50 lt/cycle or 35 l/cycle for the most efficient ones, as opposed to 150 lt/cycle in the 1990’s, due to technological advances (i.e. intelligent sensor systems, advanced and customised washing programmes, improved time functions, etc.). Dishwashers manufactured prior to the year 2000 typically consume 15-50 lt/load, while modern dishwashers consume 7-19 lt/load under normal setting and as low as 8-12 lt/load under the eco-setting, which means average water savings at the range of 40-60%. The share of water use consumed by dishwashers varies from 6-14% as it depends on the cycle time, the frequency of use and their degree of penetration in the households, the latter being influenced by e.g. lack of space, conception that this investment is not necessary due to small load of dishes feasible to be hand-washed, etc.

Water pricing reform usually involves a modification in the rate structure and/or the water tariffs in order to influence the consumers’ water use. It often includes the shifting from decreasing block rates to uniform block rates, the shifting from uniform rates to increasing block rates, the increasing of rates during summer months, or the imposing excess-use charges during times of water shortage. This economic instrument needs a very careful design as it can easily raise conflicts among users and trigger many disputes.

- **Increase supply measures**

Greywater is the dilute wastewater, originating from domestic activities such as showering, bathing, washing hands, tooth brushing, dishwashing, washing clothes, cleaning and food preparation, in brief it refers to all household wastewater other than wastewater from toilets (the so called blackwater). This water contains some organic material, yet it can be reused for some uses within the households (e.g. toilet flushing). Greywater from baths, showers and washbasins is less contaminated than that from the kitchen. Reuse in the urban and suburban environment primarily concerns irrigation of green areas, recreation and swimming activities, natural landscaping, fire-fighting, cleaning of streets, and domestic uses with the exception of drinking use. Typical domestic reuse systems collect and store greywater before reusing it to flush the toilet, while more advanced systems treat greywater to a standard that can be used in washing machines and garden irrigation. The most basic systems (i.e. direct reuse systems) simply divert untreated bath water, once cooled, to irrigate the garden. More advanced systems include short retention systems (which apply the very basic treatment of debris skimming and particles settling), basic physical and chemical systems (which use a filter and chemical disinfectants to stop bacterial growth), biological systems (which use bacteria for organic matter removal), bio-mechanical systems (which combine biological and physical treatment). The advantage of onsite domestic reuse of greywater is that the supply is regular and independent of external conditions, such as rainfall. Different systems can be used based on the cross-section of different technologies as previously mentioned, such as filtration and chlorination, advanced oxidation (H_2O_2 + UV), membrane bio-reactor (MBR), biological with media filter, ranging thus in costs (from 1,900-6,500 € for the equipment purchase and installation, and 36-420 € for maintenance), and the effluent water quality. Greywater used for flushing toilets can render savings around 20-30% of the average household water use depending on the toilet flash volume. In the UK studies showed water savings from about 5-36% introduced when using greywater reuse systems.

Rainwater Harvesting (RWH) is defined as “the capture, storage and management of water flowing on the roofs of buildings and river basins that exist on the ground with the purpose of growing crops, regeneration of pasture for animal feed production and farming in general, horticulture and domestic use”. Typical RWH systems consist of three basic elements: the collection system (area which produces runoff because the surface is impermeable or infiltration is low), the conveyance system (through which the runoff is directed, e.g. by bunds, ditches, channels, pipes) and the storage system (where water is accumulated or held for use). The storage system consists of tanks or impermeable soil and subsoil, as well as larger reservoirs. In the context of urban water cycle, RWH aims to minimize the effects of seasonal variations in water availability due to droughts and dry periods, and to enhance the reliability of domestic water supply and reduce the dependence on the mains water supply. Additional benefits include effective management of surface runoff, mitigation of flooding and soil erosion, increased productivity of domestic crops, reduction of water bills, etc. Nevertheless, there are limitations in implementing RWH techniques or relying on RWH as a source of supply, the main disadvantage being the unpredictable and often irregular supply which results in large storage space requirements. Larger schemes and structures are difficult to implement as they need acceptance by people, political backing and financial support. Finally, as rainwater usually carries small pollutant loads (depended on the location, roof building materials and collection system construction), a main light treatment and disinfection is generally needed for rainwater treatment to non-potable standards. Numerous RWH systems are available with a range of features and varying costs. Costs vary from as low as 2,000 € to as high as 8,000 € depending on the size and type of the tank (e.g. 2,000-8,000 lt), the timing of installation (retrofitting vs. installation during construction), the pumping system, additional desired UV treatment, etc.

Detention basins are part of the so-called Natural Water Retention Measures (NWRM) and Sustainable Urban Drainage Systems (SUDS). They are vegetated depressions designed to hold runoff from impermeable surfaces and allow the settling of sediments and associated pollutants. Stored water may be slowly drained to a nearby watercourse, using an outlet control structure to control the flow rate. Detention basins do not generally allow infiltration. The capacity to store runoff is dependent on the design of the basin, which can be sized to accommodate any size of rainfall event (CIRIA, 2007 identify up to a 1 in 100 year event as being not uncommon). Detention basins can provide water quality benefits through physical filtration to remove solids/trap sediment, adsorption to the surrounding soil or biochemical degradation of pollutants. Detention basins are landscaped areas that are dry except in periods of heavy rainfall, and may serve other functions (e.g. recreation), hence have the potential to provide ancillary amenity benefits. They are ideal for use as playing fields, recreational areas or public open space. They can be planted with trees, shrubs and other plants, improving their visual appearance and providing habitats for wildlife. A detention basin should be designed to be appropriate for the contributing catchment area (as well as rainfall characteristics). In theory they can be designed to accommodate any volume of runoff, from any catchment area, desired, and CIRIA (2007) states that there is no maximum catchment area. However in general, sustainable drainage principles promote managing runoff close to source, i.e. with a relatively small catchment area, and therefore it is not envisaged that a contributing area greater than 1 km^2 would be likely.

Detention basis are high land-take measures used within the urban environment. The primary cost is therefore the cost of land acquisition or the opportunity cost of not using that land for development. This will depend on the land values at the site under considerations and cannot be generically quantified. Due to the higher costs of land, it is usually more expensive to retrofit these basins to already developed areas as compared to constructing one in an undeveloped region. (Source: NWRM project (http://nwrm.eu/measure/detention-basins; for more information refer to the NWRM Detention Basins Factsheet)

Retention ponds are part of the so-called Natural Water Retention Measures (NWRM) and Sustainable Urban Drainage Systems (SUDS). They are ponds or pools designed with additional storage capacity to attenuate surface runoff during rainfall events. They consist of a permanent pond area with landscaped banks and surroundings to provide additional storage capacity during rainfall events. They are created by using an existing natural depression, by excavating a new depression, or by constructing embankments. Existing natural water bodies should not be used due to the risk that pollution events and poorer water quality might disturb/damage the natural ecology of the system. Retention ponds can provide both storm water attenuation and water quality treatment by providing additional storage capacity to retain runoff and release this at a controlled rate. Ponds can be designed to control runoff from all storms by storing surface drainage and releasing it slowly once the risk of flooding has passed. Runoff from each rain event is detained and treated in the pond. The retention time and still water promotes pollutant removal through sedimentation, while aquatic vegetation and biological uptake mechanisms offer additional treatment. Retention ponds have good capacity to remove urban pollutants and improve the quality of surface runoff.

Ponds should contain the following zones: (a) a sediment forebay or other form of upstream pre-treatment system (i.e. as part of an upstream management train of sustainable drainage components); (b)a permanent pool which will remain wet throughout the year and is the main treatment zone; (c) a temporary storage volume for flood attenuation, created through landscaped banks to the permanent pool; (d) a shallow zone or aquatic bench which is a shallow area along the edge of the permanent pool to support wetland planting, providing ecology, amenity and safety benefits. Additional pond design features should include an emergency spillway for safe overflow when storage capacity is exceeded, maintenance access, a safety bench, and appropriate landscaping. Well-designed and maintained ponds can offer aesthetic, amenity and ecological benefits to the urban landscape, particularly as part of public open spaces. They are designed to support emergent and submerged aquatic vegetation along their shoreline. They can be effectively incorporated into parks through good landscape design.

The drainage area required to support a retention pond can be as low as 0.03-0.1 km^2 (Environment Agency, 2012), or possible smaller if the retention pond has another resource of water such as a spring. There are no specific constraints on the maximum drainage area for retention ponds, although typically 3-7% of the upstream catchment area will be required for the pond (CIRIA, 2007). Larger retention ponds (>25,000 m^3 volume) require significant impoundment and may be subject to additional inspection and structural requirements (e.g. 1975 Reservoirs Act in UK). Ponds would typically be sited at a low point in the catchment where it can receive drainage by gravity. Several ponds may be required at a large site, split into topographic sub catchments. The position chosen should allow safe routing of flows above the design event for the pond, and the consequence of any pond embankment failure considered.

Retention ponds reduce peak runoff through storage and controlled outflow release. They must be appropriately sized to the catchment area and critical storm depth. They do not infiltrate runoff and therefore provide very little runoff volume reduction (with the exception of evaporation and evapotranspiration, which can be significant in some cases). Typically, retention ponds will be designed to attenuate runoff for events up to at least the 1 in 30 year storm for the drainage area (sometimes greater), with the excess storm volume drained within 24 to 72 hours (CIRIA, 2007).

Retention ponds are high land-take measures used within the urban environment. The primary cost is therefore the cost of land acquisition or the opportunity cost of not using that land for development. This will depend on the land values at the site under considerations and cannot be generically quantified. Due to the higher costs of land, it is usually more expensive to retrofit these basins to already developed areas as compared to constructing one in an undeveloped region. (Source: NWRM project (http://nwrm.eu/measure/detention-basins; for more information refer to the NWRM Retention Ponds Factsheet)

Information on the expected savings and costs of each of the above mentioned technological interventions has been collected from various literature sources as presented in Table 2-1 to Table 2-3 below. On this basis, the % expected saving and costs have been identified.

Table 2-1: Potential water saving per household water using product (WuP).

HH Water Using Product (WuP)	Consumption of "traditional" WuPs			Cnsumption of "efficient" WuPs	Water Saving		
	lt/use	Frequency of use per day	Average consumption in lt/hh/day	lt/use	lt/hh	as % of WuP's consumption	As % of total HH consumption
Low flush WC	6-12 lt/flush	7-11.6	101.8	3-4.5 lt/flash	30-170 lt/day	30-50 %	26%

Showerhead	25 lt/min; 25.7-60 lt/shower	0.75-2.5	91.8	6-14 lt/min	25 lt/day	50-70 %	8 %
Faucet aerator	13.5 lt/min; 2.3-5.8 lt/use	10.6-37.9	74.6	2-5 lt/min	12-65 lt/day	40-65 %	7-11,6 %
Dishwasher, AAA class	21.3-47 lt/load	0.5-0.7	24.3	7-19 lt/load	5,000 lt/year	40-60	4 %
Washing Machines, AAA class	39-117 lt/load	0.6-0.8	65.6	40 lt/load	16,000 lt/year	40	12 %

Source: Kossida, M., 2015 (elaboration based on multiple sources: Bio Intelligence Service and Cranfield University, 2009; BIO Intelligence Service, 2012; Cordella et al., 2013)

Table 2-2: Costs of different household water appliances and water saving devices and increase supply options

Water appliance/ saving device	*Marshallsay et al., 2007* *(convereted from £ to €)*	*Cordella et al., 2013*
WC (toilet flushing)	82-337 €	
Taps	- 51 € (basic mixer tap has no water efficiency features) - 74 € (monobloc mixer tap with pop up waste and aerator) - 94 € (monobloc mixer tap with pop up and an Ecotop cartridge)	- 35-50 € (automatic shut off, push tap) - 160-450 € (example product with integrated aerators and flow regulators) - 210 € (tap with water breaks) - 750 € (water and energy saving tap) - 375 € (sensor tap, infrared mixer)
	- 10 € for attaching a water saving device (6€ for aerator & spray fittings that can be attached to existing taps, + 4€ for the adaptor)	- 5.5 € for a flow regulator - 25 € for ecobuttons
Shower, Bath	- electric shower: 174 – 225 € - mixer shower: 225 € (+157€ if a pump is added) - basic bath/shower mixer with hand shower attachment: 31-92 €	- aeration showerhead: 20-120 € - spray pattern/mechanism showerhead: 60-220 €
	18 € for attaching an aerated showerhead to a standard mixer shower 31 € for attaching a pressure reducing valves to a standard mixer shower	
Washing Machine	282-321 €, energy rating A 343-533 €, energy rating A+	
Dishwasher	233-429 €, energy rating A	

Source: Kossida, M., 2015 (elaboration based on multiple sources: Cordella et al., 2013; Marshallsay et al., 2007)

Table 2-3: Costs of different increase supply technologies and interventions

Increase supply technologies	Capital Costs	Maintenenace Costs
Rainwater Harvesting	2,451 € equipment cost + 288-429 € installation cost (Marshallsay ey al., 2007)	
Greywater reuse (domestic)	4,534 € initial cost (Marshallsay ey al., 2007)	additional maintenance costs
Detention basins	Construction costs scale with the storage volume of the detention basin. Costs given in the UK typically range between €20 and €40 per m^3 of storage volume provided: - CIRIA (2007) - €20-€30 / m3 detention volume - Atkins (2010) - €25-€35 / m3 detention volume - UK SuDS Cost Calculator (www.uksuds.com) - €20-	Ongoing maintenance is essential to maintain the effectiveness of detention basins. Since these basins are long-lived, once in operation only minimal maintenance costs arise. Quarterly inspections of inlets and outlets as well as sediment and trash dredging might be required. Mowing around the basin

	€40 / m3 detention volume But others suggest the potential for much higher costs: - Chocat et al (2008) 9 to 90€/m3 detention volume - Certu (2006), 12 to 110 €/m3 detention volume More generally, Environment Agency (2012) indicates that the cost of a "small detention basin will typically be less than €5000". Costs will be higher where additional retaining bunds are required and lower where greater use is made of natural or existing topographic features.	margins would be possible but it may increase costs. Annual maintenance costs range between €0.5-€5 per m^2 of basin area. - CIRIA (2007), Wilson et al. (2009) - €0.5-€2.5 per m^2 basin area, - UK SuDS Cost Calculator (www.uksuds.com) - €4-€5 per m^2 basin area.
Retention ponds	Retention pond capital costs are typically between €20-€40 per m^3 of volume provided for storage. - CIRIA (2007) - €20-€30 per m^3 detention volume - UK SuDS Cost Calculator (www.uksuds.com) - €40 per m^3 attenuation volume - Chocat et al (2008) - €9-€60 per m^3 of volume provided for storage More generally, Environment Agency (2012) indicates that "construction costs may increase if lining is required". Requirements for pond lining, or construction on steeper slopes or less stable land may increase construction costs to ensure the integrity of the pond.	Annual maintenance costs vary between €1-€5 per m^2 of retention pond area. - CIRIA (2007), Wilson et al (2009) - €1-€2 per m^2 - UK SuDS cost calculator (www.uksuds.com) - €4-€5 per m^2 pond area

Water consumption patterns can vary significantly from house to house, depending on the household occupancy, the social and cultural conditions as well as on the type of the water consuming appliances installed in the houses (Memon and Butler, 2006). However, only a small proportion (approximately 15–20%) of in-house water demand is actually used for purposes requiring drinking water quality (incl. water used for drinking, cooking and cleaning dishes) (refer to Table 2-4 and Figure 2-1), and thus a knowledge of the micro-components of domestic water use are important in order to assess the neat water saving potential of the measures.

Table 2-4: Water consumption share of different household micro-components in the industrialized world

Information Sources **HH Micro-component**	***EU-wide overview***			***Country specific***			
	POST, 2000	*EA, 2007*	*Uihlein and Wolf, 2010 (across the EU)*	*EA, 2010 (in England & Wales for 2009-10)*	*Uihlein and Wolf, 2010 (for Greece)*	*EEA, 2001 (for Switzer-land)*	*Schleich, 2007 (for Germany)*
WC (toilet flushing)	31 %	30 %	25 %	26 %	25 %	33 %	32 %
Faucets	24 % *(of which 15% kitchen sink, 9% basin)*	20 %	30 % *(of which 5% for drinking and cooking)*	11 %	13 % *(5% for drinking and cooking)*	17 % *(3% for drinking and cooking)*	12 % *(3% for drinking and cooking)*
Shower	5 %	35 %	14 %	35 %	34 %	32 %	30 %
Bath	15 %		14 %				
Washing Machine	20 %	15 %	13 %	12 %	14 %	16 %	14 %
Dishwasher	1 %		2 %	9 %	8 %		6 %
Outdoor use	4 %		2 %	7 %	6 %	2 %	6 %
Miscellaneous use							
TOTAL	100 %	100 %	100 %	100 %	100 %	100 %	100 %
Rainwater Harvesting		Equivalent to: 25% toilet					

		flushing, 25% clothes washing, 22.5% external tap use					
Greywater reuse		equivalent to 30% of the water consumed by toilets within the property					

Source: Kossida, M., 2015

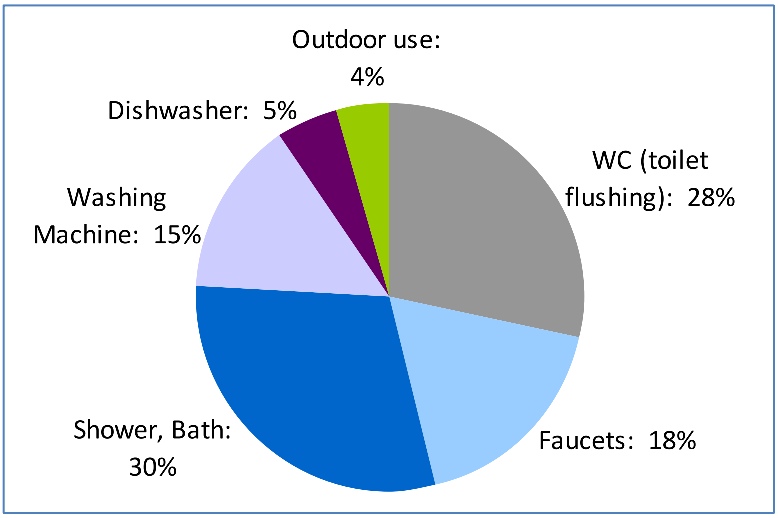

Figure 2-1: Average Water consumption share of different household micro-components in the industrialized world (based on **Error! Reference source not found.**; Source: Kossida, M., 2015)

2.2 MEASURES FOR THE AGRICULTURAL SECTOR

The main options for reducing irrigation demand are linked to decreasing losses and increasing the irrigation efficiency, i.e. conveyance and field application efficiency. This is generally achieved by replacing open canals with closed pipes, by switching to drip irrigation and/or sprinklers from furrow irrigation systems, by implementing precision agriculture, and by applying deficit irrigation. However, besides the areas of formal collective irrigation networks, additional self-supplied irrigated areas often exist, and in many countries illegal abstractions (illegal wells) might also be a problem. The main options to increase water supply for agricultural purposes is to retain water in detention basins and retention ponds (as described above in Chapter 2.2). Treated wastewater from the Bourj Hammoud Wastewater Treatment Plan (BH WWTP) could be also diverted and used in agriculture, but since the site is located quite downstream this use presents limitations since water would need to be pumped-up upstream and needs further investigation.

Replacing open canals with closed pipes targets to reduce canal leakage and increase conveyance efficiency. Water conveyance loss consists mainly of operation losses, evaporation, and seepage into the soil from the sloping surfaces and bed of the canal. Open channel networks are usually characterized by high levels of canal seepage, which lead to high water losses, and depends mainly on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals. In large irrigation schemes more water is lost than in small schemes, due to a longer canal system. From canals in sandy soils more water is lost than from canals in heavy clay soils. The losses in canals lined with bricks, plastic or concrete are very small. If canals are badly maintained, bund breaks are not repaired properly and rats dig holes, a lot of water is lost. Indicative values of conveyance efficiency in opens canals range from 60-80% for long (>2,000 m) to short (<200 m) sand earthen canals, from 70-85% for long to short loam earthen canals, from 80-90% for long to short clay earthen canals, and around 95% for lined canals. These values do not consider the level of maintenance, which, in case of bad maintenance, may lower these values by as much as 50%.

Switching to drip irrigation and/or sprinklers from furrow irrigation systems targets to increase the field application efficiency. The field application efficiency mainly depends on the irrigation method, as well as on the level of the farmers' discipline. Irrigation water losses, illustrated include air losses, canopy losses, soil and water surface evaporation, runoff, and deep percolation. The magnitude of each loss is dependent on the design and operation of each type of irrigation system. Surface irrigation losses (furrow) include runoff, deep percolation, ground evaporation and surface water evaporation. Sprinkler irrigation losses include air losses (drift and droplet evaporation), canopy losses (canopy evaporation and foliage interception) and surface water evaporation. Indicative values of the average field application efficiency are around 60% for surface irrigation (basin, border, furrow), 70% for sprinkler irrigation (traveling gun, center pivot, etc.), and 80% for drip irrigation. Lack of farmers' discipline may lower these values.

Error! Reference source not found. presents an overview of different literature values on the efficiency of irrigation methods. The values range, but in all cases it is demonstrated that, when considering single field irrigation efficiencies, sprinkler systems are generally better than furrows, and drip irrigation systems are generally the best. In any case, attainable water application efficiencies vary greatly with irrigation system type, management practices and site characteristics. The analysis of the application efficiency of irrigation systems is thus important to identify potential places where improvements can be made and plan for interventions.

Table 2-5: Field application efficiencies of different irrigation methods

Authors / Methods	Solomon, 1988	Tanji and Hanson, 1991	Morris and Lynne, 2006	Rogers et al., 1997	Howell, 2003	Hanson et al., 1999	Sandoval-Soli et al., 2013
Surface irrigation							*Low/Mean/High*
Furrow	60-75	60-90	60-80	50-90	50-80	70-85	60/73/85
Furrow with tailwater				60-90			
Border	70-85	65-80	55-75	60-90	50-80	70-85	62/73/83
Basin	80-90			60-95	80-65		72/83/93
Sprinkler							
Hand-more or portable	65-75						60/70/80
Periodic move		65-80	60-75	65-80	60-85	70-80	
Continuous move		75-85		70-95	90-98	80-95	

Traveling gun	60-70						
Center pivot	75-90		65-90		75-98		70/80/90
Linear move	75-90		75-90		70-95		73/82/90
Solid set or permanent	70-80	85-90	70-85	70-85		70-80	70/78/85
Drip/Trickle							
Trickle (point source emitters)	75-90						
Subsurcface drip			85-95	70-95	75-95		77/86/95
Microspray			85-90		70-95		
Line source products	70-85						

Source: Kossida, M., 2015 (adopted from Canessa et al., 2011)

Precision agriculture (PA) is a cultivation technique where both irrigation water and fertilizers are provided to the crop at optimum timings and doses. The practice has the purpose to sustain or even increase yields compared to the conventional cultivation ways. Numerous control technologies are available for optimizing irrigation such as evapotranspiration based controllers, soil moisture sensor controllers, and rain sensors. The typical PA system works as follows: infrared sensors are components of a wireless thermal monitoring system (Smart Crop) and identify the timing of application; soil moisture sensors back up the information for the timing while they evaluate the effectiveness of irrigation application, while an evapotranspiration sensor calculates the exact volume of water that has to be applied. Crop yields are also calculated and mapped for the purpose of estimating productivity and environmental performance indicators. All the above mentioned sensors/equipment are very easy to use, while yield maps and productivity indicators are able to demonstrate the sustainability of crop yields produced under this cultivation system and thus convince farmers for the usefulness of these technological innovations. Installation and testing of the PA technologies in the Pinios River Basin in Greece in selected pilot areas (carried out in the framework of the European funded project HYDROSENSE, www.hydrosense.org) showed that water consumption was reduced by 5-35% depending on the local conditions, while yields were increased up to 31%. Precision irrigation and fertilization have considerable costs mainly because of the equipment needed to be installed and operated. One should also consider the cost for installing drip irrigation systems in those farms that are irrigated by different methods.

Deficit irrigation (DI) is defined as the application of water below the ET requirement, and is based on the concept that in areas where water is the most limiting factor, maximizing Crop Water Productivity (CWP) may be economically more profitable for the farmer than maximizing yields. For instance, water saved by DI can be used to irrigate more land (on the same farm or in the water user's community), which, given the high opportunity cost of water, may largely compensate for the economic loss due to yield reduction. The DI practice on the farm has been widely investigated as a valuable and sustainable strategy in dry regions, coming of course with advantages and disadvantages. In general, from a wide application of the practice it can be concluded that it seeks to stabilize, rather than maximize yields and this is usually achieved when water applications are limited to specific drought-sensitive growth stages of each irrigated crop.

Land use/ crop changes involve the changes in the existing crop mix in agricultural areas, either by abandoning some areas under agricultural cultivation, or by changing the mix of existing crops, and planting less water demanding varieties. Form an economic productivity point of view it may be more beneficial to plant crops which are more drought tolerant and do not require excessive irrigation. Such a land reform requires a thorough design process to investigate the full market potential of the new crops, and a long stakeholders' process in order to showcase the benefit of such an intervention and boost its acceptability.

Economic Policy Instruments (**EPIs)** are tools based on incentives and disincentives; they change conditions to enable economic transactions or reduce risk, aiming at delivering environmental and economic benefits. These include for example agricultural subsidies for areas using limited irrigation water, economic incentives for changing land use practices, economic penalties and fines when best management practices for the rational use of water are neglected, groundwater quotas, cap and trade (tradable abstraction permits), volumetric water pricing, cooperation agreements, environmental taxes, agricultural insurance, etc.

Water pricing reform is also an EPI, and usually involves a modification in the rate structure and/or the water tariffs in order to influence the consumers' water use. It often includes the shifting from decreasing block rates to uniform block rates, the shifting from uniform rates to increasing block rates, the increasing of rates during summer months, or the imposing excess-use charges during times of water shortage. In the agricultural sector such as economic reform might be even more challenging than in the domestic sector since farmers in different areas often may not have to pay for water. Thus, this economic instrument needs a very careful design as it can easily raise conflicts among users and trigger many disputes. It is also required that water metering is in place and properly operational prior to applying any water pricing schema.

3. RECOMMENDATIONS FOR THE EX-ANTE EVALUATION OF DEMAND MANAGEMENT MEASURES

Evidence on the impacts of applied demand measures is generally limited and no concrete conclusions can be drawn on their effectiveness (Schmidt and Benitez, 2012). It is thus important to simulate response measures (and a bundle of them) against the physical system, in order to test their application and assess their true potential under specific conditions and constraints. The process of this ex-ante evaluation can be underpinned by the simulation of the measures in a physical-based distributed water resources management model (WRMM), which can capture all the salient features of water availability and demand per source and user (Kossida, 2015). To ex-ante assess the impact of these measures, the cost-effectiveness function of water saved (or water gained) versus investment cost must be investigated for each measure and mix of measures. Each measure comes with a potential water saving (or water gain) and an associated investment cost. In parallel, additional socio-economic factors come into interplay, such as the readiness of the technological solution, the social acceptability, the equitability, any constraints related to the implementation of the measures, etc. which can facilitate or impede the uptake and effectiveness of the measure. It is strongly advised to involve local stakeholders in the whole ex-ante assessment process and promote ownership and responsibility, in order to facilitate the internalization of the measures in development frameworks.

The following methodological steps are recommended to be followed in order to build cost-effective functions and evaluate (ex-ante) selected adaptation measures in a river basin or other unit of interest.

- Definition of the economic sectors of interest (e.g. domestic, agricultural, etc.)
- Selection of relevant measures (per sector) in consultation with local stakeholders to safeguard their relevance and acceptability
- Adaption of clear definitions for all measures and interventions
- Designing of a methodological approach for developing cost-effectiveness functions for each measure or bundle of measures
- Collection of the input data needed for developing cost-effectiveness functions (potential saving, costs)
- Development of the cost-effectiveness functions/ curves implementing an optimization process
- Definition of the baseline Business as Usual (BaU) scenario and development of alternative scenarios (based on a mix of the measures)
- Investigation on how to simulate the cost-effectiveness functions in a physical-based water resource management model of the river basin or other unit of interest
- Simulation of the alternative scenarios against a baseline scenario, and assessment of their impact and cost-effectiveness on the physical system
- Definition of policy targets and programmes of measures with the stakeholders through a consultation process and based on the results of the simulation and adopting a proactive risk management approach
- Internalization and mainstreaming of the defined targets and associated programmes of measures into development frameworks and sectoral policies, linking thus science to the decision and policy-making process

It is important to highlight that socio-economic factors always come into interplay, such as the readiness of the technological solution, the social acceptability, the equitability, constraints related to the implementation of the measures, etc. which can facilitate or impede the uptake and effectiveness of the measures. People's behavior is also an unpredictable factor so there is always a need to increase awareness and motivation to safeguard the proper implementation and execution of the measures. It is also essential to perform ex-post assessments based on monitored data after the measures' implementation in order to evaluate their actual effectiveness in practice. Under this context, water metering is essential in order to be able to transparently assess the before and after state.

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