Guidance on evaluation and selection of sustainable water demand management technologies

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TRANSITIONS TO THE URBAN WATER SERVICES OF TOMORROW

Guidance on evaluation and selection of sustainable water demand management technologies

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EXECUTIVE SUMMARY

This report has been prepared as part of the European seventh framework (FP7) research project, the TRansitions to Urban water Services of Tomorrow (TRUST), which aims to enable communities to achieve sustainable, low-carbon water futures without compromising service quality. Climate change, population growth, migration/urbanisation, and ageing infrastructure will all impose significant strains on urban water services in Europe, and cities across Europe will experience increasingly frequent shortfalls in supply/demand balance.

It is widely accepted that the mitigation of these and other emerging challenges should be sensitive to increasing energy prices, the environment, and the desire for low carbon intensity solutions. TRUST is supporting water authorities and Water Service Providers (WSPs) in formulating and implementing appropriate urban water policies in order to enhance urban water cycle services with regard to their cost-effectiveness, performance, safety, and sustainability under these changing and challenging conditions.

Given most of the urban water consumption in Europe is for household use, reducing this can reduce overall water demand. Household Water Demand Management (WDM) interventions such as efficient appliances and fittings, alternative water systems such as Grey Water Recycling (GWR) and Rainwater Harvesting (RWH) systems, metering and advanced tariff structures, leakage reduction measures, and soft interventions can potentially offer significant water savings and should be considered as key components of balancing supply/demand.

Household water efficiency is often considered the cheapest, easiest and least intrusive ways of reducing water demand, and is also considered the most politically and environmentally responsible intervention to implement. In cases where replacing household appliances may not be cost-effective, simple behavioural changes can be made and low-cost and easy to fit retrofit devices with short pay-back periods are available.

GWR and RWH systems can limit the amount of potable water use for non-potable uses such as WC flushing, garden watering, and clothes washing; which can reduce the dependence on mains supply. However, although these systems can relieve pressure on supply by reducing the demand for mains water and water abstraction needs, they do not necessarily reduce demand.

Water savings can also be incentivised through economic instruments such as water pricing, metering, and innovative tariffs schemes; which can act as incentives or disincentives to save water. These may also be used to raise awareness and prompt positive behavioural changes of various water users, finance infrastructure maintenance, and foster technological innovation. Metering is a prerequisite for water pricing to have any effect on water consumption.

Substantial water savings can also be achieved by using soft interventions as most reductions in water consumption often result from consumer behavioural changes. Social

instruments such as awareness-raising, information, and educational campaigns can be used to encourage behavioural changes such as time spent showering or mains water use for gardening, as well as focusing on the benefits of installing water efficient appliances and products. Such campaigns can also be used to better inform technical research agendas, strategies and policies.

Different WDM interventions will have different system impacts. In general, if water use is to be reduced then some other factor must change to accommodate this. Where a reduction of water use, cost, or energy use result in an increase of the other it is not necessarily clear which is the sustainable outcome. An understanding of these system impacts and the trade-offs between competing objectives is essential in order to plan for effective and sustainable intervention.

However, not all water produced reaches customers, which implicitly limits the extent of savings that can be made from customer-side WDM interventions. Leakage in Water Distribution Systems (WDSs) results in not only the loss of water – undermining gains made from other WDM interventions – but also the waste of energy and material resources used in abstraction and treatment of water. Effective leakage reduction can lower some aspects of demand as well as result in a decrease in the cost of production and distribution of water and a decrease in the capacity requirements for storage systems, treatment works and mains sizing. Leakage reduction can also bring in revenue from water that would otherwise have been wasted, reduce the flow rates of existing leaks, reduce the frequency of new leaks and bursts and by improving pipe integrity, and reduce surge pressure. All of these can potentially extend infrastructure lifespan and allow for deferred investment in source augmentation as well as lead to lower abstraction needs and other environmental and social benefits.

This report presents guidance for the evaluation and selection of household WDM interventions for the effective and sustainable reduction of water consumption for different water stakeholders in a technically sound, yet economically, environmentally, and socially acceptable way for all stakeholders involved. The guidance is based on previous work carried out in Work Package 42, Urban Water Demand Management, of the TRUST project. The WDM interventions considered have been evaluated largely based on the water saving potential, cost-effectiveness, water-related energy use, as well as impact on the reliability of supply/demand balance.

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LIST OF ABBREVIATIONS

ACL	Active Leakage Control
AHP	Analytical Hierarchy Process
BATNEEC	Best Available Technologies Not Entailing Excessive Costs
BAU	Business As Usual
BMA	Bathroom Manufacturers Association
CARL	Current Annual Real Losses
CP	Compromise Programming
DA	Decision Analysis
Defra	Department for Environment, Food and Rural Affairs
DMA	District Metered Area
DWI	Drinking Water Inspectorate
EA	Environment Agency
EA	Evolutionary Algorithm
ELL	Economic Level of Leakage
EPS	Extended Period Simulation
EST	Energy Saving Trust
EU	European Union
EU	European Union
GHG	Green House Gas
GUI	Graphical User Interface
GWR	Grey Water Recycling
ILI	Infrastructure Leakage Index
IWA	International Water Association
LCD	Litres per Capita per Day
MCDA	Multi-Criteria Decision Analysis
MNF	Minimum Night Flow
NRW	Non-Revenue Water
Ofwat	Office of Water Services
PaVLOS	Pump and Valve Logic Optimal Scheduling
PCC	Per Capita Consumption
PDD	Pressure-Dependent Demand
PMA	Pressure Management Area
PRV	Pressure Reducing Valve
RWH	Rainwater Harvesting
SCADA	Supervisory Control And Data Acquisition
SME	Small and Medium Enterprise
SuDS	Sustainable Drainage System
TRUST	TRansitions to the Urban Water Services of Tomorrow
UARL	Unavoidable Annual Real Losses
USEPA	United States Environmental Protection Agency
UWOT	Urban Water Optioneering Tool
WDM	Water Demand Management

WDS	Water Distribution System
WECalc	Water-Energy-Climate calculator
WEI	Water Exploitation Index
WEPLS	Water Efficient Product Labelling Scheme
WFD	Water Framework Directive
WSP	Water Service Provider

1. INTRODUCTION

1.1. European Water Resources Challenges

The quality and the quantity of fresh water resources are increasingly facing challenges in many parts of Europe as a result of developments such as climate change, rapid population growth, diminishing freshwater resources, and ageing infrastructure. Environmental regulations that impose increasingly stringent limits on chemical contaminants in drinking water (Baumann et al., 1998) further reduce potential sources of water supply (Water UK, 2011). Seasonal or inter-annual variations in the availability of water also lead to water stress (EEA, 1999). With the global demand for water continuing to rise at a pace that is double the rate of population growth (PI, 2010); Water Service Providers (WSPs) must manage the available supply in an effective and efficient way to ensure the sustainability of future supplies.

Water scarcity and droughts are a growing concern throughout Europe, particularly in the central and Mediterranean regions, and climate change is expected to amplify both water scarcity and droughts in coming years (EC, 2008). Supply/demand balances are already being affected across Europe and this is no longer an issue specifically for southern countries (Waterwise, 2009). An example of this is the severe drought of 2005 which affected countries as far north as Denmark. Changes in precipitation will increase the intensity and frequency of these hydrologic events. This will increase the amount of runoff and non-point source pollution of water resources, often in regions with rapid population growth and urbanisation (UN, 2009).

These extreme events are likely to worsen, as most climate models project increasing precipitation rates for central and northern Europe and decreasing rates for southern Europe (EEA, 2003). This will result in more frequent and intense seasonal flooding in northern countries and seasonal droughts in southern countries. Sea level rise will also have significant implications on fluctuations in groundwater levels, and the intrusion of salt water into fresh water resources. An intrusion of just two percent of salt water into freshwater will make it unusable. Even if GreenHouse Gas (GHG) concentrations stabilise, some impacts from climate change such as extreme hydrologic events and water stress will be unavoidable (UN, 2009).

However, whilst climate change will create important challenges on access to water, it is not currently the most important driver of these challenges. The most important driver influencing the demand for water is the rapid rise in population, its distribution, and density (EEA, 1999). The world's population is currently 7 billion and is growing by about 80 million each year. The population of the EU has increased by more than 72 million since 1960. With the demographic pattern of the population also changing, the age distribution of a population will also have an impact on water use as different age groups tend to have different per capita water usage (EEA, 2004). More diverse family living arrangements coupled with the steady decline in household sizes since the 1960s has resulted in more people living in smaller, single person households (EC, 2010). The trend towards smaller household sizes means higher per capita water use (Waterwise, 2009c). Increased affluence with rising per capita incomes will also have an impact on water consumption, such as more use for water consuming appliances.

The world is also undergoing rapid urbanisation, with more than half of the world's population currently living in towns and cities (UNFPA, 2007). For example, more than two thirds of the population in the EU live in urban areas, and the proportion of the population living in settlements below 2, 000 inhabitants clearly decreasing in most countries (EEA, 1999). If the current population, urbanisation, and associated consumption trends persist, there will be an increase in freshwater demand of about 64 billion cubic meters per year (UN, 2009).

Whilst population is rapidly increasing, water resources have remained constant in many places, and are receiving increasing pollution load from the growing population (SWITCH, 2011). It is estimated that the global demand for water will surpass its availability by 56 percent by 2025, and it is likely that water resource development will not keep up with this population growth in some places (PI, 2010). The rapid rate of urbanisation is resulting in many cities and towns facing major challenges of providing their increasing populations with adequate and sustainable water services (SWITCH, 2011).

Some components of most water infrastructure were built over 100 years ago to cater to the consumption needs of 100 years ago. WSPs are therefore increasingly facing challenges with costly repairs and upgrades of ageing infrastructure. Although these old components perform satisfactorily most of the time, failures due to deterioration in the internal condition do occur sporadically, increasing the risk of contaminating surface and groundwater resources, with potential detrimental effects on human health and the environment (Boxall ca., 2011). Aged components are more susceptible to leaks and main breaks, which not only waste valuable water resources, but can lead to discoloration, odour, reduced hydraulic capacity due to internal pipe corrosion, and increased disinfectant demands due to the presence of corrosion products, biofilms, and regrowth (USEPA, 2002).

Human demand for water is in direct competition with overall water needed for agriculture, industry, and tourism; and often exceeds local availability (EEA, 2010). Over abstraction of water resources remains a major concern in parts of Europe, such as the coast and islands of the Mediterranean (EEA, 2003). The Water Exploitation Index (WEI), an indication of how the total water demand puts pressure on water resources, indicates that 18 percent of Europe's population live in countries that are water stressed. Water resources are considered to be under stress or over stretched if their WEI exceeds 20 percent. This water stress is likely to be further exacerbated by climate change and other impacts (EEA, 2010).

Despite all these challenges however, the underlying trend is that we are all using more and more water, with a third of the water used being flushed down the toilet (Waterwise, 2009). As a result of this, water conservation and water demand management (WDM) interventions and technologies for reduction of water wastage in all spheres of the water sector is urgent (SWITCH, 2011). In order to sustainably meet future supplies, various options need to be taken into consideration, including a wide range of both supply and demand management interventions.

1.2. Urban Water Demand Management

Two principal approaches are often considered for bridging the gap between the future need for water supply and the current availability of water – supply augmentation and demand management. Historically, efforts to satisfy the increasing demand of water have often been expended principally on increasing the supply of resources, which were available abundantly and at relatively low cost (EEA, 2001a; EEA, 2010). However, supply augmentation involving the development of new reservoirs, dams, treatment plants, desalination plants, and large scale water-transfer infrastructures are too costly. Moreover, the over reliance on the development of new water supply systems to respond to increasing demand often encounters significant public opposition as they are viewed as a potential cause of environmental degradation, hence there is a need for a general paradigm shift to consider WDM as well (SWITCH, 2011).

Supply augmentation also tends to be unresponsive to economic, environmental, social, and political constraints and the important contributions that can be obtained from comprehensive demand interventions (Baumann et al., 1998). As a result of this, WDM is increasingly concentrating on ways of influencing water demand in a way that is both cost-effective and favourable for the water environment (EEA, 2001a).

WDM has an important role to play by encouraging people to reduce water consumption through water efficiency and leakage reduction measures. WDM aims to sustainably reduce consumption of water to conserve the resource, save money, and reduce negative environmental impacts by making a more efficient and rational use of water resources whilst still satisfying the needs of consumers. WDM strategies typically search for cost-effective measures to reduce water use by increasing efficiency through technical fixes, process and operational improvements, economic incentives, and consumer education. These strategies offer an alternative to additional water supply but have so far often been considered as temporary options until supplementary supplies are secured. However, in the face of ever growing demand, current uncertainties and change, it is increasingly evident that reducing the specific demand for water is our best 'source' of 'new' water (Brandes and Brooks, 2007).

WDM has been defined in many different ways, and can generally be considered as any action that modifies the level and/or timing of demand for the water resource (White and Fane, 2001). In the wider sense, WDM may be any method – whether technical, economic, administrative, financial, or social – that will accomplish one (or more) of the following actions (Brooks, 2005):

- Reduce the quantity or improve the quality of water required to accomplish tasks;
- Adjust the nature of tasks or the way they are undertaken so that they can be accomplished with less water or with lower quality water;
- Reduce the loss in quantity or quality of water as it flows from source to use to disposal;
- Shift the timing of use from peak to off-peak periods; and

- Increase the ability of water systems to continue to serve society during times when water is in short supply.

WDM interventions, such as the use of efficient household appliances and fittings, as well as alternative measures including Grey Water Recycling (GWR) systems, Rainwater Harvesting (RWH) systems, and Sustainable Drainage Systems (SuDS) can also provide cost and energy savings to water users and WSPs. WDM interventions can also have a positive impact on the supply/demand balance, help reduce pollution, lower water and energy costs, lead to a reduction the amount and flow pattern of wastewater to the drainage system, reduce the total volume of wastewater arriving at treatment works, and extend the life of existing supply and waste treatment facilities (DEFRA, 2008). This is addressed in section 2 of this report.

However, not all water produced reaches customers, which implicitly limits the extent of savings that can be made from customer-side WDM interventions. Reducing water losses from Water Distribution Systems (WDSs) can significantly lower water demand as well as result in a decrease in the cost of production and distribution of water as well as in the capacity requirements for storage systems, treatment works, and mains sizing (Trow and Farley, 2006). This, along with other WDM interventions that WSPs and policy makers can use to reduce water demand – such as water pricing, metering, advanced tariff structures, and soft interventions, is addressed in section 3 of this report.

1.3. Aim of the Report

This report presents technical guidance on the evaluation processes developed in work package 42 of the TRUST project (Bello-Dambatta et al., 2012a; Bello-Dambatta et al., 2012b; Rozos et al., 2012; Morley et al., 2012; and Bello-Dambatta et al., 2013), and how it can be used to evaluate and prioritise WDM interventions for different water stakeholders – householders, WSPs and policy makers – based on their system impacts. Section 4 of the report presents guidance based on the reviews and case studies in sections 2 and 3 on the selection and evaluation of WDM interventions, and the different instruments that can be used to encourage and motivate water users and WSPs to save water, and the impact of policy on WDM.

1.4. Structure of the Report

The remainder of this report is organised as follows:

A review of WDM interventions and technologies that can be used by households to reduce/manage their water consumption is provided in section 2. Section 3 provides an overview of the interventions and techniques WSPs and policy makers can introduce to encourage water efficiency and reduce wastage. Section 4 outlines some guidelines for the evaluation and selection effective and efficient household water demand management interventions. Section 5 concludes the report with summary and conclusions. Case studies have been provided in each chapter to demonstrate the contributions that the WDM interventions and technologies presented the chapters can make to WDM.

2. DEMAND MANAGEMENT: HOUSEHOLDS

2.1. Introduction

European urban water use typically consists of household, Small and Medium Enterprises (SMEs) and public water consumption. It estimated that on average, 85 percent of European urban water use is used by households (EEA, 2011; Scardigno, 2011) to satisfy basic needs for drinking and sanitation, and other needs such as house cleaning, laundry, dishwashing, and outdoor water use (EEA, 2004). The amount of household water use depends on a wide range of factors, including household size, type, income, and water prices (EEA, 2004). This is increasing as a result of increased consumption for personal hygiene and use of water using appliances as a result of increasing standards of living (EA, 2007b). Reducing household water consumption can reduce overall urban water demand. The current average water Per Capita Consumption (PCC) in Europe is around150 Litres/Capita.Day (LCD), with considerable variation of water use across Europe because of different climates, cultures, habits, economies, and natural conditions (EEA, 2001b). There is also large differences in consumption between and within countries (EEA, 1999), with considerable variations even amongst communities and over time (Baumann et al., 1998). Available figures show that on average about a third of this water is flushed down the toilet, and only about 4 percent is used for drinking (Figure 1).

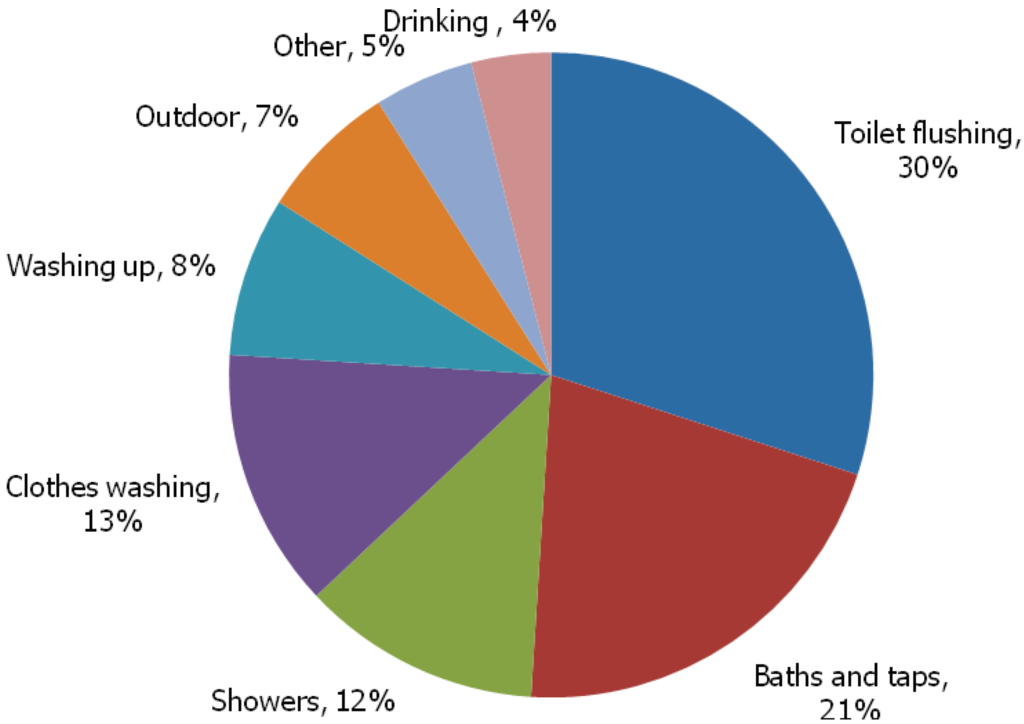

Figure 1 – UK daily water consumption by micro-component (Waterwise, 2011)

A clear understanding of household water consumption enables better of water consumption trends, which allows for more efficient use of water and better forecasting of future water demand. In order to understand household water consumption patterns and trends more clearly, it is necessary to study the individual consumption of water within the household (Memon and Butler, 2006). One method of doing this involves breaking consumption into different micro-components of demand, for example for water use for WC flushing, bathing, clothes washing, dishwashing, and outdoor use.

Several studies have shown that there is a strong and clear relationship between household occupancy and water consumption, with PCC decreasing as occupancy increases (Table 1). Water consumption can also vary considerably between households, depending on household socio-economic factors (Table 2). Cultural and religious factors may also play a large role in peoples' attitude to water consumption (Jeffrey and Geary, 2006).

Table 3 and Table 4 show a comparison of average household water use by micro-components of use in different European countries. One way of reducing overall demand is to make the existing homes more water efficient (EA, 2007d; Butler et al., 2009), which could be accomplished by using efficient household micro-components, such as low flush volume WCs, low flow showers and taps, efficient washing machines and dishwashers; and through social interventions such as public awareness campaigns to encourage water saving (EA, 2008).

Table 1 – Per capita consumption versus household occupancy (EA, 2007a)

	LITRES/CAPITA·DAY (LCD)		
Occupancy	WRc (2005)	Scottish (1999)	Edwards and Martin (1995)
1	205	193	222
2	173	162	158
3	144	130	133
4	119	99	122

Table 2 – Domestic water use as a function of affluence (Memon and Butler, 2006)

HOUSEHOLD TYPE	AVERAGE CONSUMPTION (LCD)
High quality housing areas	225
Urban residential areas	180
Suburban low cost housing	95
Urban areas served by standpipes	60
Rural areas served by standpipes	40
Rural dwellings with distance to source > 1 km	20

Table 3 – Comparison of household water use in different European countries (EEA, 2001a)

MICRO-COMPONENT USE	ENGLAND AND WALES (%)	FINLAND (%)	SWITZERLAND (%)
WC	33	14	33
Bathing and showering	20	29	32
Washing machines and dishwashing	14	30	16
Drinking and cooking	3	4	3
Miscellaneous	27	21	14
Outdoor use	3	2	2

Table 4 – Average water use by household appliance in some European countries (EEA, 2001a)

MICRO-COMPONENT USE	ENGLAND AND WALES	FINLAND	FRANCE	GERMANY
WC	9.5 l/flush	6 l/flush	9 l/flush	9 l/flush
Baths	80 l/bath	150–200 l/bath	100 l/bath	120-150 l/bath
Showers	35 l/shower	60 l/shower	16 l/minute	30-50 l/shower
Washing machines	80 l/cycle	74–117 l/cycle	75 l/flush	72-90 l/cycle
Dishwashers	35 l/cycle	25 l/cycle	24 l/flush	27-47 l/cycle

2.2. Household Water Demand Management

Different types WDM interventions and technologies such as efficient household micro-component appliances and fittings and alternative water systems can be used to reduce household water consumption. Increasing water costs have greatly expanded the options for WDM so much so that it is believed that cost-effective water savings of 20–40 percent is readily available (Brandes and Brooks, 2007). Given that household water and energy use are inextricably linked, reducing household water consumption by using efficient household appliances and fittings, especially hot water using appliances, can help to substantially reduce overall energy demand and household energy costs (Fidar et al., 2007; Beal et al., 2012). On average, around a third of household energy use is for heating and hot water use. Also, because the level of water-related energy use has a direct relationship with GHG emissions, WDM interventions can be viewed not only as a potential means of aiding the security of future water supplies, but also as a means of reducing emissions (Fidar et al., 2010).

The recent trend is an increase in water industry energy use, which is driven by conveyance and treatment of water and wastewater and to increasing quality standards (MTP, 2011a). In the UK for example, energy use in the water industry rose 10 percent between 2001 and 2011 to 9, 016 GWh (Water UK, 2011b). However, this represented only 11 percent of the total water-related energy use, with 89 percent attributed to household water use, particularly hot water use which constitutes 95 percent of household water-related energy use (Fidar et al., 2010). Water supply and wastewater management operations alone are therefore a poor indicator of the energy use associated with the urban water sector (ibid), and an assessment of household water-related energy use is needed to better determine energy use in the urban water sector.

However, not all WDM interventions will result in reduction in water-related energy use and some interventions could increase energy use. In general, if water use is to be reduced then some other factor must change to accommodate this, and where a reduction of water use or water-related energy use result in an increase of the other it is not necessarily clear which is the most sustainable outcome (MTP, 2011a). An understanding of these water-energy-cost savings trade-offs is therefore essential in order to plan for sustainable WDM interventions. The different outcomes that could result from any intervention are (Fidar, 2011):

I. Energy and water use are equally reduced;
II. Energy and water use both reduced, with the reduction in energy use proportionately greater than that of hot water;
III. Energy and water use both reduced, with the reduction in water use proportionately greater than that of energy use;
IV. A decrease in energy use as a result of water savings;
V. An increase in energy use as a result of water savings;
VI. Reduction in energy use, with water use remaining the same; and
VII. Reduction in water use, with energy use remaining the same.

2.2.1. Household Micro-Component Appliances and Fittings

Efficient household fittings and appliances that have been designed to encourage water and/or energy efficiency such as tap and shower fittings that aerate and/or restrict flow; different types of toilets such as low-flow/dual-flush/vacuum toilets; and water and/or energy efficient appliances such as washing machines and dishwashers have produced significant reductions in water and energy consumption – some of which have been found do the same or even a better job with less water. These water efficient products can also offer the potential for significant water savings at point of use (Grant, 2006; EEA, 2001a; Table 5).

The Best Available Technologies Not Entailing Excessive Costs (BATNEEC) lists how domestic water consumption can theoretically be reduced to 76 LCD using 2001 appliances and 53 LCD using 2006 appliances (Table 6). A similar reduction could be made in other urban sectors water consumption. For example, saving measures for SMEs and public water sectors are similar to those for households and have the potential to significantly reduce water consumption by retrofitting or installing efficient appliances (EU, 2007).

Retrofitting houses and efficiently fitting new developments is least sensitive to issues of human interface, as no lifestyle changes are required, and are therefore the easiest intervention to implement (Grant, 2006). This is estimated to potentially reduce water consumption from 150 to around 80 LCD (EU, 2007). Some of these technologies also have shorter payback periods which further enhance their uptake possibilities (EU, 2007).

Table 5 – Water consumption of different household micro-components (Grant, 2006)

MICRO-COMPONENT	% USE	WATER USED (LCD)	FREQUENCY OF APPLIANCE USE (USES/CAPITA/DAY)	ASSUMED FREQUENCY OF USE USING BATNEEC (USES/CAPITA/DAY)
WC	35	52.5	5.25	4.12
Baths	15	22.5	0.28	0.34
Showers	5	7.5	0.5	0.6
Kitchen sinks	15	22.5	2.25	2.25
Washbasins	8	12	2	2
Washing machines	12	18	0.18	0.157
Dishwashers	4	6	0.21	0.214
Outdoor water use	6	9	1	0
Total	**100**	**150**		

However, the selection of household fittings and appliances is usually a subjective (design) matter linked more with affordability than actual water or energy use (Butler et al., 2009). Difficulty is often encountered in encouraging consumers to increase market penetration of efficient household fittings and appliances (EEA, 2001a) even though the efficient alternatives are generally very similar to conventional products and are likely to display similar price variations and ranges when they come into mass production, meaning additional costs are unlikely (Butler et al., 2009). Increasing the market penetration requires information campaigns that clearly explain the reasons and advantages of the products, for example in terms of reduced water and energy bills (EEA, 2001a). Moreover, overall water and energy savings would depend on the proportion of household water demand in total urban demand and on how widespread the use of efficient household fittings and appliances are (ibid).

Table 6 – Estimate of water consumption with BATNEC technologies (Butler et al., 2009)

USE	FREQUENCY OF USE/CAPITA/DAY	BATNEC (2001) LITRES/USE	BATNEC (2001) LITRES/DAY	BATNEC (2006) LITRES/USE	BATNEC (2006) LITRES/DAY
WC	4.12	4	16.48	3	12.36
Baths	0.34	70	23	50	17
Showers	0.6	20	8	6	3.6
Kitchen sinks	2.25	3	12	2.8	6.3
Washbasins	2	3	6.75	2.5	5
Washing machines	0.157	45	7.07	35	5.5
Dishwashers	0.214	18	3.85	14	2.996
Outdoor water use	0	0	0	0	0
Total			76		52.8

2.2.1.1. WCs

WCs have traditionally represented the largest single consumption of water in households, particularly in older properties (Grant, 2006; EA, 2007b). As such, WCs are usually the first target for any water efficiency intervention (EA, 2003). An average household (assuming an average occupancy of 2.4) with a nine litre WC cistern flushes around 110 litres of mains water down the pan (Grant, 2006). This represents about 30 percent the total water consumption per day (ibid). WC flush volumes have reduced and continue to fall as older WCs are been replaced by more efficient newer ones with lower and/or variable flush volumes.

WC models are now available that use significantly less water than was required in the past (EA, 2007b). WC models are now available with single flush volumes of 4.5–6 litres and dual-flush volume of 6/3 litres. Low flush WCs with full flush of 4 litres are generally thought to represent a lower limit for use with existing gravity drainage (Grant, 2006). Dual flush WCs have a two-way flushing mechanism that gives users a choice of a part-flush or full-flush. Ultra-low flush toilets with effective flush volumes of 3 litres or less have been designed to maintain the same flush performance as conventional toilets with less water (DEFRA, 2008b).

With care, most WCs can have a very long service life with an estimated replacement period of around 15 years or longer (DEFRA, 2008b), and WCs are most likely to be replaced for reasons of style rather than failure (EA, 2007b). Replacing WCs is therefore considered costly, and may only be appropriate when constructing a new building or carrying out major renovation work (ibid). Moreover, replacing WC a 7.5 litre leak free WC with 6-litre model that will leak or jam cannot be considered a cost/water efficient option (ibid). Although it is known that valves will eventually leak/jam, there is currently no sufficient body of evidence of long-term performance or when and how this will occur (EA 2007b).

Where an older WC uses more water than it needs, a cost effective domestic water efficiency measure is to convert and/or optimise the full flush volume (Grant, 2006; Table 7) by using water efficiency devices such as cistern displacement or variable flush devices that reduce water use. Cistern displacement devices can be placed underneath the WC cistern float to reduce the capacity of the cistern. However, this can only be beneficial if the existing full flush is 7 litres or more as usually 6 litres is required for efficient flush for current WC models. Retrofit flush devices, such as interruptible and variable flush devices, can be used to modify flush mechanism by offering a choice between a full and a reduced flush volume offer a more robust solution to reducing flush volumes than cistern displacement devices (EA, 2005a).

2.2.1.2. Baths and Showers

As WC flush volumes have fallen and bathing habits have changed, some households use more water for baths and showers than for WC flushing (EA, 2003). Baths and showers currently account for around 45 percent of the water used in households, with modern plumbing, en-suite bathrooms and changes in lifestyle all contributing to the significant steady increase in water use for bathing and showering (EA, 2007b).

Baths are available in a wide range of shapes and volumes. The main variables which determine how much water is used to fill a bath are its volume and shape (EA, 2007b; Table 8). There are no current standards for determining the volume of a bath, and there is no agreed method of testing for the volume used, therefore data is not always available (EA, 2007a). However, very few modern baths hold less than 130 litres, which is about 60 litres of water with a submerged adult. Some larger baths hold more than 300 litres, which is equivalent to the average volume of water two people use each day (EA, 2007b). No significant developments in bath technology are expected in the future that could see reductions in the volume of water used (EA, 2007a).

Table 7 – Low cost retrofit devices and alternative WC technologies (EA, 2007b)

DEVICE/TECHNOLOGY	SAVING PER FLUSH	RELATIVE COST
Cistern displacement device	0.5-2.5 litres	Low
Interruptible flush device	30%	Medium
Variable flush device	30%	Medium
Dual flush (part flush default) WCs	30%	High
Dual flush (full flush default) WCs	30%	High
Ultra Low Flush toilets	-	Very high
Vacuum and compressed air toilets	100%	Very high
Macerating toilets	-	Very high
Dry toilets	100%	Medium

A shower typically uses around 9 litres of water per minute (DEFRA, 2011). When used responsibly, showers will use about a third of the water used in baths, and can therefore represent a water saving alternative to baths (Table 9, Table 10). However, people tend to take showers more frequently (EA 2007b), and recent trends in power showers and mains pressure systems in countries like the UK have increased flow rates to the point where a long shower can use more water than a bath (ibid). Even a quick five minute shower using a poorly designed power shower can use as much as 60–70 litres of water (Waterwise, 2007).

Domestic showers are perhaps the most complex type of water fitting to assess and compare in terms of water efficiency. The flow rate for showers can be measured in a similar way to that of a tap, however the very function of a shower means that flow rate alone cannot be the only criterion against which showers are assessed. Water use in showers depends on a number of factors, including the heating mechanism, type of shower control (fixed/adjustable), the shower flow rate, the spray pattern and the pressure of the water droplets on the skin (EA, 2007b).

Table 8 – Bath water consumption by product capacity (EA, 2007a)

BATH TYPE	CAPACITY TO OVERFLOW (LITRES)	USAGE (LITRES/FILL)	PERCENTAGE OF CAPACITY USED (%)
Undersize	165	65	39
Corner	140	65	46
Shower	250	100	40
Standard	225	88	39
Roll top	205	80	39
Whirlpool / spa	225	88	39
Outdoor large spa	400	300	75

Although there is little scope for water saving in older houses with electric showers or simple gravity-fed mixer showers, cheap and easy-to-fit retrofit devices that reduce water use in showers are available with short payback periods, and homes with pumped or mains pressure can be fitted with simple aerators/flow restrictors. Flow regulators can be used for showers above 1 bar to limit maximum flow rates to a water sufficient level. Most water saver showers introduce air to atomise the water drops to improve wetting for a given flow rate. The result feels like a power shower but with perhaps 4–9 litres per minute rather than 12–20 that might be delivered by power showers (Grant, 2006). However, this is still more than many electric showers and some gravity fed showers will deliver. Pressure Reducing

Valves (PRVs) that provide low outlet pressure can also be used to reduce the flow rate of gravity showers. PRVs can cut the outlet pressure to as low as 0.5 bar or the minimum pressure required for a particular shower to operate (EA, 2007a). Other types of low cost shower gadgets are also readily available, such as 4–5 minute egg timers and shower alerts that lets a person know when they have used 35 litres of water (Which?, 2011).

Table 9 – Flow rates and water consumption per visit for showers (EA, 2007a)

SHOWER TYPE		OVERALL FLOW RATE (LITRES/MINUTE)	OVERALL CONSUMPTION PER VISIT (LITRES)
Electric shower	7 kW – 7.9 kW	3.46	21.26
	8 kW – 8.9 kW	3.96	24.68
	9 kW – 9.9 kW	4.52	28.37
	10+ kW	4.99	31.34
Mixer shower (gravity fed and mains pressure hot water systems)	Mixer – gravity	7.88	48.72
	Mixer with integral pump	9.85	56.23
	Mixer – separate pump	11.82	67.47
	Mixer – pressurised	11.82	67.47
Bath / shower	Bath / shower mixer	6	37.96

2.2.1.3. Taps

Up to a quarter of domestic water use flows through taps (EA, 2007b). This can be from bath taps for bath water usage, washbasin taps for bathrooms and cloakrooms, and taps for kitchen sinks. A tap can often deliver flow rates of up to 20 litres per minute depending on pressure (Environwise, 2007b). A good deal of this water flows down the drain without performing any useful purpose, as water is often wasted whilst waiting for the tap to run hot (or cold). Taps vary widely in flow volume, from 2–25 litres per minute, and user behaviour such as how much a tap is opened and for how long it runs, determines volume of water used (Waterwise, 2011).

Table 10 – Comparison of bath and shower water use in England (EA 2003)

	BATH	ELECTRIC SHOWER
Volume per use	80 litres	6 litres/minutes = 36 litres at 6 minutes
Uses/(person·day)	0.34	0.6
Heating	30°C	10.8 kW electric
Water efficiency	75 percent	100 percent
Energy (kWh)	3.48	1.08
Kg CO_2/kWh	0.19	0.41
Kg CO_2/bathing	0.66 (for heating only)	0.44 (for heating only)
Energy £/kWh	0.02	0.07
Water and sewerage costs £/m^3	1.5	£1.5
Water/person.year, m^3	9.9	7.88
Kg CO_2 (water)	9.9	7.88
Water £/yr.	14.85	11.83
Energy £/yr.	8.64	16.56
KgCO_2/yr.	91.8	104.24
Total £/yr.	23.49	28.39

As with showers, three variables determine the amount of water use through taps. These are tap event duration, flow rate and frequency of use (Fidar, 2011). Event duration of taps is dependent on user behaviour. The flow rates of taps vary widely and are governed by several physical factors, including water pressure and specific tap designs. The frequency of use of taps is related to household occupancy, and the number of tap use events per person reduces as the occupancy of the household increases (ibid). Water efficient taps can significantly reduce both the amount of water consumed and water wasted (DEFRA, 2010). There are widely varying estimates about the water saving potential of these efficient taps; with manufacturers claiming water savings of 50–80 percent (Fidar, 2011).

Taps can be made efficient through design or through addition of flow restrictors or regulators that limiters can be incorporated within the tap or fitted on to the pipework supplying the tap (WEB, 2011). Most old taps have no water efficiency features. Where water is supplied at mains pressure, low cost and easy-to-fit retrofit devices such as aerators and flow restrictors are readily available that can be used to reduce water use with short payback times (Envirowise, 2007b). Tap inserts such as aerators or laminar flow devices that eliminate splashing whilst regulating flow rates and providing the illusion of more water flowing can be attached to existing taps to modify flow rates or spray pattern to lower consumption (Grant, 2006; EA, 2007a).

Taps currently available on the market include spray taps, aerated taps, variable flow rate taps with a ‘brake’ of flow between efficient and standard flow rates, self-closing taps, automatic taps and electronic taps for a wide variety of application in kitchens, bathrooms and cloakrooms. Another innovation is a water-saving cartridge for single-lever mixer taps. As the lever is lifted, resistance is felt. If a higher flow is needed, the lever can be pushed past this step. Some designs make sure that only cold water comes out when the lever is in the middle position (WEB, 2011). However, although these tap technologies are mature technologies; their water savings are variable and are dependent on user awareness (Grant, 2006).

No figures are available for energy savings from taps but saving water will make a difference (EA, 2007a). No significant developments in tap technology that could reduce water consumption are expected in the future, although sensor taps could rise in popularity within households, decreasing reliance on the user to switch taps off, particularly in bathrooms and cloakrooms. However, this would alter the duration of use, rather than the flow rate (EA, 2007a).

2.2.1.4. White Goods

Washing machines and dishwashers account for around 16 percent of the total volume of water used in a typical household (EA, 2007b). The performance, energy, and water efficiency of new machines has increased significantly over the past decade (Grant, 2006; Figure 2). New washing machines use about half the water and energy of the average 10 year old machine (EA, 2007b). Water and energy efficiency no longer carries a price premium, and this has seen a steady elimination of inefficient household appliances (EA, 2003; Grant, 2006).

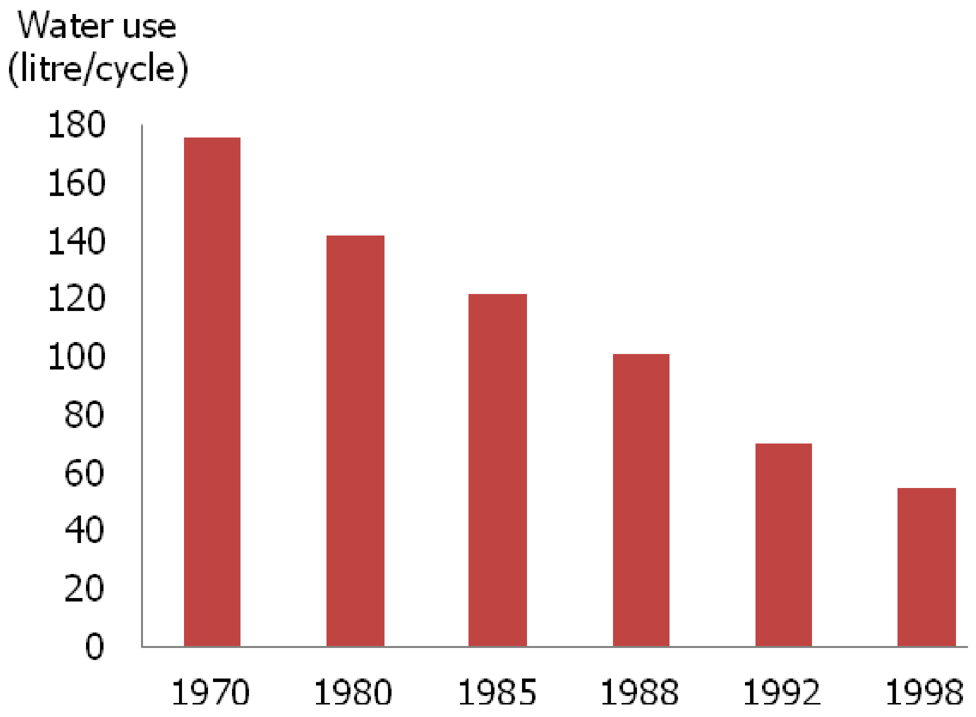

Figure 2 – Evolution of water used for washing machines 1970 - 1998 (EEA, 2001a)

Domestic washing machines with various water consumption specifications are available on the market, ranging from 45–68 litres per cycle, with a typical lifespan of about eight years (EA, 2007a). Most new washing machines now use less than 50 litres of water per 6 kilogram wash and the most efficient machines claim less than 40 litres for the same 6 kilogram load (EA, 2007a). However, some washer-dryers use mains water to condense moisture and they do not need an external vent. This can increase water consumption to between 100–170 litres per wash even though most cannot dry the whole load because of the smaller drum.

Water efficiency of washing machines is strongly influenced by use, as part loads are much less efficient than full ones. A trend towards machines with a larger capacity of 6 or even 8 kilogram could, unless used at full capacity, further reduce part load efficiencies. Innovations like half load buttons and fuzzy logic functions are only a partial solution and may encourage people to use part loads. It is likely that current washing machine models have reached the limit of water and energy efficiency as measured by Energy Label test methods with full loads (EA, 2003). Real-world improvements could be achieved by improved part-load efficiency and control of detergent dosing or by further education of users to only wash full loads with the minimum amount of detergent appropriate to the level of soiling and water hardness (EA, 2003).

Dishwashers are not as water consuming as is often thought, and using a dishwasher can be a more water efficient way of doing the dishes than hand washing (Which?, 2011; Figure 3). It has been estimated that washing the same crockery by hand would use 40 litres of hot water (EA, 2007a; EA, 2007b). The use of dishwashers can easily be justified in terms of water saving therefore, especially when items have not been rinsed before and the dishwasher is fully loaded before switching on. Some of the cheapest dishwashers claim a respectable 14 litres to wash 12 place settings17 (EA, 2007b). However, actual water saving with dishwashers will ultimately depend on the model used and the program selected. Some half-load dishwasher programs have been found to use the same amount of water as full ones (Grant, 2006).

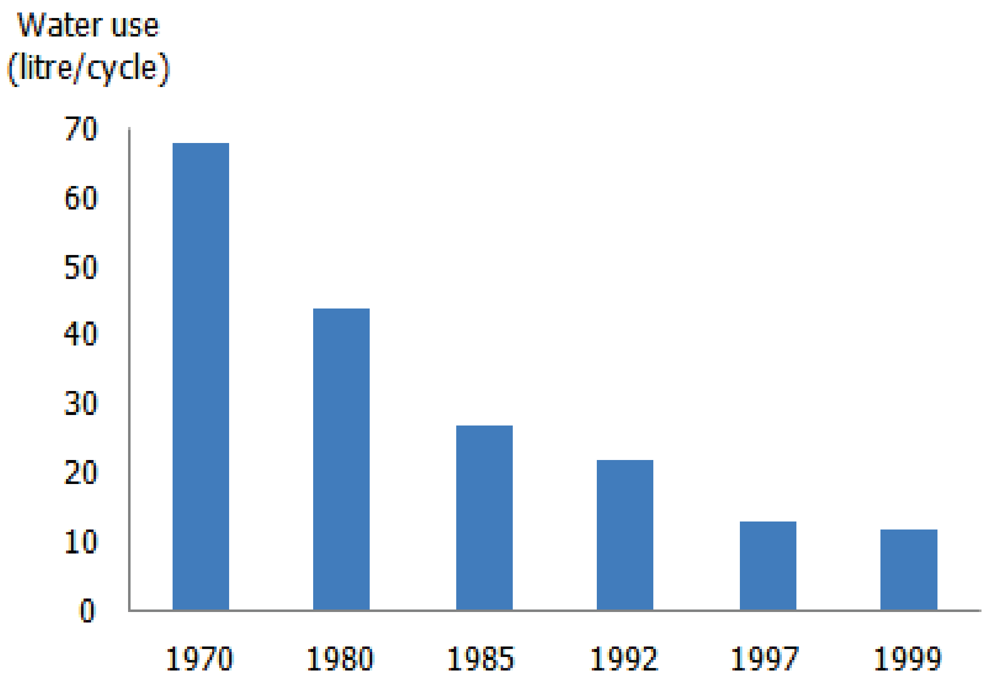

Figure 3 – Evolution of water use for dishwashers1970 – 1999 (EEA, 2001a)

As with washing machines, dishwashers are becoming more water and energy efficient and the trend for dishwashers is towards 'A' ratings for energy and low water use. Domestic dishwashers with various water consumption specifications are available in the market, and most models now using between 12 and 18 litres to wash 12 place settings (EA, 2007b). Whilst there is still potential for technical improvement from manufacturers, the greatest savings are now to be achieved by using the appliances carefully, for example only washing full loads and not rinsing dishes before putting them in the machine (Grant, 2006).

2.2.1.5. Outdoor Water Use

Using treated mains water for outdoor uses such as garden watering and car washing is an inefficient use of resources. The average amount of water used outdoors in Europe accounts for about six percent of the amount of total household water used each year (EA, 2007b). Whilst this accounts for only a small percentage of annual domestic water use, it peaks to over 50 at a time of highest water stress (Grant, 2006; Waterwise, 2011). On hot summer days, when supplies are tightest, over 70 percent of the water supply may be used for watering gardens. Much of this water is probably not doing plants that much good as water evaporates quicker on drier days (EA, 2007b). It is possible to have a beautiful and productive garden without using mains water with good design and appropriate planting (EA, 2007b; Grant, 2006).

Where gardens need a lot of watering, simple low cost grey water diversion systems can save considerable quantities of water at a time of peak demand. Similarly, rainwater can be collected to provide adequate amount of water needs for all but the largest garden (EA, 2007b; Grant, 2006). Water efficient irrigation systems such as drip irrigation and sprinkler timers can be used to reduce outdoor water use by eliminating wastage from evaporation and run-offs.

However, technical fixes such as drip irrigation and sprinkler timers are probably unnecessary complications for all but the driest regions, and can lead to water wastage if incorrectly used or maintained (Grant, 2006). Sprinkler systems can be retrofitted with devices such as rain shutoff devices, soil moisture sensors and humidity sensors to reduce water wastage by only watering when needed. Smart irrigation systems that adjust based weather conditions can be used to cut outdoor water use by half (Laskow, 2011).

Outdoor water use can also be reduced by making simple behavioural changes in water use. Watering lawns and gardens at the right time of the day (early in the morning or late in the evening) when evaporation rates are lowest can significantly reduce water wastage. Using mulch and bark in the garden can also reduce evaporation by up to 75 percent (Waterwise, 2011). Watering only when the soil is dry and giving the lawn a good deep soaking when watering encourages root systems to grow more deeply and make plants more drought resistant (SE, 2005). Letting lawns go brown in dry months is eco-friendly, and the lawns will recover immediately after rainfall (Waterwise, 2011). Converting to water efficient landscaping and gardening by mixing some drought resistant bedding and perennial plants will save water and add diversity. Using a broom rather than a hose to clean up sidewalks and driveways and washing the car with a bucket saves water (SE, 2005). Using a bucket and sponge for washing cars and a watering can for gardening can significantly reduce the amount of water wasted. If a hosepipe must be used, attaching a trigger nozzle can halve water use (Waterwise, 2011).

2.2.2. Alternative Water Systems

Alternative systems such as Grey Water Recycling (GWR) systems, Rainwater Harvesting (RWH) systems, and Sustainable Drainage Systems (SuDS) can also be used to reduce water consumption by limiting the amount of potable water use for non-potable uses such as WC flushing, garden watering, and clothes washing; thereby reducing the dependence on mains supply, resulting in reduced use of mains water (EA, 2010). WDM systems also have a positive effect on wastewater by delaying/reducing peak inflow into wastewater systems (EA, 2010).

The use of these systems is increasing within the EU, mostly to alleviate the lack of water resources in certain regions, such as in southern European countries but also to protect the environment especially in coastal waters by removing discharges into sensitive receiving waters (EEA, 1999). In Mediterranean countries for example, the importance of the direct reuse of wastewater is increasing and there is a trend towards considering treated wastewater as an economic good (EEA, 2001a). However, although the technical aspects of these systems are generally in place, there is a lack of standards and national regulations, and standards and guidelines are urgently needed (ibid). There is also a need for economic incentives to establish new programmes for uses of water which do not require high quality (ibid).

2.2.2.1. Grey Water Recycling Systems

Grey water is wastewater from showers, baths, and washbasins (in some cases washing machines), which after treatment can be used safely for non-potable water use (Butler et al., 2009; EA, 2011). Grey water excludes water from the kitchen sink and WC due to their high organic content, which is known as black water (Butler et al., 2009). The quantity of water from wash basins, showers, and baths is similar to that used for WC flushing. This means supply of water for WC flushing will roughly equate to demand, as each person will generate their own water. This will in turn result in minimal to no reliance of mains water top-up and much smaller tank for GWR, which reduces installation and running costs.

The potential for GWR for urban use with high percentage of potable water consumption is considerable, and a decrease in this can result in significant reduction in total mains water demand (Roaf, 2006). If used for WC flushing for example, a well designed and fully functional GWR system could potentially save up to a third of the mains water used in the home (EA, 2007a), and savings of around 20–25 percent in offices (Butler et al., 2009). Further reductions can be made used if used for other non-potable domestic uses such as garden watering and laundry (EA, 2011). GWR can also reduce the amount of water discharged into the sewerage system, and therefore metered customers could save money on both their water supply and wastewater bills (ibid).

GWR systems vary significantly in their complexity and scale – from small scale systems requiring no or very little treatment to large scale systems that require complex treatment processes (EA, 2011; Warner, 2006). Stored grey water will require some level of treatment, as untreated grey water deteriorates quickly. Treatment alternatives vary in complexity, efficiency, and efficacy, and range from simple filtration and/or disinfection systems that require little or no maintenance to complex units that need monitoring (Warner, 2006).

GWR systems have the potential to save more water compared to other WDM options but with significantly higher life time carbon emissions (EA, 2010c). The carbon footprint of residential GWR systems can range from 0.5-2.8 tonnes, and 13–47 tonnes for larger multi-residential systems (ibid). The Environment Agency of England and Wales estimates that, with the exception of short retention GWR systems, potentially up to 100 percent more carbon is emitted when using a grey water recycling system instead of mains water (ibid).

The cost-effectiveness of a full GWR system will depend on a number of factors, including household occupancy, volume of water saved, price of mains water replaced, and the costs of installing, running, and maintaining the system (EA, 2011; Table 11). Although great savings have been achieved with many GWR systems under trial, economic benefits are directly related to occupancy levels (Grant, 2006). For single occupancy households, the payback period for a system with representative annual water saving of around 20 percent is more than 50 years for the highest UK water charger (Warner, 2006). At the household level the current payback time on commercially available systems make them unattractive for all but a small number of households who have specific water demand and usage passage (Roaf, 2006).

Table 11 – Mains water offset by grey water recycling systems on different scales (EA, 2010c)

GREY WATER RECYCLING SYSTEM	POTENTIAL GW YIELD (M^3/PR/YEAR)	GW DEMAND, WCS ONLY (M^3/PR/YEAR)	GW DEMAND, WC AND LAUNDRY (M^3/PR/YEAR)	GW DEMAND, ALL (M^3/PR/YEAR)
Residential (3 occupants)	101	32	52	57
Multi-residential (160 occupants)	1, 093	667	1, 059	1, 059
Community scale (900 occupants)	1, 337	N/A	3, 119	N/A

2.2.2.2. Rainwater Harvesting Systems

Rainwater harvesting (RWH) is the process of collecting, diverting, and storing rainwater from an area (usually roofs or another surface catchment area) for direct or future use. Rainwater harvesting does not necessarily reduce water demand, but it can reduce water abstraction needs (EU, 2007), the demand for mains water and relieve pressure on available supplies (EA, 2010). The concept of RWH is not new, and before mains supply became the norm, rainwater was collected and used for laundry, washing up and cleaning (EA, 2010). RWH is receiving renewed interest as a source of water supply in many parts of the world due to economic, operational and environmental difficulties associated with centralised mains water systems and increase in water demand due to population growth (Fewkes, 2006).

Rainwater has been used as the main or supplementary source of potable and/or non-potable water supply in situations where centralised piped systems are uneconomical due to low population density and/or the unreliability or poor quality of groundwater supplies, for example in rural parts of Australia, Canada and the United States. The governments of these countries consider the use of rainwater harvesting as a viable and ecologically sustainable method of supplementing/substituting supplies in urban areas (Fewkes, 2006). In Europe, Germany is the renowned leader in RWH technology. Over 100,000 RWH systems have been installed in low and high density buildings to meet non potable demand (Butler et al., 2009), and 35 percent of new buildings in Germany are equipped with a RWH system (Butler et al., 2009; EA 2010).

Modern day RWH involves the collection of rainwater directly from the surfaces it falls on, such as roofs and pavements, which would otherwise have gone directly into the drainage system or been lost through evaporation and transpiration (EA, 2010). Properly collected and stored rainwater is generally accepted as suitable for use in WC flushing, washing machines and for garden use (Grant, 2006). If used for WC flushing for example, a RWH system could potentially reduce pressure on mains supply by approximately 39 LCD (26 percent), significantly reducing the average daily use of mains water (EA, 2010). Further savings could be made if harvested rainwater is used for other non-potable use such as washing machines, garden irrigation, and car washing. Where a specific requirement exists, for example where a building cannot access the national grid, harvested rainwater can be bought up to potable drinking water standard by inclusion of additional purification devices (UKRHA, 2011). For example, more than 1 million people rely on rainwater for potable use in Australia, and 20,000 RWH systems have been installed to meet domestic water needs in rural areas of the United States (Butler et al., 2009).

The overall water savings potential of RWH will depend on a number of factors, including: rainfall patterns, the demand for non-potable water, storage volume and duration, the amount of rainwater that can be collected to meet this demand and whether the property is charged by volume of water used (Butler et al., 2009, Table 12). All of these factors have a direct impact on choice of tank size (Butler et al., 2009). The optimum storage tank size depends on rainfall, collection area and the demand for collected rainwater, which in turn depends on the type of building to which the system is applied (EA, 2010c). Energy use for pumping and treating equivalent volume of harvested rainwater is generally higher than for mains water (Grant 2006), which makes some RWH systems more carbon intensive than mains water (EA 2010). However, a number of new energy systems are under trial which show significant promise (D. Butler, personal communication, October 2013).

2.2.2.3. Combined Grey Water and Rainwater Harvesting Systems

It is possible to combine GWR and RWH systems in the same system (FM, 2004), where one or the other of the non-potable sources is insufficient to meet the intended demand on its own (EA, 2011). This has both advantages and disadvantages. The advantage is that the volume of water collected will be greater and will be more consistent in volume than a RWH system (Dixon et al., 1999). The disadvantage is that there will be a greater storage volume than a simple GWR system or RWH system, with the same need for disinfectant (since the water must be treated according to the lowest quality). Additionally, on its own, the overflow from a RWH system can be discharged into surface sewers. However, a combined GWR and RWH system will normally require all overflows to discharge to foul sewer as the two non-potable sources may be mixed in the same tank (EA, 2011).

Table 12 – Mains water offset by rainwater harvesting systems on different scales (EA, 2010c)

RWH SYSTEM SCALES	RAINFALL ZONE	TANK SIZE, LITRES	ANNUAL NON-POTABLE DEMAND MET BY COLLECTED RAINWATER, M^3	% DEMAND MET (NON-POTABLE)	% DEMAND MET (TOTAL)
Residential scale (3 occupants)	Low	1, 000	18	32	11
	Medium	1, 500	26	45	16
	High	1, 850	32	57	20
Multi-residential scale (160 occupants)	Low	15, 000	279	38	13
	Medium	22, 000	401	26	9
	High	30, 000	524	49	16
Community scale (900 occupants)	Low	40, 000	678	22	14
	Medium	50, 000	958	31	19
	High	70, 000	1293	41	26

2.2.2.4. Sustainable Drainage Systems

The construction of roads, paved surfaces and buildings as a result of development increases the amount of impermeable cover and reduces natural percolation of stormwater and infiltration of water into the ground (Butler et al., 2009). The increase in impermeable cover results in less water being available for infiltration into the ground disrupting natural drainage patterns which has a damaging impact on the environment (EA ca., 2007). The traditional approach to drainage systems is not sustainable because natural drainage patterns are disrupted as land is developed (ibid). This is because the traditional approach to drainage design systems is not based on sustainability of the drainage system, but on hydraulic performance which is often associated with the capacity of the drainage system to deal with extreme events rather than evaluation of its total performance (Butler et al., 2009).

Rain falling on impermeable surfaces also rapidly picks up pollutants such as dust, oil, litter, and organic matter, with implications on the quality of groundwater where discharges soak into the ground (EA ca., 2007). These pollutants, if not intercepted, will eventually drain into receiving waters and can cause damage to aquatic life (Butler et al., 2009). The increased rate of surface runoff may also cause soil erosion and sediment build-up in watercourses (ibid).

Sustainable Drainage Systems (SuDS) are a collection of systems and techniques that help manage the quantity and quality of run-off by mimicking natural drainage to better manage the future likelihood of flooding and water quality issues by encouraging natural groundwater recharge, thereby increasing the amount of water available for use (DEFRA, 2009). The collected run-off can be treated for non-potable use. SuDS addresses these issues of drainage systems by managing stormwater locally (as close its source as possible) to mimic natural drainage and encourage its infiltration, retention, and passive treatment (Butler et al., 2009).

SuDS are also used to reduce the negative impacts of development on natural drainage such as flood risk management, improved water quality, protection and promotion of natural habitat and biodiversity, groundwater recharge, reduction in soil erosion rate and subsequent sediment build-up rate in watercourses and creation of recreational features (Butler et al., 2009). The basic requirements of SuDS are that: water runoff from an area following development should be no greater than it was before development; following development there should be no deterioration in downstream water-ways or habitat; and water resource management be integrated into the design of a development from the outset (UKRHA, 2011).

SuDS provide a number of options for draining an area, which fall into three broad categories: (i) source control and prevention techniques; (ii) permeable conveyance systems; and (iii) end of pipe systems (EA ca 2007). Some SuDS techniques fall into more than one group. For example, attenuating flow and providing treatment (ibid). Source control and prevention techniques such as green and blue roofs, permeable surfaces RWH systems and infiltration basins/trenches are designed to counter increased discharge from developed sites, as close to the source as possible and to minimise the volume of water discharged from the site (ibid). This reduces the risk of flooding by increasing the retention and control of surface/storm-water (EA, 2011). Permeable conveyance systems such as filter drains and surface water swales move runoff water slowly towards a receiving watercourse allowing storage, filtering and some loss of runoff water through evaporation and infiltration before it reaches the discharge point (EA ca., 2007). End of pipe systems use natural processes to remove and break down pollutants from surface water runoff. Stormwater from SuDS can be considered as a valuable water resource and harvested and recycled for non-potable uses (DECNSW, 2006).

SuDS techniques can be adopted for most new and redeveloped sites to give a reduced environmental impact from surface water drainage (EA ca., 2007). A wide variety of off-the-shelf SuDS solutions such as soakaways and RWH systems are readily available commercially, which quite simply are designed to avoid, or delay (giving drainage infrastructure more time to cope), more rain-water leaving a site post-development than before (UKRHA, 2011). Although the effectiveness of RWH systems as a demand management option is fairly established, the information on the quantification of benefits which RWH systems could offer as a stormwater management option is limited (Butler et al., 2009).

2.3. Household Water Use Assessment

Several methodologies have been developed by researchers, government agencies, consumer groups, and WSPs for assessment of WDM interventions, including AQUACYCLE (Mitchell et al., 2001), UWOT (Makropoulos et al., 2008), CWB (Mackay and Last, 2010), and UVQ (Mitchell and Diaper 2010). Other methodologies that assess the performance of household water and energy use such as the UK Code of Sustainable Homes (DCLG, 2006) and the Sustainable Building Alliance (Crowhurst et al., 2010) do so in isolation of each other, and provide no means of assessing the inevitable trade-offs that could result between different performance indicators. Most of these methodologies also do not consider water-related energy use as a component of the performance of either energy or cost savings and cannot be used to assess the extent to which household water savings can fully affect energy use.

Various tools have been developed based on the methodologies above, such as the UK Bathroom Manufacturers Association (BMA) Water Calculator can be used to assess household water and energy use as set out in the “Water Efficiency Calculator for New Dwellings” (DCLG, 2009). The BMA calculator employs the Water Efficient Product Labelling Scheme (WEPLS) database to obtain information on water consumption for hundreds of products. The calculator produces a report providing the total water consumption and the breakdown per appliance based on the data a user provides. The Energy Saving Trust (EST) water energy calculator is another UK-based tool that can be used to provide a household’s total annual water and energy consumption; breakdown of water use per appliance; a comparison with average UK figures; and recommendations on how to improve household water and energy efficiency (EST, 2013). The Australian Water Usage Calculator can be used to estimate annual household water consumption and provide a plan save water, money and the environment (HW, 2013).

In the US, the Environmental Protection Agency (EPA) WaterSense calculator provides estimates of the amount of water and energy that can be expected to be saved by installing household WaterSense labelled micro-component appliances and fittings, household occupancy and other simple inputs (US EPA, 2013). The Water-Energy Toolkit can also be used to reduce carbon footprint through water efficiency in the US (Griffiths-Sattenspiel, 2010). Another US-based too, the Water-Energy-Climate Calculator (WECalc), can be used to estimate water consumption and water-related energy use and associated GHG emissions based on water-using habits (Allen et al., 2010). WECalc provides personalised recommendations to improve efficiency. Like many other tools, WECalc is only suitable for US households as it requires the zip code to determine the rate of evapo-transpiration, the inlet water temperature and GHG emissions from electricity generation using state averages.

The National Geographic's Change the Course water calculator uses conditions of household water appliances and user habits; dieting habits, transportation and energy related habits; and habits related to the products and services that a user purchases (to calculated embedded water use) to provide the overall water consumption profile of a person (not the household) (NG, 2013). The calculator encourages users, if they use more water than average, to pledge using even less water in one or more areas of daily life. Companies can sponsor the restoration work that puts water back into the Colorado River for each pledge made. The Water Consumption Calculator uses details about frequency of use and duration of use of water using appliances to provide a breakdown of household water consumption per appliance to provide a comparison with the average household water consumption of the local area (CSGNetwork, 2013). The Home Water Works Water Calculator can be used to estimate household water use and a comparison with average and efficient household water use in the same region (HWW, 2013). The calculator also provides an estimate of energy use and carbon footprint of hot water usage, which can be used to identify actions that can improve overall household water efficiency.

A comparison of the tools above is provided in Table 13 below. The following general conclusions have been drawn regarding the tools reviewed above. The tools have been designed to be simple, requiring minimal information that is meaningful to the average household water user. Most of the tools attempt to estimate household water consumption using average values of duration and frequency of use of various water appliances. The tools focus on a relatively narrow target group (usually the customers of the WSPs or water users of specific countries or even localities) and include only those options applicable to specific target groups. As such, the application of the tools to other cases than the ones for which they are intended for could prove problematic because of variations in water using appliances and habits.

Most of the tools reviewed do not take into account the climatic conditions for estimating the contribution of rainwater harvesting. Only one tool does this but the approach used is simplistic and also requires specialised technical information. If RWH scheme is to be studied, both the depth and the distribution of the annual rainfall play an important role in the efficiency of the scheme. As such, the tools that do not take both into account cannot provide reliable results.

Table 13 – The comparison of tools for assessing household water

	DEVELOPER	OBJECTIVE	PROS	CONS
The Water Calculator	Bathroom Manufacturers Association, Newcastle-under-Lyme, UK	Support the calculations described in Part G of the Building Regulations and the Code for Sustainable Homes	Uses WEPLS database to provide easy access to characteristics of water appliances. Rainwater/grey water applicable to arbitrary geographical region.	Requires from the user to contact the supplier or manufacturer of the rainwater/grey water system to get some required data.
WeCalc	Pacific Institute California, USA	Motivate consumers to save water and energy at home.	Suggests predefined values in text boxes to be used wherever user is unsure. Provides fixed options in drop-down menus to facilitate/ standardize data input. Provides targeted suggestions for improving the efficiency.	Does not provide option to estimate the contribution of rainwater/grey water recycling. This calculator is set up for use in the United States only Non SI units (gallons, **Fahrenheit**).
Water-Energy Toolkit	River Network, Portland, USA	Estimate how much water/ energy can be saved if toilet/ shower are replaced with modern ones.	Simple, quick and easy to use.	Separate tools for different water appliances (no integration). Non SI units (gallons).

WaterSense	United States Environment Protection Agency	Estimates the amount of water and energy that you can expect to save by installing WaterSense labelled products.	Simple, quick and easy to use.	Targeted only to faucets and toilet. Non SI units (gallons, lbs).
Water Energy Calculator	Energy Saving Trust, UK	Calculate the water bill and the energy cost from water use.	Appealing and friendly user interface. Comprehensive report on household profile and potential improvements, all downloadable in a pdf format. After initial assessment, allows investigating potential interventions to individual appliances to estimate the potential benefits.	Simplistic rainwater harvesting approach (only existence or not of a water butt).
Change the Course	National Geographic	Raise awareness on the restoration of freshwater ecosystems	Friendly interface. Human water profile taking into account the total water-cost of typical human actions.	No information about assumptions and methods. Non SI units (gallons).

Water Consumption Calculator	CSGNetwork, Palm Springs, California, USA	Calculate water consumption of a household.	One-screen/one-step fill-in form.	Requires information (frequency of use and duration of use) that cannot be estimated correctly by the average user. No rainwater/greywater recycling. No SI units (gallons).
Home Water Works Water Calculator	Alliance for Water Efficiency, Chicago, USA	Examine which water uses in a household are efficient and which are not.	Appealing and friendly user interface. Comprehensive report on household profile and potential improvements.	No rainwater/greywater recycling. Non SI units (gallons, square feet)
Water Usage Calculator	Hunter Water, Newcastle, Australia	Motivate customers to save water and money.	Friendly interface with simple questions to be answered.	Not detailed consumption break-down No rainwater/greywater recycling.

2.4. Case Study – Scenario Assessment of Household Water Savings

A scenario assessment of hypothetical household water savings under two different EU climatic conditions – Oceanic and Mediterranean – has been carried out using some of the tools described above in section 2.3 in order to demonstrate their practical application. Different tools have been used for the two climatic conditions considering that most of the water calculators are only suitable for the region they have been developed for. The BMA calculator, which uses the intermediate approach of the BS8515 (2009), has been used to assess household water savings under Oceanic climatic conditions; and the Urban Water Optioneering Tool (UWOT) (Rozos and Makropoulos, 2013) has been used to assess household water savings under Mediterranean climatic conditions. The time-series of rainfall for Mediterranean climatic conditions were obtained from a weather station in former Athens international airport (Freemeteo, 2013b). Three alternative water saving scenarios:

- A Business As Usual (BAU) scenario, which considers no water recycling scheme
- A RWH scenario, which considers rainwater RWH systems
- An GWR scenario which contains both GWR and RWH systems

All three scenarios were investigated assuming both conventional and BATNEEC household micro-component appliances and fittings. The EST water calculator was used for the BAU scenario because it is comprehensive and closer to EU conditions. The hypothetical household is assumed to have only one occupant (to directly obtain results corresponding to water and energy consumption/person.year). The household is assumed to have, no bath, no garden and no outside uses. The BMA water calculator was used for RWH under Oceanic climatic conditions and UWOT was used for Mediterranean climatic conditions.

The specifications of the conventional and BATNEC household micro-component appliances and fittings used in the BAU scenario are provided in Table 14 above. The inputs to the EST Water Calculator for the appliances and fittings used in the BAU scenario are given in Table 15, and the results of the simulations of EST Water Calculator and UWOT (annual potable demand and consumed energy in water related appliances) are given in Table 17.

Table 14 – Micro-component appliances and fittings in BAU scenario.

	CONVENTIONAL	BATNEEC	FREQUENCY OF USE (USE/PERSON.DAY)
WC	9 L/use	4.4 L/use	5.25
Washbasin	6 L/use, 0.09 kWh/use	6 L/use, 0.09 kWh/use	2.00
Shower	60 L/use, 2.23 kWh/use	35 L/use, 1.05 kWh/use	0.71
Kitchen sink	10 L/use, 0.15 kWh/use	10 L/use, 0.15 kWh/use	2.25
Washing machine	100 L/use, 1.14 kWh/use	45 L/use, 0.93 kWh/use	0.16
Dishwasher	35 L/use, 1.05 kWh/use	18 L/use, 1.05 kWh/use	0.21

Table 15 – BAU scenario input in EST Water Calculator

		CONVENT.	BATNEEC
WM	How many times do you use your washing machine per week?	1	1
	What temperature do you generally wash your clothes at?	40C	40C
	What is the energy rating of your washing machine?	B	A+
	Do you fully load the washing machine before using it?	Yes	Yes

DW	How many times do you use your dishwasher per week?	1	1
	How old is your dishwasher (bought before or after 2000)?	Pre 2000	Post 2000
	Do you use the eco setting?	No	Yes
	Do you fully load the dishwasher before using it?	Yes	Yes
KS	How many times does your household wash up by hand each week?	1	1
	Do you use a bowl for washing up?	No	No
SH	What kind of shower do you have?	Std. Mix.	Electric
	How many showers does your household take per week?	5	5
	How many minutes, on average, does one shower last?	7	7
	Do you have a low flow or eco shower head?	No	No
WB	Do you leave the tap running when you clean your teeth?	Yes	No
	Do you ensure taps are fully turned off to prevent drips?	Yes	Yes
	Do you have tap inserts?	No	Yes
WC	When was your toilet manufactured?	1940-80	Post 2001
	Does your toilet have a dual flush mechanism?	No	Yes

Table 16 – Results of EST Water Calculator and UWOT

	CONVENTIONAL	BATNEEC
Calculator Water (l/yr.)	52760	34943
Calculator Energy (kWh/yr.)	888	580
UWOT Water (l/yr.)	53911	34102
UWOT Energy (kWh/yr.)	914	596

The BMA Water Calculator was used to estimate the water saving potential of RWH for the RWH scenario (Table 17). In the RWH scenario, rainwater collected in the roof (100 m^2 total area) is stored in a local tank to cover the demand of the WC flushing and washing machine. This demand was calculated based on the consumption per usage and frequency of use values provided in the corresponding table of the previous section at 63 L/day for conventional micro-component appliances and fittings. The amount of rainwater collected per person daily is 81 L/day, and the rainwater savings (litres/person.day) is 63.3 L/day, or 20,805 L/yr. This amount subtracted from the 52,760 L/yr (demand of conventional water micro-components as estimated in the previous section by the EST Water Calculator) result in 29,673 L/yr. Following a similar procedure for BATNEEC (rainwater demand is 30.3 L/day for BATNEEC micro-components) the result is 23,883 L/yr.

The household water network under the Mediterranean climatic condition was simulated with UWOT to estimate the potable water demand, required energy (see results in Table 18) and water level fluctuation inside the local tank. If the amount of stored water exceeds the capacity of the tank, the tank spills. If there is no water inside the tank then the tank fills with water from mains to cover the demand of washing machine and WC flushing. Therefore, ideally the tank should not get empty and should not spill. To facilitate the choice of the optimum capacity of local tank, a series of simulations were performed (manual calibration).

The fluctuation of water storage inside the local tank (according to UWOT simulation) for Mediterranean (Csa) and Oceanic (meteorological data for Cfb obtained from Freemeteo, 2013a) climatic conditions (Figure 4), conventional micro-components and 50 percent green roof coverage. From this figure is apparent that for Cfb, 9000 L is the minimum required capacity to always have rainwater inside the local tank. However, concerning the

Mediterranean climatic conditions, a tank with 15000 L capacity is required to store all harvested rainfall, which yet do not suffice to cover the demand during the summer period.

Table 17 – Inputs used in the BMA Water Calculator for the RWH scenario

A. COLLECTION AREA (M^2)	100
b. Yield co-efficient and hydraulic efficiency	0.36
c. Rainfall (average mm/year)	820.9
e. Percentage collected (%)	100
f. Number of occupants	1
h. Rainwater demand (litres/person/day)	63.3

Table 18 – The results of UWOT simulation and BMA Water Calculator

	CONVENTIONAL	BATNEEC
Calculator Water (L/y)	29673	23883
Calculator Energy (kWh/y)	888	580
UWOT Water (L/y)	30824	23042
UWOT Energy (kWh/y)	948	612

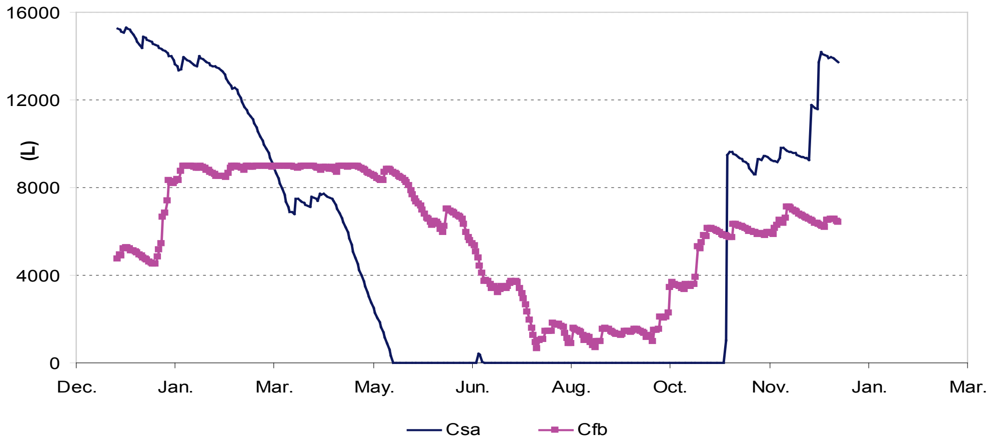

Figure 4 – Simulated water level inside local tank for Mediterranean (Csa) and Oceanic (Cfb) climatic conditions.

In Mediterranean climates a GWR scheme could be used alone or in combination with RWH. The capacity of the local treatment unit should be sufficient to treat the output of hand-basin and shower. The daily water consumption of hand-basin and shower (1 occupant) is 54.60 L/d for conventional or 36.85 L/d for BATNEEC micro-components. Therefore the maximum amount of water that can be recycled with the local GWR treatment unit is 19,929 L/y for conventional or 13,450 L/y for BATNEEC. The maximum amount of recycled water that can be used inside house (i.e. demand of washing machine and WC) is 63.25 and 30.30 L/d for conventional and BATNEEC respectively (23,086 and 11,059 L/y).

Table 19 gives the estimated potable water demand and energy consumption of a household in Mediterranean region that implements only GWR. It should be noted that the energy is slightly increased, compared to the BAU, because of the energy consumption of the local treatment unit. The annual water consumption for conventional micro-components is 33,982 L, i.e. slightly higher than 30,824 L (see Table 18) which is the annual consumption in RWH under Oceanic climatic conditions. On the other hand, the annual water consumption for BATNEEC equals that of RWH under Oceanic climatic conditions (23042 L). This is because the recycled grey water suffices to cover the demand of WC and washing machine for BATNEEC, but is slightly lower than the demand of the conventional micro-components.

Evidently GWR alone is good choice for Mediterranean climatic conditions either using conventional or BATNEEC appliances. The combination of GWR with RWH is advantageous only if recycled water is going to be used for irrigation also. Then, harvested rainwater can be used to minimise or eliminate any increase of potable water demand.

Table 19 – Water consumption of a household implementing GWR and RWH.

	CONVENTIONAL	BATNEEC
UWOT Water (l/y)	33982	23042
UWOT Energy (kWh/y)	1051	715

3. DEMAND MANAGEMENT: WATER SERVICE PROVIDERS

3.1. Introduction

Not all water produced reaches customers, which implicitly limits the extent of savings that can be made from customer-side WDM interventions like water efficiency. Reducing water losses from WDS can also significantly lower water demand as well as result in a decrease in the cost of production and distribution of water as well as in the capacity requirements for storage systems, treatment works, and mains sizing (Trow and Farley, 2006). Ageing infrastructure represents a further challenge as it exhibits increased risk of leakage over time. Given the pressure-dependent nature of much leakage in WDSs, it is imperative to reduce the operating pressures in the network as far as possible to reduce the volume of water lost to leakage whilst continuing to maintain the minimum operational pressure requirements throughout the network (Awad and Kapelan, 2008). This, along with other WDM interventions such as water pricing, metering, tariff structures, and soft interventions that WSPs can use to reduce/manage water loss between the source of production and the customer meters are explored in this section.

3.2. Water Pricing, Metering and Tariff Structures

3.2.1. Water Pricing

Water pricing can be used to reduce water demand. The introduction of two key economic principles in the Water Framework Directive (WFD) has brought a new approach to water management for many EU countries (EC, 2008). The first principle requires that water users pay for the cost of water services they receive at a price which fully reflects the services provided. The price for water should cover the operation and maintenance costs of its supply and treatment and the costs invested in infrastructure and any associated environmental impacts. This is based on the assumption that pricing can incentivise efficient use of water resources, and that if users pay the real costs of water they will certainly waste less of it (EC, 2008). The WFD also requires an affordable price to guarantee a basic level of domestic water supply (EEA, 2008). This principle also allows for the environmental costs of water supply to be reflected in the price of water (EEA, 2003). The second principle requires the use of economic instruments in the management of water resources and to assess both the cost-effectiveness and overall costs of alternatives when making key decisions (EC, 2008). The WFD also obliges the use pricing for water-related services as tool for promoting water conservation (EEA, 2003).

To meet the increasing requirements of the WFD and public expectations for high water quality, WSPs increasingly have to use complicated and high-technology treatment plants to supplement simple, natural processes for treating drinking water with additional cost borne by WSPs (EEA, 1999). The quality of the water supply therefore has a great influence on water prices, as the expenditure necessary to purify drinking water is determined by the quality of the raw water (Piotrowski, 1998). The cost of water in Europe varies. Some countries, like Germany and the Netherlands, as well as England and Wales have prices that are relatively high. Countries such as Italy and Spain, in which there is still a high level of state subsidy have lower prices per cubic metre. France falls between these two (ibid). There has been a general trend towards higher water prices in real terms throughout Europe over the past 20 years (EEA, 2008), with wide variations in water charges within individual countries (Figure 5).

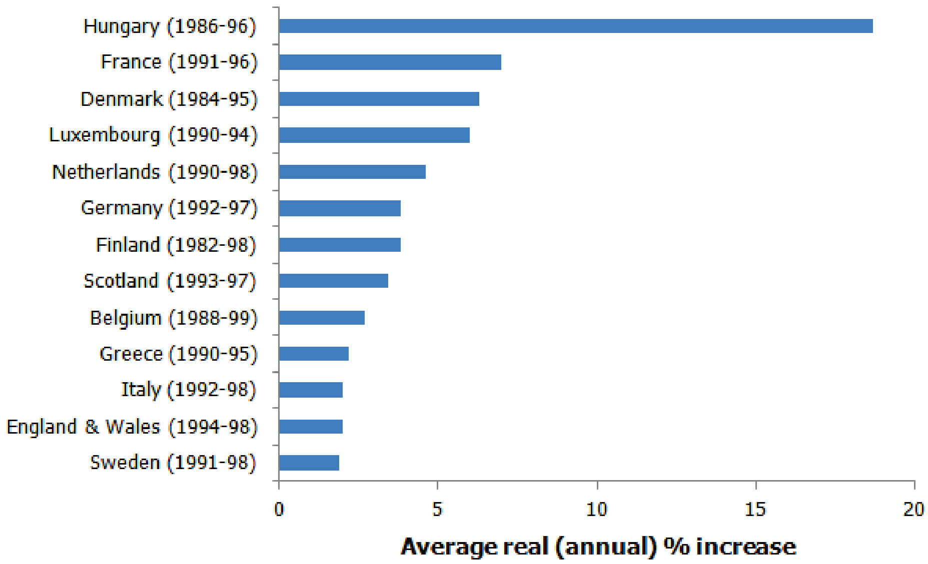

Figure 5 – Average household water and sewerage bills price (water only for Germany and Luxembourg) trends in Europe (OECD 2004)

Increasing water prices is an important measure that can enable behavioural changes to water use (EA, 2003b) as economic instruments are only effective when consumers can actually benefit by responding to the increased charge by reducing consumption (EEA, 1999). Several studies have demonstrated that rising water prices for domestic consumers have a positive effect on both indoor and outdoor water conservation efforts and immediate savings from the introduction of revenue-neutral metering are estimated to be about 10–25 percent of consumption. However, these figures disguise the fact that the impact of water services charges tends to be much more significant for the poorer section of society than for the more affluent sections (EEA, 1999). As such charges will generally hit the poorer population proportionately harder than the other consumers (ibid). Therefore, it is necessary to make economic decisions compatible with social objectives (EEA, 2001a). Keeping costs down, while ensuring companies can make a fair return on their investments is considered the most effective way of ensuring people can afford their water bills (Walker, 2009).

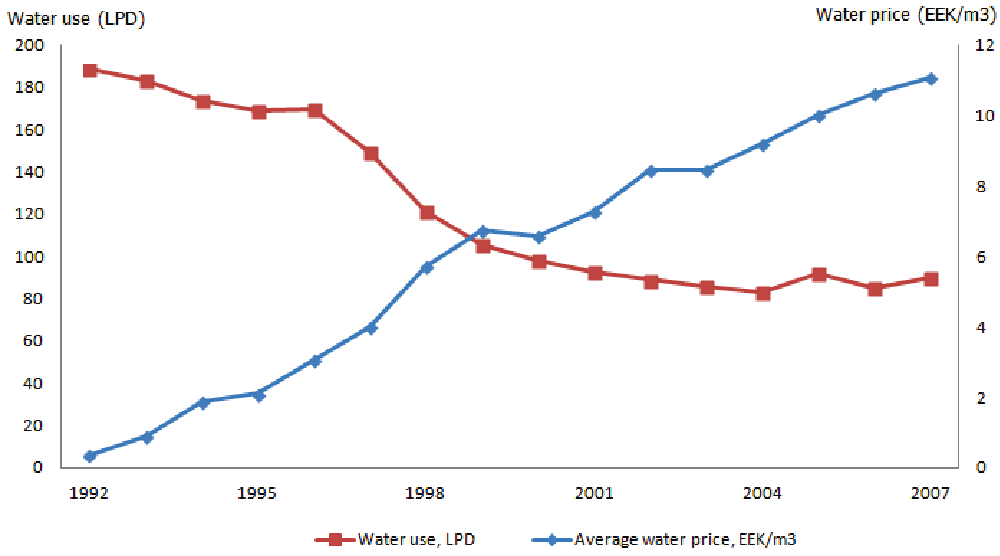

Figure 6 – Domestic water price vs. water use in Estonia (EEA, 2011)

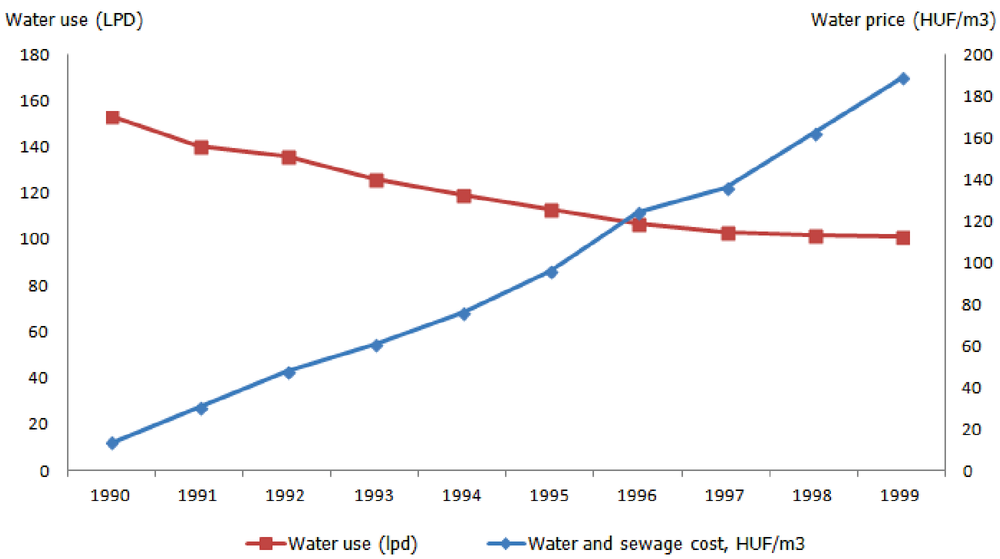

Figure 7 – Domestic water and sewerage costs vs. water use in Hungary (EEA, 2011)

There is also evidence that increase in water price has significantly decreased household water use in several countries. For example, the removal of heavy water subsidies in many eastern European countries during their transition to market economies resulted in significant decrease in water use (EEA, 2008). In the Czech Republic water use fell 55 LCD when above inflation charges were introduced to cover operating costs (EEA, 2003a). In

Estonia a fivefold increase in water prices has led to more than 50 percent reduction in domestic water use in the last 16 years (Figure 6). A reduction of water demand of about one-third has also been observed in Hungary after the removal of subsidies and an increase in price (Figure 7).

3.2.2. Water Metering

Measuring water consumption is a prerequisite for water pricing to have any effect on water demand. Metering therefore also has a role to play in encouraging households to reduce water consumption. In some cases, such as in Denmark, Germany, and Switzerland meter readings are also used to calculate a pollution tax, on the basis that the amount of water used indicates the discharge to the sewage treatment plant (EEA, 2001a). Metered households nearly always use less water than those who pay a flat rate charge (EA, 2008), as metering provides a financial incentive to make better use of resources and save water (EA, 2007d).

Research suggests that metered households use around 10–25 percent less water than unmetered households (DEFRA, 2008). However, the impact of metering on water use is difficult to separate from other factors, in particular the water charges applied as the introduction of metering is usually accompanied by a revised charging system and regulations on leakage (EEA, 2001a). However, it has been argued that this figure does not stand up to scrutiny as many of the countries with the highest meter penetration are also those with the highest water consumption (e.g. Canada and the USA), whilst many of those with the lowest penetration have the lowest water consumption (e.g. England) in world terms (Staddon ca., 2010).

Additional costs are incurred by installing meters (Figure 8), including: (i) installation of the meter and the financing of installation costs, (ii) costs of replacing the meter when it wears out, (iii) costs related to meter reading, and (iv) costs of additional billing and handling of customer queries over and above the costs of unmetered charging (Walker, 2009). Water meters turn out to be a relatively expensive way to save water – even allowing generous assumptions about water savings as compared with household fittings (Staddon ca., 2010).

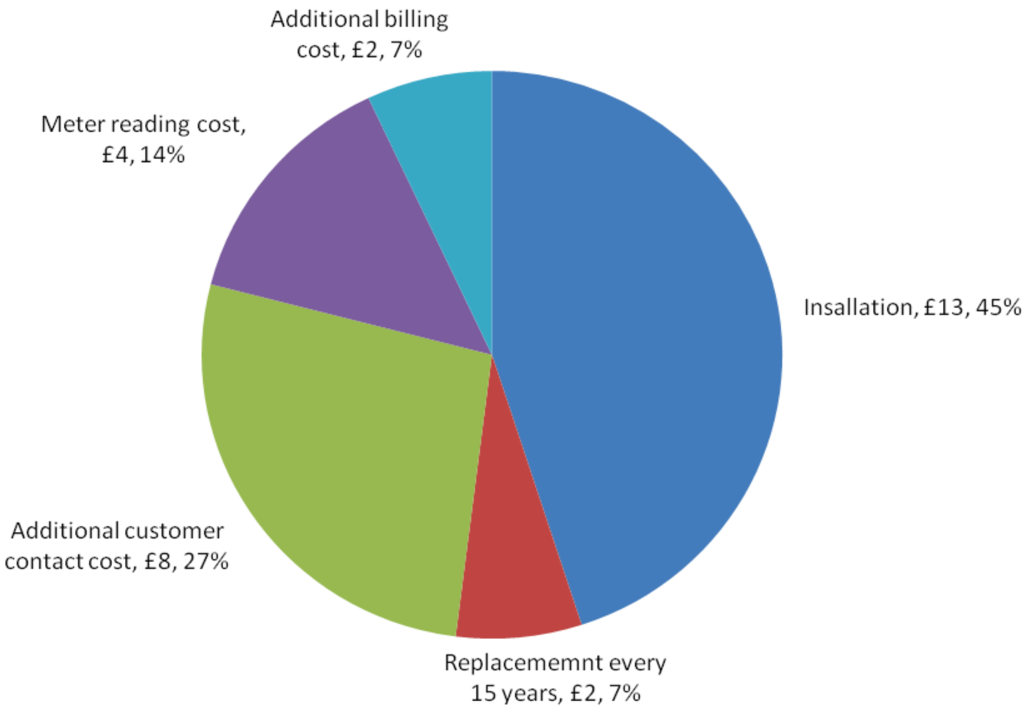

Figure 8 – Typical effects on bills for household measured charging based on installation of a simple meter (Walker, 2009)

There are many benefits that can be derived from household metering, such as information on consumption to customers and WSPs and the identify leaks in customer supply pipes which would otherwise have gone unnoticed (Walker, 2006). Water savings from metering can represent average total water saving of around 25 LCD. This can translate into considerable water saving of about 16 percent of average household demand which can significantly reduce the effect of water abstraction on the environment, make water available for other uses, and can reduce/delay future expenditure on increasing supply or expanding the system's capacity (ibid).

3.2.3. Innovative Tariff Structures

Many studies have shown that metering may achieve little by itself, and needs to be considered in tandem with meaningful water tariff structures (Staddon ca., 2010). Domestic water users can be charged based on a flat rate tariff system or volumetrically, i.e. according to the volume of water actually used or (EEB, 2001). The flat rate tariff system involves applying a uniform charge for all households and is the simplest charging arrangement and the cheapest system to administer (Walker, 2009). This can be based on the number of people living in a household, and is in line with charging based on volume of water usage without meter installation.

However, data on occupancy is not usually available in most countries for this to be feasible, and relying on voluntary disclosure is impractical because it could be open to deception and subject to constant changes making enforcement extremely difficult. Additionally, occupancy is not the only indicator of usage and other factors such as garden watering, water using appliances and fittings, and customer behaviour can have significant impact on water consumption. Unless these other factors are also taken into account, water bills would not match usage for a significant number of customers.

In countries where water is metered and the metering coverage wide, the water charge is related to the volume of water consumed (EEA, 2001a). A tariff based on volume of water use is considered to be the fairest approach to water charging. This is thought to incentivise water saving, as opposed to non-volumetric tariffs such as flat rate tariffs occupancy do not necessarily incentivise water saving. Charging on the basis of water consumption requires a meter to be installed to the customer's supply pipe and read periodically.

Metering allows a much wider range of tariff structures. The choice of tariff structure influences how the total costs of the services are recovered from customers, and how customers are likely to behave (Walker, 2009). The most common metered tariff is a two-part tariff with a standing charge that is the same for all customers, and a volumetric charge that depends on the volume of water used by each household (ibid). More sophisticated tariff structures, like those used in the energy sector, can provide different incentives to customers and distribute the costs across customers in different ways (Walker, 2009). These include:

- Rising block tariff which uses a tiered billing structure that charges different rates for different blocks of use, e.g. low charge for essential use and higher charges for each subsequent block of water used.
- Declining block tariff which sets lower unit prices for each subsequent block of water used. It can be used to reduce bills for very high users and although it weakens incentives for them to reduce discretionary water use, it can reflect the economies of scale from bulk supplies for high water users.
- Seasonal tariff with differential summer and winter rates and a fixed date on which the rates change to reflects additional costs of seasonal water supply, or a seasonal rising demand tariff with the winter period determining the household's essential use.
- Time-of-day tariff where the unit rate varies according with the time of the day when the water is used. Such tariffs are usually used when peak demand at certain times of the day causes or will cause additional costs to the supplier, typically by requiring investment in additional sources of supply or additional pumping.
- Social tariffs should be considered in situations where there are concerns about affordable water supplies. In one area of Belgium, for example, 'free minimum' amounts of water (first 15 cubic metres) to poorer households are based on the number of people living in that household rather than on the household as a unit, which is more commonly the case (EEA, 2003b).

The bulk of the meters currently being installed in many places would not allow the use of more sophisticated tariffs such as those seasonal or time-of-day tariffs that require all meters to be read more frequently, or all read over a relatively short period of time (Walker, 2009). Smart meters would allow such a use as they can store data and/or be interrogated remotely (ibid). Reading smart meters is cheaper than reading simple meters, although this must be balanced against the higher cost of the meter and any telecommunications network costs involved (ibid).

3.3. Soft Interventions

Substantial water savings can also be achieved by using soft WDM interventions which aims to modify personal water use behaviours and habits through campaigns to raise awareness of the public for the need to save water (Grant, 2006). It is estimated that soft WDM interventions can result in significant reductions in water use as most reductions in water consumption often result from consumer behavioural changes such as taking shorter showers, turning the tap off whilst brushing teeth and only running washing machines and dishwashers on full loads (AWE, 2010). Soft interventions can also be used to better inform technical research agendas, WDM strategies, and policies (Doron et al., 2011).

The successful implementation of WDM intervention requires commitment from the local water utility and its customers, as well as the required political will and leadership from governments to generate consensus and provide suitable legislation (Inman and Jeffrey, 2006). The social acceptability by a range of stakeholders such as water users, WSPs, policy makers, and regulators is a key barrier as well, as uptake requires public participation (Ward et al., 2011). However, the social acceptability of soft interventions can be a major hurdle because the public is quite often resistant to changing established patterns of water use.

Individual perceptions of changes in water behaviour are constrained by habit and lack of knowledge about what changes can be made and how (Doron et al., 2011). These underlying perceptions make it more difficult to achieve changes in water use behaviour (Butler et al., 2009). Change in public behaviour cannot be forced however, but must be delivered through incentives or persuasion as they are more likely to happen if they match the context of users' lives (Butler et al., 2009). WDM programs need to be designed form the analysis of what motivates people to take action and change behaviour (Smout, Kagaya 2008). Public opinion can be influenced by effective public awareness and education campaigns that highlight the need for water efficiency amongst consumers and can play an important role by modifying the behaviour of water consumers and increasing the social acceptability of WDM interventions.

Different types of public awareness and education campaigns are needed to engage and appeal to different stakeholders to ensure maximum behavioural change and prevent the risk of alienating some segments of the population (CCW, 2006a). As such, a multi-strand campaign that aims to educate, enable, encourage, and inform the population, whilst working towards the ultimate goal of facilitating behavioural changes or developing informed action should be used (CCW, 2006b). This can be done using different tools (Jeffrey and Geary, 2006): (i) social marketing campaigns such as public broadcasting announcements, brochures and hand-outs, billboards, public displays, slogans, bill inserts, internet sites, door-to-door campaigns, celebrity endorsements, newspaper articles, and radio/television programs; (ii) published materials such as 'how to' manuals, case studies, technical reports, resource libraries; (iii) school materials such as activity books, interactive games, videos and CDs, poster contests, in-class visits, teaching guides; (iv) competitions, awards and recognition programs; (v) education centres; (vi) one-on-one meetings with major water users; and (vii) workshops with specific water users. School programs in particular are important for influencing short- and long-term water conservation as any behavioural changes that result from this are often shared with adults in the household and readily implemented (SWITCH, 2011).

The main objective of these types of campaign should be to inform and educate the public about the need to use water efficiently, the benefit of reducing water consumption for the individual in view of the overall water resources situation in the community, catchment area and globally, the liabilities that will result from not reducing water consumption, and the actions needed to achieve water saving goals (AWE, 2010; SWITCH, 2011). Public awareness campaigns should ideally be aimed at individual behaviour change, which requires a high critical mass and takes time before results are noticeable (CCW, 2006b).

Behavioural change campaigns can only be truly effective if they are clear what specific behaviour they are trying to change and the desired outcomes (WWF, 2009). Additionally, to be effective, the campaigns should be planned out and implemented in a consistent and continual manner (SWITCH, 2011). Another important part of such campaign should be to provide information on specific actions and measures water consumers should undertake and inform the target audience of positive changes these actions have caused, encouraging greater participation in WDM programs (ibid).

Different people will have different motivations to save water, and an understanding of these motivations can allow the use of different types of communications for different people (WWF, 2009). This requires a good understanding of how people learn and how they are motivated (CCW, 2006b). Moreover, for this these campaigns to be effective, behaviour in both in the style of water use and the nature of the water-using facilities installed must be modified (McDonald et al., 2011). At the crudest level, this can, in theory be driven by price through metering and tariffs (ibid). For example, comparison of attitudes and behaviour amongst metered and unmetered customers suggests that positive effects are possible from metering (CCW, 2006a). However, it is not known if this is because metered customers are more water efficient than unmetered customers (CCW, 2006a).

Both psychological and facilitating factors should be used to aid actual behavioural change regarding water consumption. Psychological factors can put people in the right frame of mind to alter their behaviour and could include convincing the public that there is a need to save water and that water efficiency could lead to other savings such as energy and money. There is evidence to suggest metering could also be used to psychologically put people in the right frame of mind to be water efficient. Facilitating factors involve putting people in a position to be able to alter their behaviour. These could include providing customers with information on water use by comparing their bills with average bill-payers, motivating water efficiency through education, and/or public awareness campaigns, and providing information on the availability and performance of low-cost water saving devices and retrofits (CCW, 2006a). Demographic, as well as psychographic considerations that dictate peoples' willingness and/or ability to take action should also be taken into account when developing campaigns targeting different types of behaviours (CCW, 2006b).

Research carried out by the Consumer Council for Water (CCW) in England found that people recall television adverts, bill inserts and newspaper articles and adverts, with people recalling television adverts the most. A significant number of people felt they were most receptive to messages in newspapers and on the Internet (Table 23). However, the same research also found that only a limited amount of change was evident in consumers' attitudes as a result of their exposure to information campaigns even though in most cases people displayed a greater awareness and ability to discuss issues in more detailed terms (CCW, 2006b).

Table 20 – What types of adverts stick in memory in general? (CCW, 2006a)

MEDIA	PERCENTAGE*
TV adverts	65
Radio adverts	10
Magazine/newspaper articles /adverts	19
Celebrity endorsement campaigns	7
Billboards	9
Other	18

* Multiple responses

The most common use of awareness campaigns is to obtain immediate behavioural change in times of water shortages such as seasonal drought or water supply interruptions (AWE, 2010). These temporary shortages often highlight the need for efficient water use and increase social acceptability WDM interventions. There are documented cases where public awareness campaigns have resulted in very effective results in reducing water use during times of crises, with some WSPs in the United States reporting reductions in water consumption by more than 20 percent after such campaigns (ibid). However, these behavioural changes have been found to wane over time, usually losing all effect in less than a year even when the campaign continues (ibid). Therefore, despite the initial effectiveness, public awareness campaigns alone cannot be considered sufficient for effective long-term WDM strategy, as the public still need to be willing and able to reduce their water consumption.

Understanding consumers' capacity for change is essential in underpinning any WDM programme (Doron et al., 2011). Campaigns that seek to change behaviour must be underpinned by the right services and infrastructure such as regulatory incentives and water efficiency products and services that are socially acceptable and easily available (WWF, 2009). A low awareness of water use is one of the key barriers to sustainable water efficiency. Most people simply do not know how much water they use and how much of it is wasted. The actual source of water, as well as what happens to it once it has been used, is even more vague (Doron et al., 2011). This is mainly due to the relatively low cost of water compared to other utilities (such as energy) and the perception that it is plentiful (Jeffrey and Geary, 2006), and a general lack of understanding of the environmental and energy impacts of centralised mains water.

Using financial incentives to promote participation therefore may not be the most effective strategy (Butler et al., 2009). It was found that reducing water bills to encourage residents to try new technologies can offer a strong incentive, but the effect is temporary (ibid). Even where water meters are installed in all households, some generally tend not to read them nor monitor their consumption (ibid). Research indicates that most people will do more to save water if they thought their WSP was doing more in reducing leakage and/or improving collection and storage of water, water saving devices were cheaper, and more easily available and information on how to conserve water was more easily available (CCW, 2006a).

People generally fall into four broad categories according to their willingness and ability to change their water using behaviour. These categories are (i) willing and able, (ii) willing but unable, (iii) unwilling but able, and (iv) unwilling and unable to change behaviour (CCW, 2006a). Campaigns should engage and build awareness of people who are unaware or disbelieving of the need for water efficiency as a first priority. Those who are 'unwilling but able' to affect change need educating, and provided with further evidence of the need to save water in order to convince them to take action. Those who are 'willing and able' to take action need continual encouragement as with encouraging such people can also have a significant influence over other consumers, who trust them to provide unbiased testimony. Finally the public need to be continually informed of how their actions fit into the wider context, and what actions other stakeholders such as the WSPs themselves are also taking (CCW, 2006b).

3.4. Leakage reduction

Leakage reduction is an essential component of any comprehensive WDM intervention and sits comfortably alongside other interventions, such as water efficiency, alternative water systems, implementing regulatory frameworks and the introduction of metering policies

(Trow and Farley, 2006). It a challenging task as it involves balancing trade-offs between minimising the cost of supplying water to customers whilst meeting the operational requirements of WSPs. This goal is difficult to achieve because hydraulic networks exhibit largely non-linear behaviour which, coupled with a wide variation in system demand and operational and regulatory constraints, result in a highly dimensional, partially discrete non-linear problem (Morley et al., 2013).

Leakage levels depend on several factors, including the characteristics of the pipe network, the network pressure, frequency and typical flow rates of new leaks and bursts, the proportion of new leaks detected and the level of background leakage (Wu et al., 2011). Although water lost from leakage returns to the environment, it may not be to the same aquifer from which it was originally abstracted and the treatment process may mean that the water chemistry of potable water can be substantially different from that of the aquifer to which it returns (CIWEM, 2009). The water lost will also have already required a substantial energy input in terms of treatment and pumping. Effective leakage reduction can therefore be used to save both water and energy.

As WDSs are largely underground, many leaks do not manifest themselves visibly and may go undetected indefinitely. Even when water does reach the surface, it may be nowhere near the actual leak (Wu et al., 2011). Leakage detection and reduction is an expensive and time consuming process which requires a range of equipment and techniques. However, unlike supply augmentation, there is less scope to exploit economies of scale (Trow and Farley, 2006). Leakage reduction can, though, bring in revenue that would otherwise have been wasted from lost water by reducing the flow of existing leaks, the frequency of new bursts and by improving pipe integrity – all of which can allow for deferred investment in source augmentation. It can also lead to a lower water abstraction and other environmental and social benefits.

There are two principal types of leakage in WDS – background leakage and bursts (Morrison, 2004). Background leakage comprises losses from all fittings in the network that are individually too small to be detected and that can only be reduced by pressure management or through infrastructure renewal (Figure 9). Burst (also break) leakage is comprised of losses from fractures in the network pipeline which can potentially be managed through Active Leakage Control (ALC) and speed and quality of repairs (Figure 9). ACL involves a proactive strategy of detecting and repairing non-visible leaks using specialised equipment.

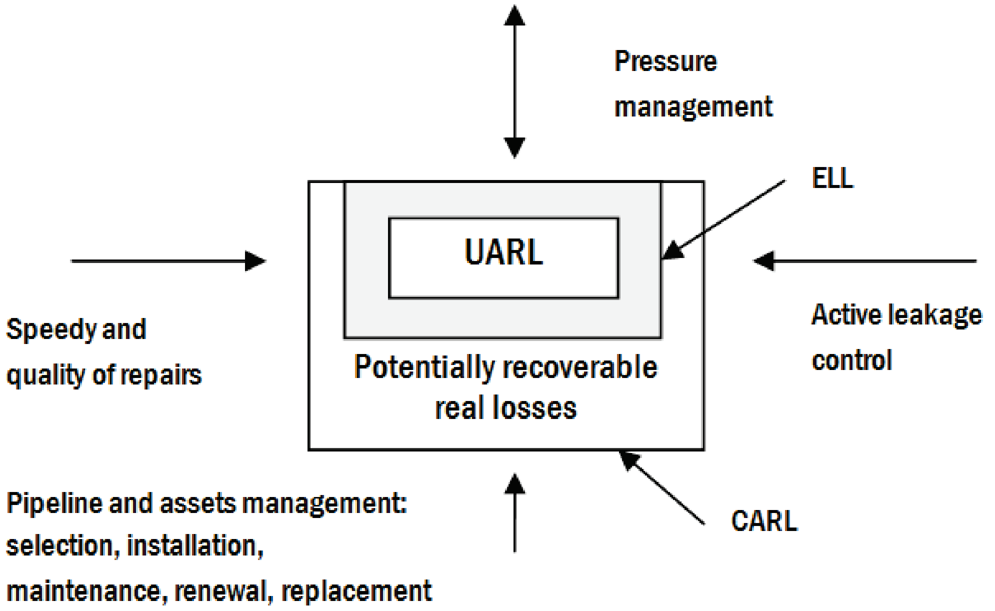

Figure 9 – The four basic methods of managing Real Losses (Fanner, 2004)

A leakage reduction strategy that addresses how much water is lost, where the losses are, what should be done to reduce/recover losses and how to control the losses within a sustainable level can be implemented by following each of the four methods of managing real losses (Figure 9). An effective method of doing this involves dividing the WDS into smaller District Metered Areas (DMAs) and Pressure Management Areas (PMAs) into which the quantity of water entering and leaving are metered (Morrison, 2004). In the case of PMAs, this is regulated with a pressure-regulated control device. DMAs and PMAs can be used to estimate which area of the WDS is experiencing the highest level of leakage or to discount areas with limited leakage so that resources can be targeted to the greatest effect (Morrison, 2004). Best practice analysis of DMA flows requires the estimation of leakage when the flow into the DMA is at its minimum.

Once leakage has been identified, it can be assessed by one or more of three methods: top-down annual water balance, bottom-up analysis of night flows, and component analysis (Fanner, 2004). The top-down annual water balance method involves determining the total volume of leakage as the volume remaining after authorised consumption and apparent losses have been deducted from system input volume. This can be carried out using the International Water Association (IWA) international best practice standard for water balance calculations (Figure 10), the principal components of which are (Lambert, 2003):

- System input volume – the annual input to a defined part of a WDS.
- Authorised consumption – the annual volume of metered and/or non-metered water use by registered users and other authorised users (e.g. fire-fighting). This includes water exported, leaks, and overflows after the point of customer metering.

- Water losses – the difference between system input volume and authorised consumption. This consists of apparent and real losses. Apparent losses consist of unauthorised consumption and metering inaccuracies and are often the result of local customs, combined with low water tariffs or inadequate metering policies. Real losses (leakage) consist of the annual volume lost through all leaks, bursts, overflows on mains, service reservoirs, and service connections up to the point of customer metering.
- Non-Revenue Water (NRW) – the difference between system input volume and billed authorised use. This water is considered lost, and consists of unbilled authorised consumption and water losses.

System input volume (corrected for known errors)	**Authorised consumption**	**Billed authorised consumption**	**Billed metered consumption (including water exported)**	**Revenue water**
			Billed unmetered consumption	
		Unbilled authorised consumption	**Unbilled metered consumption**	**Non-Revenue Water (NRW)**
			Unbilled unmetered consumption	
	Water losses	**Apparent losses**	**Unauthorised consumption**	
			Customer metering inaccuracies	
		Real losses	**Leakage on transmission and/or distribution mains**	
			Leakage and overflows at utility's storage tanks	
			Leakage on service connections up to point of customer metering	

Figure 10 – The IWA international 'best practice' standard water balance (Lambert, 2003)

The top-down water balance does not provide information about the different components of water loss – i.e. losses due to background losses or losses due to bursts (Fanner, 2004). A bottom-up analysis of night flows can be used to check the leakage volume obtained in top-down analysis. The Minimum Night Flow (MNF) normally occurs during the early morning period (usually between 02:00 and 04:00 hours), during which leakage is at its maximum percentage of total flow. If undertaken across the whole WDS, a bottom-up analysis can be used to estimate the level of leakage and identify areas of high leakage so management work can be prioritised.

Annual leakage can also be assessed from first principles using component analysis to break down the total volume of leakage into its constituent components for each element of the system infrastructure, based on their most influential parameters. A calibrated component analysis can be a very useful method for evaluating alternative options for managing leakage, not only by its volumes but also by its financial impacts, so that investments can be targeted where they will generate the highest rate of return (Fallis et al., 2011).

Leakage cannot be eliminated completely and there will always be a level of leakage in WDS which has to be tolerated and be maintained (Trow and Farley, 2006). The lowest technically achievable annual volume of leakage for well maintained and well managed systems (at current operating pressure) is known as Unavoidable Annual Real Losses (UARL) (Figure 9). For most WSPs, it will not be economic to reduce leakage to UARL (Fanner, 2004). The highest annual volumes of water losses do not necessarily correspond to the highest financial losses of a WSP (Figure 11). Especially at the beginning of a leakage reduction programme, the recovery of apparent losses is possible with relatively low costs and will create a direct financial improvement to the water utility. These recovered funds can serve to finance long-term leakage management activities (Thornton et al., 2008).

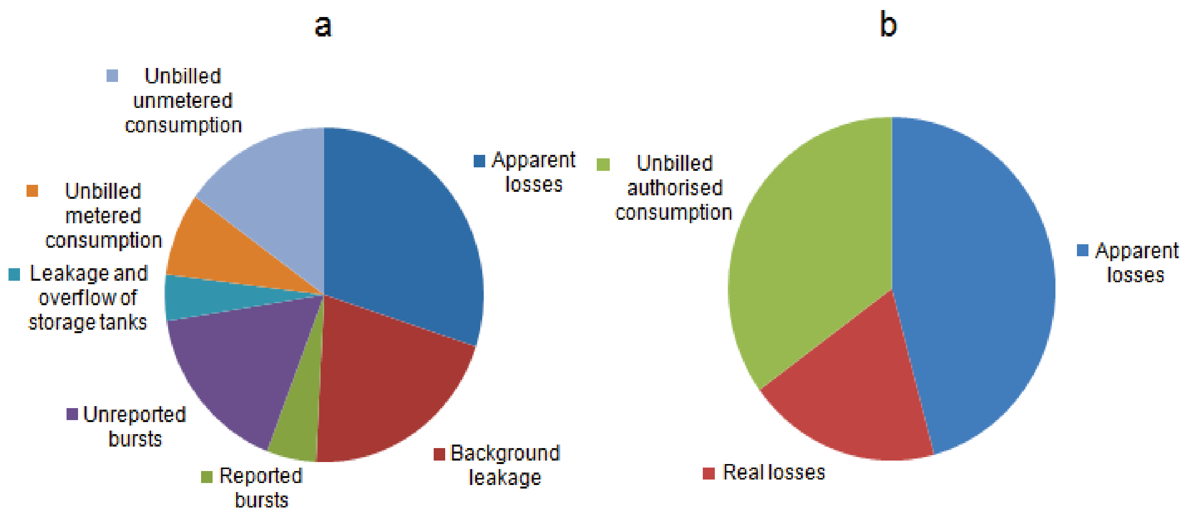

Figure 11 – Example of the (a) volumetric and (b) financial distribution of losses of a WDS (Thornton et al., 2008)

The level of leakage below which it will not be cost-effective for WSPs to make further investment or use additional resources to drive down leakage further (Trow and Farley, 2006), even taking into account the social and environmental costs associated with leakage (Wu et al., 2011), is known as the Economic Level of Leakage (ELL) (Figure 9). ELL can be achieved by ensuring that each of the four component methods of managing leakage is independently economic, and implementing as priorities those aspects with highest benefit: cost ratio (Fanner, 2004). In the short term the ELL can be achieved by managing the average duration of leaks through ALC and speed and quality of repairs of all leaks and bursts. In the medium- to long-term the ELL is achieved by influencing the number of leaks and bursts which occur each year through improved pressure management and pipeline and asset management.

Different performance indicators can be used for real losses (Table 21). Many WSPs still use percentage water loss rate (e.g. 40 percent of water losses). However this varies with the consumption and is therefore not a good indicator for leakage reduction strategies. The IWA performance indicator for real losses is referred to as the Infrastructure Leakage Index (ILI), which is the ratio of Current Annual Real Losses (CARL) and UARL (Figure 10). ILI can be used to measure the effectiveness of managing real losses (Rizzo et al., 2004). However the ILI does not imply that pressure management is optimal as it is usually possible to reduce the volume of real losses (but not ILI) by improved active pressure management (ibid).

Table 21 – Limitations of traditional water losses performance indicators (Lambert et al., 1999)

TRADITIONAL PI FOR REAL LOSSES	CONTINUITY OF SUPPLY	LENGTH OF MAINS	NUMBER OF SERVICE CONNECTIONS	LOCATION OF CUSTOMER METERS ON SERVICES	AVERAGE OPERATING PRESSURE	GROUND CONDITIONS
Percentage water loss rate	No	No	No	No	No	No
Litres/property/day	No	No	Only if 1 property/ connection	No	No	No
Litres/service connection/day	No	No	Yes	No	No	No
m↖/km mains/day	No	Yes	No	No	No	No
m↖/km of system/day	No	Yes	Possibly	Yes	No	No
ILI	Yes	Yes	Yes	Yes	Yes	No

3.4.1. Pressure management

Pressure management is a key element of a well developed leakage management strategy as it impacts on the three other components of leakage management (Awad and Kapelan, 2008). Pressure management is an efficient method of controlling and maintaining leakage in WDS (Wu et al., 2011) and is generally more cost-effective than repairs to numerous leaks in buried pipes (Barry, 2007). It can increase revenue from water that would otherwise have been wasted and provide several other benefits, including: reducing the frequency of new leaks and bursts, flow rates through existing pipes, surge pressure, and some components of consumption as well as potentially extending infrastructure lifespan (Wu et al., 2011; Thornton, 2003).

Pressure management is usually achieved using PMAs where flows are monitored by using permanently installed bulk-flow meters at the inlet as well as at the boundary and pressures controlled by using automatic control valves. The most common form of pressure management is pressure reduction, which can be undertaken by various methods, usually depending on the ELL and the ability of the WSP to maintain the equipment (Thornton, 2003).

- Pressure reduction can involve (Wu et al., 2011):
- Establishing pressure zones to maintain pressure at higher elevations.
- Using throttling gate valves to create head loss.
- Using pump control by to meet demand in areas of higher elevation or by adjusting pump speeds to maintain minimum pressure and provide effective system pressure control in zones fed by variable speed pumps.
- Breaking pressure tanks to convert the transmission main on the downstream side into a gravity pipeline thus insulating the pipeline from unwanted transient pressure (surge).
- Installing Pressure Reducing Valves (PRVs) to reduce higher inlet pressure into lower constant outlet pressure, regardless of fluctuating flow and varying inlet pressure by throttling automatically so that the downstream hydraulic grade line always maintains a set value.

Hydraulic models are effective means of assessing the impact of pressure management in WDS. Due to high levels of uncertainty, leakage can be modelled using different methods, including conventional nodal demand, orifice flow based on emitter hydraulics, Pressure-Dependent Demand (PDD) and distributed demand along pipelines (Wu et al., 2011).

In general, there are two types of demand: (i) volume-based demand involving appliances such as WCs, baths, washing machines, dishwashers etc; and (ii) PDD involving appliances such as taps, showers, sprinklers (Wu et al., 2011). Volume-based demand is unlikely to be affected by nodal pressure, whereas PDD, by definition, is directly dependent on available nodal pressure.

In WDS two cases can arise – differential pressure or PDD (Wu et al., 2011). Differential pressure occurs in the case of 24/7 supply with substantial variation in day and night demand. During peak hours, demand is greatest but the nodal pressure is at its lowest, whereas during night hours the demand is least and the pressure is generally at its highest. This problem can be solved by undertaking Extended Period Simulation (EPS) modelling and installing PRVs at appropriate locations. PDD occurs when system pressure is affected by pump failure or due to insufficient water at source. This is solved using pressure management methods.

Two principal methods are used to model hydraulic systems – demand-driven and pressure-driven analysis. Conventional hydraulic analysis assumes that the nodal demand is independent of pressure (demand-driven analysis) and is always satisfied under all operating conditions (Jung et al., 2009). However, nodal demand is independent of pressure only during normal operating conditions and under abnormal operating conditions it may be that demand cannot be met in full – e.g. at reduced, zero or negative pressures (Jung et al., 2009; Mansoor and Vairavamoorthy, 2003). The more appropriate method for modelling leakage is PDD (also, head-driven) analysis because is sensitive to the variations in system pressure (ibid).

3.4.2. Energy management

Energy costs constitute a significant proportion of the operational cost of water supply. Excessive distribution pressures and leakage contribute substantially to high energy demand (Parker et al., 2008). In some cases, this can represent more than 25 percent of the energy requirements of water production and distribution. For most WSPs, energy costs represent the largest controllable operational expenditure (Liu et al., 2012). Improving the energy efficiency of WDSs will reduce energy requirements for water production and distribution by as much as 30 percent (Parker et al., 2008; Bunn and Reynolds, 2009, Liu et al., 2012), and have 1-5 year payback periods (Liu et al., 2012). Energy efficiency via leakage management will also reduce operational costs; the wastage of energy embodied in lost water, as well as reduce velocities and frictional losses within the network (Parker et al., 2008).

Energy can also be lost from WDSs as a result of poor design specification, installation and/or maintenance of pumps. Energy efficiency can be improved through the replacement or refurbishment of pumps; installation of variable speed drives so that station output is matched to demand and/or ensuring the correct sizing of pumps and/or impellers (Parker et al., 2008). Even relatively small improvements in pump efficiency can have a significant impact on energy costs, carbon emissions and revenue (Savic et al., 1997; Reynolds and Bunn, 2010). Historically, efforts to improving pump efficiency have concentrated on the static process of carrying out a pump curve calibration, assuming an operating point, and then either replacing, modifying, machining, polishing, or coating the pump surfaces (Bunn and Reynolds, 2009). While these measures have been shown to be beneficial, they do not take into account the dynamic nature of the actual operating range of a pump (ibid).

Given variable electricity tariffs, where prices are lower during periods of low overall consumption – e.g. overnight – it is clearly advantageous to seek a pumping schedule that will undertake as much of the necessary pumping as possible under the lowest-cost regime (Giacomello et al., 2012). WSPs with sufficient storage facilities can optimise their energy cost savings by rescheduling as much of the pumping load as possible to occur off-peak when energy tariffs are lowest. However, this can increase pressures in the system and therefore leakage at night. The system can optionally be configured to provide dedicated pumping mains feeding the reservoirs, rather than supplying the reservoirs through the WDS in order to offset any increases in distribution pressures and hence leakage that might result from increased off-peak pumping (Parker et al., 2008). However, although off-peak pumping can lead to a better utilisation of electricity plants and reduce energy costs, it does not reduce energy use per se (Parker et al., 2008). The only way energy savings can be made is if the pumps themselves are operated more efficiently (Reynolds and Bunn, 2010).

3.5. Case study – Leakage Reduction in Reggio Emilia, Italy

A new methodology for leakage reduction via integrated energy and pressure management in water distribution systems has been developed with the aim of saving both water and energy (Morley et al., 2013). The methodology approaches the management problem by means of a single, integrated multi-objective optimisation task, rather than two separate problems (as is currently done) by considering simultaneous use of PRVs /throttle valves and improved pump and source water scheduling. The optimisation seeks to minimise the total costs of network operation and minimising leakage whilst ensuring that minimum network performance constraints continue to be met. Leakage is evaluated using a pressure-dependent component to the demand for each node in the network thus the optimisation will seek to reduce the pressure in the system to minimise the leakage whilst simultaneously attempting to maintain any minimum pressure requirements. The outputs of the optimisation process result in leakage reduction and direct and indirect energy savings.

The optimisation employs a number of constraints – violation of which will result in a solution being marked as infeasible and, therefore, unlikely to play a significant role in the progress of the optimisation. Firstly, a solution must be hydraulically feasible – that is to say that there are no nodes in the network experiencing negative pressures and that all of the demands on the system should be met in full. To produce a system operation that is repeatable over successive days, a further constraint is implemented such that the levels of any tanks/reservoirs in the system should be at least as high as they were at the beginning of the scheduling horizon.

The methodology has been implemented as a stand-alone software application, the Pump and Valve Logic Optimal Scheduling (PaVLOS) software tool, which employs a pressure-driven WDS hydraulic model to quantify the pressure-dependent leakage of a system. PaVLOS has been designed generically so that it can operate on additional case studies with little or no modification. Having said this, the software is data hungry and the principal requirement for any further application of the model is that a fully calibrated, extended-period hydraulic model is available for use with the EPANET hydraulic solver (Rossman, 2000).

The methodology has been applied to the real-life case study of the Langhirano distribution system in Reggio Emilia, Italy in order to demonstrate the cost-effectiveness of leakage reduction on the operations of a WDS. The Langhirano WDS is a completely independent system comprising of only one point of transfer of water to a neighbouring network. The network is characterised by significant variance in elevation necessitating the use of pumped storage. The WDS serves a town of approximately 10, 000 inhabitants and covers a surface area of 70.8 km^2 with a pipeline of about 222 km. An overview of the Langhirano WDS showing available water resources, wells, tanks and PMA boundaries is shown in Figure 12.

The WDS retrieves water either from springs located in the higher portion of the municipal territory or from wells in the lower part, where the latter act as the major source. Only 68.5 percent of the system input volume is subject to disinfection. About 35 percent of the system input volume is NRW. The most densely populated part of the system is divided into seven PMAs, whose inlets are controlled by fixed setting PRVs. The operation of the well pumps is controlled by a Supervisory Control And Data Acquisition (SCADA) system or a timer control.

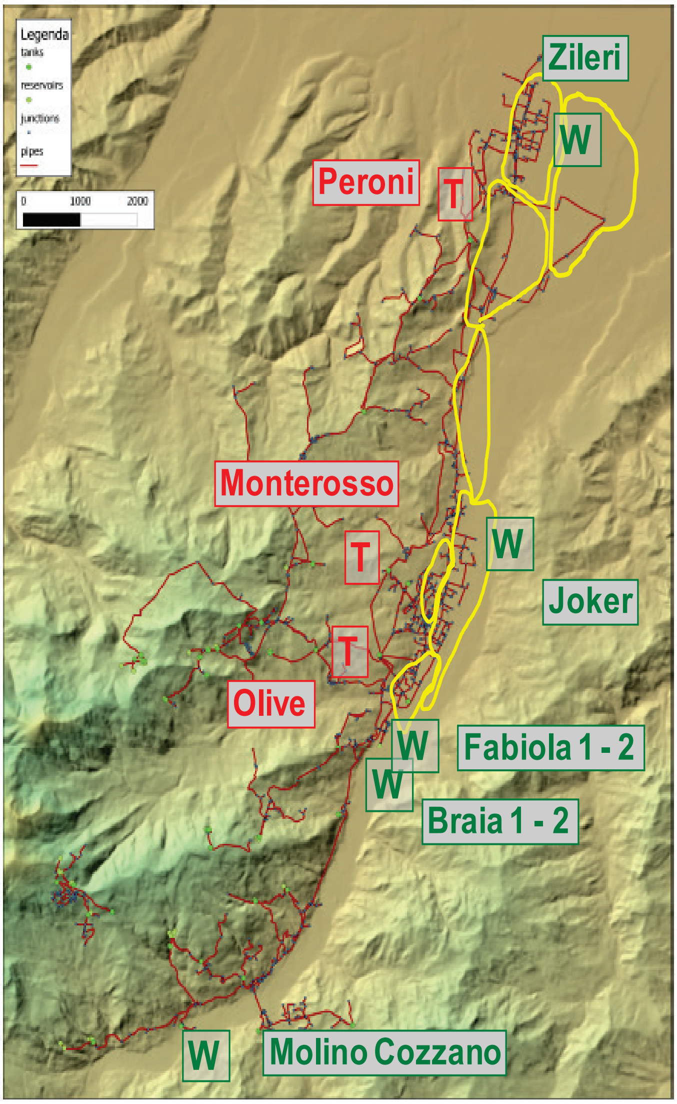

Figure 12 – Langhirano: WDS showing available water resources S (spring), W (well); main tanks T; boundaries of PMAs indicated with the yellow line

Three different optimisation scenarios have been considered for the Langhirano WDS:

I. PUMP only optimisation in which the operation of the pumps can be changed at hourly control intervals. The decision variables of this scenario are defined by the status of each pump (1 - working, 0 - not working) at each interval of the scheduling horizon. In addition, prior to the optimisation, each pump may have its status fixed to “Always on”, “Always off” or to respect the existing pump control as defined in the hydraulic model. In this scenario, the PRV settings are fixed and tank levels are fixed. The initial tank levels are the same as the baseline condition.
II. PUMP and PRV optimisation in which the operation of the pumps and the setting of the PRVs can be changed at hourly control intervals. Similar to the PUMP only optimisation, the operation of the pumps and PRV settings can be fixed a priori preventing the optimisation from considering changes to individual pumps or valves, or changed at each interval of the scheduling horizon. In addition, if desired, selected PUMPs and PRVs can be entirely disabled prior to optimisation thus effectively removing them from the system. In this optimisation scenario, the initial level of tanks is the same the baseline condition.
III. PUMP, PRV, and Levels optimisation in which the operation of the pumps, the setting of the PRVs and the initial tanks levels can be changed at hourly control intervals. The decision variables in this scenario are defined by the operation of pumps, PRV settings and the addition of the initial level for each tank.

The best solution for each of the three scenarios was compared to each other, and to the baseline condition which represents the actual operation of the Langhirano system. The results show the new methodology and the accompanying software tool can deliver substantial savings to water utilities. Both pressure and energy management, i.e. the scheduling of pumps and valves can lead to a substantial reduction in system leakage and the associated costs. Pump scheduling leads primarily to the reduction of energy costs (by taking into account different tariffs) whilst the PRV scheduling leads primarily to leakage reduction (via reduced system pressures) which then, in turn, leads to reduced energy costs (due to reduced volume of water pumped). Integrating pressure and energy management, i.e. simultaneous scheduling of pumps and valves resulted in lower leakage and costs, which clearly demonstrates the benefit of integrating the two tasks rather than each on their own. Figure 13 shows the Pareto optimal fronts (i.e. trade-offs) obtained for each of the optimisation scenarios using PaVLOS. Table 22 summarises the best optimal scheduling for the recovery of water and energy costs. The following conclusions can be drawn from Figure 13 and Table 24:

1. Optimisation of pump schedules and PRV settings can lead to a substantial reduction in system leakage and the associated costs when compared to the baseline cost. Savings of 23.8 and 43 percent can be obtained for energy costs and leakage respectively.

2. Optimising simultaneously for pump and PRV settings leads to lower WDS leakage (1,689,520 L/day) when compared to the cases where pump settings are optimised alone of 1,922,690 L/day. This is because pump scheduling leads primarily to the reduction of energy costs (by taking into account different tariffs) whilst the PRV scheduling leads primarily to leakage reduction (via reduced system pressures) which then, in turn, leads to reduced energy costs (due to reduced volume of water pumped).
3. The initial tank level seems to be an important decision variable in the optimisation process as its careful selection is likely to lead to further leakage and cost savings, 4 and 10 percent here, respectively (relative to the Pump and PRV scenario).
4. The optimal scheduling of two of the main pumps operating shows optimal scheduling of pumps in all three scenarios results in pumps working less hours (especially during peak tariff hours) than in the baseline case thus reducing energy costs.

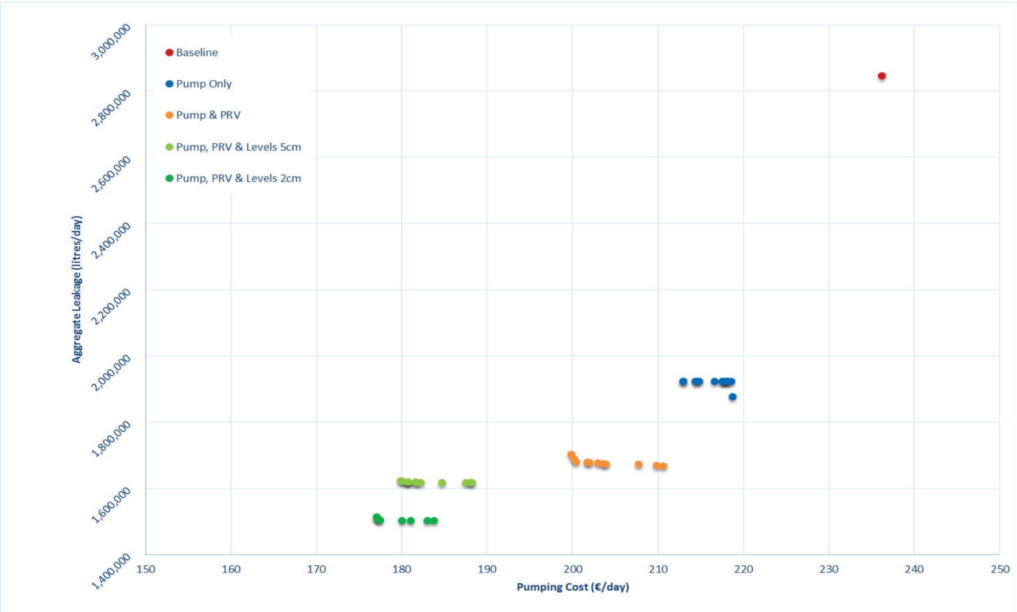

Figure 13 – Best solutions found for PUMP only; PUMP and PRV; and PUMP, PRV and Levels optimisation scenarios compared with the baseline condition

Table 22 – Results in terms of recovery of water and energy cost for the optimal scheduling

	ENERGY COST (€/YEAR)	LEAKAGE (ML/DAY)
Baseline condition	86, 209.35	2.8
Optimal scheduling		
Pump only	77, 719.45	1.9
Pump and PRV	73, 047.45	1.7
Pump, PRV and tank level	65, 648.90	1.6

4. EVALUATION AND SELECTION OF WATER DEMAND MANAGEMENT INTERVENTIONS

WDM has an important role to play in balancing supply/demand in a way that is both cost-effective and favourable for the water environment. Both householders and WSPs have an important role to play in reducing water consumption, and different WDM interventions can be used to enable the different water stakeholders to reduce waste and achieve more sustainable WDM practices (EEA, 2012). Different WDM interventions will offer different water saving potentials and also come with varying costs, energy requirements, as well as impacts on wastewater systems and supply/demand balance. Moreover, different cases will have different, and oftentimes multiple, objectives and evaluation criteria to consider when identifying the most effective and sustainable intervention(s) to implement. When selecting WDM intervention to implement, trade-offs have to be considered between competing and often conflicting technical, social, economic, and/or environmental objectives and evaluation criteria.

These trade-offs can be assessed using Decision Analysis (DA) methods, for example, which provide a scientifically sound framework for evaluating decision alternatives using multiple and/or conflicting criteria which cannot be easily condensed into simple monetary expressions (Bello-Dambatta et al., 2012a). These methods can generally use different types of data/information to evaluate alternatives, ranging from the extremely qualitative to extremely quantitative, and also provide consistency, rationality and transparency to a decision-making process (ibid). A case study demonstrating how DA can be used to evaluate and prioritise household WDM alternatives is provided in Section 4.2.

Different WDM interventions and technologies will have different system impacts. In general, if water use is to be reduced then some other factor must change to accommodate this. Where a reduction of water use, cost, or water-related energy use result in an increase of the other it is not necessarily clear which is the most sustainable outcome. A better understanding of these impacts is therefore essential in order to plan for effective and sustainable interventions. Various tools that can be used to assess household water use and encourage/motivate household water efficiency are freely available (see Section 2.3). However, most of these tools currently estimate household water use using average values and have been designed to be simple, requiring and providing minimal information that is meaningful to the average household water user. The tools also focus on a relatively narrow target group (usually the customers of the WSPs or water users of specific countries or even localities) and include only those options applicable to specific target groups. As such, the application of the tools to other cases than the ones for which they are intended for could prove problematic because of variations in water using appliances and habits. A case study which assesses the system impacts of household water savings is provided in Section 4.3.

4.1. Case Study – Prioritisation and Selection of Interventions

Prioritisation analyses of some household WDM interventions have been carried out in order to identify and rank the most sustainable option using both single and multiple evaluation criteria. The WDM options used in the prioritisation are: (i) efficient appliances and fittings, (ii) GWR systems, (iii) RWH systems, (iv) metering with tariff change, and (v) metering without tariff change. A description of the options is provided in Table 23 below. The evaluation criteria used for the prioritisation are: (i) water saving potential (%/m^3), (ii) cost-effectiveness (£/m^3), (iii) energy use (kWh/m^3), and (iv) social acceptance.

Table 23 – Water demand management options

WDM OPTION	DESCRIPTION
Efficient fittings and appliances	Assuming a full household retrofit with water efficient fittings and appliances and average household weekly water use of 80 LCD and water saving potential of 70 LCD.
GWR systems	Residential greywater recycling system that can be used to supply water for WC flushing for a single household with average household occupancy of 2.4 people and water saving potential of 21 LCD
RWH systems	Residential RWH for WC flushing and garden irrigation, with average household occupancy of 2.4 people, roof area of 70m^2, and 500 litre storage tank and water saving potential of 22 LCD.
Metering, no tariff change	Metering program with no tariff change assuming water saving potential of 10 percent to give a water saving potential of 15 LCD.
Metering with tariff change	Metering program with tariff changes to incentivise water savings with water saving potential of 16 percent to give a water saving potential of 24 LCD.

The water saving potential criterion is the total amount of water saved, the cost-effectiveness criterion is the actual money saved per volume of water saved, the energy use criterion is unit of operational energy used, and the social acceptance criterion represents the relative social acceptance of the WDM options. Both qualitative and quantitative were used. All criteria have been considered equally important the analysis, so have been assigned equal weighting. Two different Multi Criteria Decision Analysis (MCDA) methods (i) the Analytical Hierarchy Process (AHP) a utility-based MCDA method, and (ii) Compromise Programming (CP) a distance-based MCDA technique.

Table 24 – Cost of efficient household appliances and fittings (after EA, 2007a)

MICRO-COMPONENT APPLIANCES	LIFESPAN, YEARS	CAPITAL COST, GBP	LIFETIME COST, GBP[1]
WC x 2	15	67 x 2 = 137	246.73
Standard bath	15	118	212.51
Mixer shower	12	184	294.59
Washbasin tap	15	10	18.01
Kitchen mixer tap	25	42	111.97
Mid-range washing machine	13	244	406.28
Mid-range dishwasher	13	250	416.27
Outdoor tap	n/a	10	10
Total costs		995	1, 716.36

[1] Costs (GBP) taking into account interest rate of 4 percent over the lifespan of the appliances and fittings .

Assumptions current EU average water consumption of 150 LPD using efficient household fittings and appliances assuming a full-retrofit of water using micro-components has been estimated to capital cost approximately £1000 – with a lifetime capital cost of around £ 1, 700 (**Error! Reference source not found.**). The current most efficient appliances and fittings have estimated to reduce water consumption from 150 to around 80 LPD (EU, 2007). Assuming an average unit cost of £2 and a standing charge of £ 25, this will result in annual cost saving of £ 38 (and £1, 035 over the average lifespan of the appliances and fittings) for water supply. Further savings will be made in terms of reduction in water-related energy use and sewerage charges. Metering with no tariff change will result in water savings of about 10 percent per year, and metering with tariff change will result in water savings of around 16 percent (Walker, 2009).

Table 25 – Water saving potential of GWR and RWH systems (FM, 2004)

	COST, £/YEAR	WATER SAVING, M^3/YEAR	COST SAVING, £/YEAR	PAYBACK, YEARS
GWR system	1, 000	18	23	44
RWH system	400	19	2, 500	16

Table 26 – Potential savings from metering with and without tariff change (Walker, 2009)

	INSTALLATION COSTS, £ /HOUSEHOLD	WATER SAVING, % / YEAR	COST SAVINGS, £/ HOUSEHOLD/ YEAR
Metering	250	10	25
Metering with tariff change	250	16	30

The WDM options were evaluated and ranked with respect to each evaluation criterion in the single criterion analysis. The result of the analysis shows that efficient appliances and fittings rank as the most sustainable option for each of the evaluation criteria, with the exception of the cost criterion (Table 27). The result of the multi-criteria analyses indicate that efficient fittings and appliances, followed by metering and RWH consistently ranked the most sustainable WDM options with respect to all the evaluation criteria considered, even when very different prioritisation methods have been used in deriving the ranking (Table 28).

Sensitivity analyses were carried out to check the effect of changing the criteria weights on the multi-criteria rankings. In the AHP analysis, a slight change in ranking is observed when the water saving potential criterion is prioritised over the other evaluation criteria, and a significant change in ranking is observed when the cost criterion was prioritised. There was no change at all in ranking when the energy use and social acceptance criteria were prioritised. Overall, the most robust criteria in the AHP analysis were the energy use and social acceptance criteria as changing their weights resulted in no change in ranking. In the CP analysis, the result shows efficient appliances and fittings to be the best solution in all cases. Metering with and without tariff change consistently ranked second and third options, with the exception of water saving potential and social acceptance criteria. The ranking of GWR and RWH systems were variable, depending on the weight of the criteria changed.

Table 27 – Single criterion ranking of WDM technology options

WDM OPTION	WATER SAVING POTENTIAL, M3/YEAR	COST-EFFECTIVENESS, £/YEAR	ENERGY USE, KWH/YEAR	SENSITIVITY ANALYSIS
Efficient fittings and appliances	1	4	1	1
GWR system	2	4	2	2
RWH system	4	3	2	2
Metering with no tariff change	4	1	1	3
Metering with tariff change	3	2	1	3

Table 28 – Comparison of multi-criteria rankings

WDM OPTION	AHP RANKING	CP RANKING
Efficient fittings and appliances	1	1
GWR system	5	4
RWH system	4	5
Metering with no tariff change	3	3
Metering with tariff change	2	2

4.2. Case Study – Impact Assessment in Bucharest, Romania

WDM interventions are increasingly being used to reduce water use and water-related energy use, reduce cost and negative environmental impacts and have a positive impact on supply/demand balance, whilst still satisfying the needs of consumers. Given that most of the urban water use in Europe is in households (EEA 1999), reducing household water use can reduce overall water demand, which can also lead to a reduction in household energy bills, overall water-related energy use, as well as associated GHG emissions and have appositive impact on supply/demand balance. However, not all WDM interventions will result in reduction of water-related energy use and some could increase both energy use and costs. Different degrees of water savings can be achieved depending on the WDM intervention strategy considered, and impacts of water saving can vary significantly.

A new impact assessment tool (Bello-Dambatta et al., 2013) has been used to demonstrate how different types and combinations of WDM interventions may be used to deliver different impacts on water, cost, and energy savings; as well as on the supply/demand balance of a WDS. The tool uses current average EU per capita water consumption data, household micro-component water use as baseline and average EU household occupancy as well as assumptions from other tools and reports. The tool has been applied to a case study of the Bucharest WDS by running different WDM interventions to assess system impacts of water savings on the WDS.

The WDM options in the tool include different types of household micro-component appliances and fittings and domestic GWR and RWH systems. Three types of appliances and fittings have been considered in the tool:

- Conventional household micro-component appliances and fittings comprising of the current household appliances. These have been assumed to represent 100 percent asset ownership in households in the impact assessment tool;
- Efficient household micro-component appliances and fittings comprising the current BATNEEC technologies; and
- Retrofit devices and fittings which represent a comparably low-cost alternative to replacing household micro-components with efficient appliances and provide a low-cost means of water, costs and energy savings. Domestic GWR systems collect grey water from baths and showers, filter, disinfect and reuse for WC flushing. The domestic RWH systems can provide water for household WC flushing, outdoor water use (garden watering, car washing) and washing machines, and can therefore potentially provide further water savings compared to GWR systems.

The water supplier of the Bucharest WDS is operating on a 25 year concession contract that began in 2000. Since privatisation, the water supplier has invested 20 million EUR and has seen significant improvement at all system levels: NRW has decreased from 300 to 136 million m^3 and water use has decreased from 400-150 LCD, perhaps as a result of universal metering coverage and relatively higher water rates.

However, despite universal metering; around 1, 000 of the water supplier's connections are to housing blocks serving up 1,000 inhabitants each. These connections represent around 80 percent of domestic water use and access to them is only through household associations. Hence, there is currently no data available for per capita or household micro-component breakdown, and as such assumptions based on average EU water use and household micro-component breakdown, as well as other assumptions from previous work have been used.

The water supplier has 100, 000 contractual customers, serving a population of 1.9 million people. With no major industrial use, water use in the city is mainly domestic. The current total water demand is around 225 million m^3 per year, about 45 percent (102 million m^3 per year) of which is for domestic use and about 40 percent (90 million m^3 per year) of which is NRW. The remaining 15 percent is for commercial and municipal water use. The NRW of 40 percent represents only real losses, as the water supplier's responsibilities are limited to point of customer metering. In terms of supply/demand balance, the water supplier has the capacity to produce around 520 million m^3 per year, of which only about 230 million m^3 per year is sold. Therefore the water supplier is currently producing is twice as much water as it sells.

Despite the huge water savings made since privatisation, water use can be further reduced by using WDM interventions, which can also lead to reduction in energy use and cost, as well as have an impact on supply/demand balance which could improve the security of future water supply without corresponding investment in supply infrastructure. Also the Bucharest WDS, like many in Europe, is over-dimensioned and any further decrease in water demand will have severe system impacts (T. Wintgens, personal communication, October 2013).

Table 29 – Existing household conditions in the Bucharest WDS

	DATA
Permanent population	1,900,000
Maximum supply capacity, m^3/day	1,600,000
Total system supply capacity, m3/year	520,000,000
Total domestic water demand, m^3/year	230,000,000
Total household demand m^3/year	102,000,000
Water rate, EUR/m^3	0.8
Total embodied energy (electricity), kWh/year	38,000,000
Domestic embodied energy, kWh/year	23,000,000
No of domestic metered connections	108,000
Domestic metering coverage, %	100

A summary of existing household conditions in the WDS is given in Table 29. Where case study data is not available, assumptions in Table 30 have been used. These are assumed to remain constant over the planning horizon (2010 – 2050). The figures for Population Growth Rate (PGR) and the unit cost of energy have been obtained from World Bank and

Europe's Energy Portal respectively. It is assumed that the negative population growth will also remain constant over the planning horizon. Assumption for interest rate is based on the European Central Bank's long-term interest rate statistics for EU member states.

Table 30 – Household assumptions in the Bucharest WDS

ASSUMPTION	DATA
Average household size, people	2.5
No of households	760,000
Population growth rate, %	-0.2
Unit cost of energy, EUR/kWh	0.12
Discount rate, %	0.02
Interest rate , %	0.04

Three different intervention strategies have been considered to assess the impacts of different water savings in terms of their energy use, cost and impact on supply/demand balance:

I. Business as usual intervention – where the current EU average per capita water use of 150 LCD remains the same through the intervention interval (2010-2050), with household appliances and fittings are replaced in line with average product lifespan.
II. Alternative systems intervention – where household appliances and fittings are replaced in line with average product lifespan; and GWR and RWH systems are introduced at 5 percent of households at each intervention interval.
III. Aggressive intervention – where water use is reduced by 30 LCD, which will result in water use of 120 LCD by 2050. For example, a reduction of per capita water use to 120 LCD at 2050 by reducing water use by 10 LCD between 2012–2020, 2020–2030 and 2030–2040 by using different combinations of WDM interventions.

The result of the WDM interventions (Figure 14, Table 31) show different degrees of water savings can be achieved depending on the type and proportion of household micro-component appliances and fittings considered. Demand will decrease in all three interventions if the negative population trend continues for the duration of the intervention period, indicating adequate security of future supply without corresponding investment in supply infrastructure.

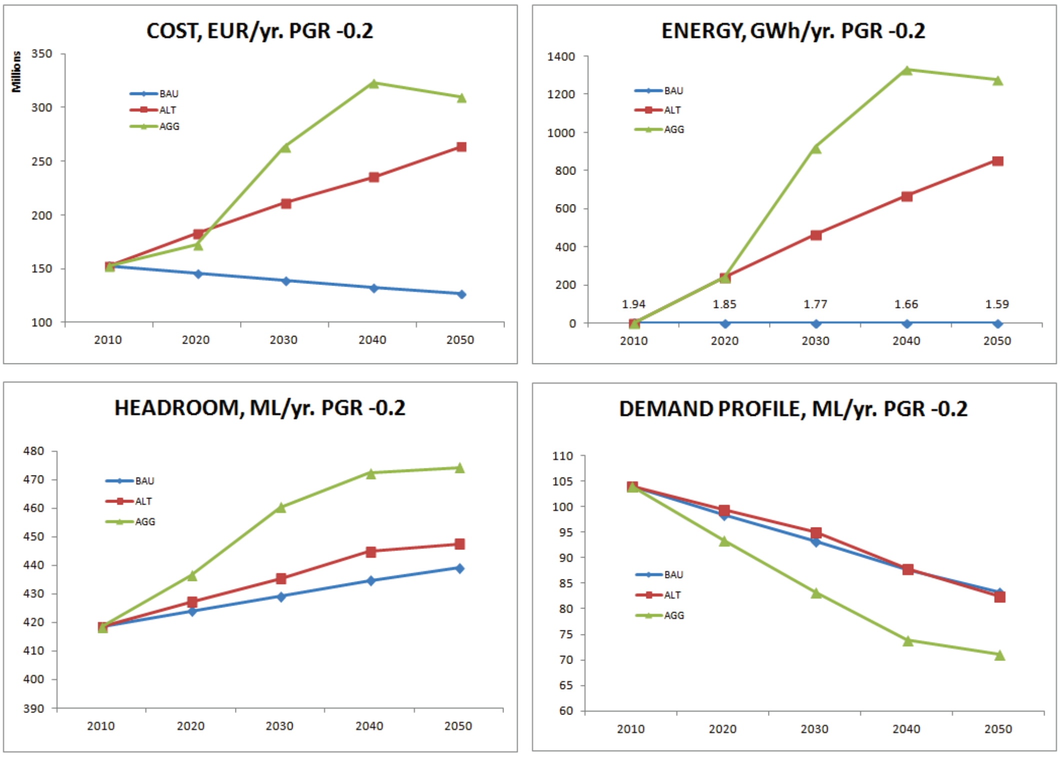

Figure 14 – Results for the three WDM intervention strategies under current negative PGR

However, reduced demand will result in less revenue for the water supplier and the unit cost of water may have to increase to reflect this reduction which could make water saving and uptake of efficient household micro-component appliances and fittings to help with water savings more appealing for households. The increase in water cost will however shorten the payback period of appliances and fittings. Moreover, because water-related energy use and cost are directly related to water savings, any increase in energy costs will increase the cost of the WDM interventions further. The current EU energy trends indicate considerably higher costs of energy in the future even with lower energy consumption.

A lot of uncertainties could arise over the intervention period – increase in unit cost of energy and/or water, climate change could impact the availability of water resources, and there could be an (unlikely) increase in industrial/commercial (i.e. non-household water use) over time or an increase in population and these could severely impact on supply/demand balance and potentially lead to periods of water shortages if no WDM intervention is implemented and/or new supply infrastructure is developed to mitigate this.

Sensitivity analysis was carried out with respect to increasing demand using different PGRs. The result of the sensitivity analysis indicates WDM intervention will depend on headroom available and the maximum supply capacity of the WDS. Although the BAU intervention performs the least in terms of water saving and impact on headroom, it performs best in terms of energy use and cost at all PGRs considered and will be the best intervention if current negative population trend continues even without a reduction in per capita water use. The AGG intervention offers the most water saving at all PGRs considered, but also has the most energy use and cost. However, because of the energy use and cost involved in the AGG intervention, it will only be suitable at PGR over 1 percent. The ALT intervention is a compromise between the BAU and AGG interventions in terms of all the performance indicators, but at a relatively higher energy use and cost than in BAU with respect to water savings. However because of the reduction in headroom in the BAU intervention from PGR 0.2 percent, the ALT intervention will be the most appropriate to consider for PGRs more than 0.2-1 percent.

Table 31 – Household micro-component water use at the end of the planning horizon (2050)

HOUSEHOLD MICRO-COMPONENTS	BASELINE, LCD	BAU, LCD	ALT, LCD	AGG, LCD
WC	35	28	29	25
Bath	15	25	25	15
Shower	5	6	6	8
Washbasin tap	8	8	8	9
Kitchen sink tap	15	15	15	18
Outdoor tap	6	6	6	8
Washing machine	12	9	8	10

Dishwasher	4	3	3	3

4.3. Guidelines for Evaluation and Selection of Water Demand Management Interventions

It is clear that household WDM has an important role to play in balancing supply/demand and ensuring the security of future water supply. However, in order for WDM to play this important role, all stakeholders including water users, WSPs, and policy makers will have a role to play in ensuring that it can be efficient and effective. Questions such as which intervention measure will reduce the most consumption and which mainly reallocates water, as well as the cost-effectiveness and system impacts of interventions given multiple objectives and constraints need to be answered. Different WDM interventions will also have varying water saving potentials, energy requirements, as well as impact on supply/demand balance. The social acceptability of the interventions by a range of stakeholders needs to be considered as well, as it could be a key barrier to public participation. The challenge therefore remains as to how to balance inevitable trade-offs between these competing and/or conflicting criteria when implementing WDM interventions. An understanding of these trade-offs is therefore essential in order to plan for effective and sustainable WDM interventions. Additionally, there will be case-specific objectives to meet and constraints to consider. It is therefore necessary to consider some guidelines in the selection and implementation of WDM interventions:

- Most of the urban water consumption in Europe is for household water use, and reducing this can reduce overall water demand, have a positive impact on the supply/demand balance, lead to a reduction the amount and flow pattern of wastewater to the drainage system, reduce pollution, reduce the total volume of wastewater arriving at treatment works, and extend the life of existing supply and waste treatment facilities.
- Reducing household water use using water efficient appliances, especially hot water using appliances, should also significantly reduce overall energy demand, as well as household water and energy costs. Water-related energy use has a direct relationship with GHG emissions and household WDM interventions can be viewed not only as a potential means of aiding the security of future water supplies, but also as a means of reducing emissions.
- The water efficiency of current appliances and fittings has vastly improved over recent decades and these are becoming the standard in new buildings. However, considerable scope exists for greater uptake and use in older houses. In general, household water efficiency is often the cheapest, easiest and least intrusive ways of reducing household water demand (case study, Section 4.2) (Billi et al., 2007).

- Households can be encouraged to switch to efficient appliances and fittings through rebates and exchange programmes, which are seen as more publicly acceptable than other WDM interventions such as price increases or water restrictions (Lee et al., 2011). In cases where replacing household appliances and fittings may not be cost-effective, simple behavioural changes can be encouraged and low-cost and easy to fit retrofit devices with short pay-back periods are available.
- Various tools are freely available (below) for the assessment of household water use, some of which have been reviewed in Section 2.3. However, it should be taken into account that most estimate water use using average values of duration and frequency of use of various water using micro-component appliances and fittings. The tools also focus on a relatively narrow target group (usually WSP customers or water users of specific countries or even localities) and include only those options that are applicable to specific target groups. As such, the application of the tools to other cases than the ones for which they are intended for could prove problematic because of variations in water using appliances and habits.
    - The BMA Water Calculator http://tinyurl.com/qdtwven
    - Pacific Institute WeCalc http://tinyurl.com/pdnr4zq
    - Water-Energy Toolkit http://tinyurl.com/oenlqp3
    - US Environment Protection Agency WaterSense http://tinyurl.com/pwszv3v
    - Energy Saving Trust Water Calculator http://tinyurl.com/d5kc7ac
    - National Geographic Change the Course calculator http://tinyurl.com/ba8lfxq
    - Water Consumption Calculator http://tinyurl.com/68h6ls
    - Home Water Works calculator http://tinyurl.com/pqu233f
    - Water Usage Calculator http://tinyurl.com/c26cylh
- There is a need for detailed evaluation of several WDM interventions based on case-specific objectives and constraints. There are important trade-offs to be made between the different objectives as not all interventions will result in water savings and/or reductions in costs, energy use or have a positive impact on supply/demand balance. What works well in one country or for one WSP/WDS may not necessarily be best option for another. Moreover, different efficiencies can be achieved depending on the WDM intervention(s) implemented.
- Different interventions will also have different system impacts, which need to be carefully evaluated. In general, if water use is to be reduced then some other factor (e.g. costs, energy use or headroom) must change to accommodate this. Where a reduction in water use results in an increase of another factor, it is not necessarily clear which is the most sustainable outcome. An understanding of these impacts, and the trade-offs that will

be required is in order to plan for sustainable WDM interventions (case study, Section 4.1).

- Alternative systems such as GWR and RWH systems can also be used to reduce the amount of potable water use for non-potable uses such as WC flushing, garden watering, and clothes washing. However, it should be noted that although such systems can reduce mains water demand (and relieve pressure on available supplies and reduce water abstraction needs) they do not necessarily reduce water demand. Additionally, the energy used in manufacturing, installing, and maintaining the necessary infrastructure can yield energy use and GHG emission greater than using mains water.
- Water savings can be incentivised through economic instruments such as water pricing, metering, and innovative tariffs schemes, which can act as incentives or disincentives to save water. They may also be used to raise awareness and prompt behavioural changes of water users. To be truly effective, these instruments have to reflect the true costs of water, including environmental and resource costs. Increasing water prices are only effective when consumers can actually benefit by responding to the increased charge by reducing consumption by changing their behaviour; significantly reduce water abstraction needs, make water available for other uses, and can reduce/delay future expenditure on increasing supply or expanding the system's capacity.
- Economic instruments may also be used to raise awareness and prompt positive behavioural changes of various water users, finance infrastructure maintenance, and foster technological innovation (EEA, 2012; Thivet and Fernandez, 2012). To be truly effective, economic instruments have to reflect the true costs of water, including environmental and resource costs (EEA, 2012). Increasing water prices are only effective when consumers can actually benefit by responding to the increased charge by reducing consumption by changing their behaviour; which can significantly reduce water abstraction needs, make water available for other uses, and can reduce/delay future expenditure on increasing supply or expanding the system's capacity.
- Metering is a prerequisite for water pricing to have any effect on water consumption. Metered households nearly always use less water as metering provides a financial incentive to make better use of resources and save water. Metering information can be a very important tool for raising awareness about water use by providing factual information and feedback to water user. Many other benefits can be derived from metering, such as providing information on consumption and identifying leaks in customer supply pipes which would otherwise have gone unnoticed (Walker, 2009). However, fully implementing metering for all users is also a key control and governance measure (EEA, 2012).
- Metering may achieve little by itself however, and may need to be considered in conjunction with appropriate pricing and tariff structures. In

general, tariffs based on volume of water use is considered the fairest approach to water charging and is thought to incentivise water saving. The choice of tariff structure influences how the total costs of the services are recovered from customers, and how customers are likely to behave.

- Substantial water savings can also be achieved by using soft interventions such as awareness, information, and educational campaigns as most reductions in water demand often result from behavioural changes such as time spent showering or mains water use for gardening, as well as focusing on the benefits of installing water efficient appliances and products. Access to information such as clear information on the real cost of water and the impact of current and future water scarcity can be key to modifying consumption habits, which can have positive impacts on both water quality and quantity (Volkery et al., 2011). Fundamentally, behaviour in both in the style of water use and the nature of the water-using facilities installed must be modified. At the crudest level, this can, in theory be driven by price through tariffs, but this may only have an impact if water is metered and is linked to an escalating tariff such as the rising-block tariff (McDonald et al 2011).
- Awareness-raising campaigns aimed at household water users can play an important role in water efficiency. Such campaigns encompass a number of different approaches, including websites, education programmes in schools, brochures and leaflets, advertising stands at live events, and the use of general media outlets (i.e. television, radio and newspapers and, increasingly, social media) (EEA, 2012).
- Leakage reduction is an essential component of any comprehensive WDM intervention, which can be used to save both water and energy as water lost from leakage will have already required a substantial energy input in terms of treatment and pumping. Effective leakage reduction can lower some aspects of demand as well as result in a decrease in the cost of production and distribution of water and a decrease in the capacity requirements for storage systems, treatment works, and mains sizing.
- Leakage reduction can also bring in revenue from water that would otherwise have been wasted, reduce the flow rates of existing leaks, reduce the frequency of new leaks and bursts by improving pipe integrity, reduce surge pressure, and even reduce some components of consumption. All of these can potentially extend infrastructure lifespan and allow for deferred investment in source augmentation as well as lead to lower abstraction needs and other environmental and social benefits.
- Pressure management is an efficient method of controlling and maintaining leakage in WDSs and is generally more cost-effective than repairs to numerous leaks in buried pipes. Given that energy costs constitute a significant proportion of the cost of producing and distributing water, improving energy efficiency in WDSs can reduce the energy requirements with relatively short payback periods. Energy efficiency via leakage management will also reduce operational costs, reduce the waste

of energy embodied in lost water, as well as reduce velocities and frictional losses within a network.

- Leakage reduction via integrated energy and pressure management (case study in Section 3.5) can lead to a substantial reduction in system leakage and energy costs compared to if energy and pressure are managed in isolation. This is because energy management leads primarily to the reduction of energy costs whilst the pressure management leads primarily to leakage reduction which then, in turn, leads to reduced energy costs.

5. SUMMARY AND CONCLUSIONS

Given that the quality and the quantity of fresh water resources are increasingly facing challenges in many parts of Europe as a result of a wide range of issues, and that conditions are expected to amply in the coming years, various types of water supply and demand management interventions need to be taken into consideration in order to sustainably meet future water supplies. Historically, efforts to satisfy water demand have involved augmenting supply by developing new infrastructure. However, this is now considered too costly as it tends to be unresponsive to economic, environmental, social, and political constraints.

WDM has an important role to play in balancing supply/demand and as a potential means of aiding the security of future water supplies. The successful implementation of WDM intervention requires commitment from WSPs and their customers, as well as the required political will and leadership from governments to generate consensus and provide suitable legislation (Inman and Jeffrey, 2006). Effective WDM intervention will require a holistic approach that recognises the complexity of the inter-relationships between the different stakeholders affecting demand, and calls for the creation of an enabling environment based on an adequate set of mutually supportive policies and a comprehensive legal framework with a coherent set of incentives and regulatory measures to support these policies (Thivet and Fernandez, 2012). More stringent mandatory policies (when well-enforced) tend to have stronger effects than voluntary policies and education programs (Olmstead and Stavins, 2007).

Policy instruments such as legislative, economic, technical/operational, and social instruments can be used to encourage and motivate water saving. These can be backed by regulations to enforce compliance (Volkery et al., 2011). Legislative instruments such as requiring minimum standards on design, performance, and use of water using appliances can be used to generate efficiencies and improve services, and equitably share those efficiencies between different stakeholders (EEA, 2001a; Ballance and Taylor, 2001). In the UK for example, regulatory pressure has been a major factor for change in the UK water industry (Griffiths, 2002). WDM has featured strongly in this regulatory framework, largely by mandating levels of ACL and water efficiency which appear to have been successful in contributing to a stabilisation of total demand over the years (Howarth, 2006). However, policies and regulations, though necessary, are not sufficient and putting WDM into practice will also require strengthening and/or creating institutions and mechanisms that can transcend the traditional boundaries involving effectively a variety of users and other stakeholders (Thivet and Fernandez, 2012).

Technical/operational instruments such as the use of water efficient household appliances and fittings, alternative water systems such as GWR and RWH systems, and leakage reduction measures can potentially offer significant water savings and can be considered as key components of balancing supply/demand. Household water efficiency is often the cheapest, easiest and least destructive ways of reducing water demand; and it is also considered the most politically and environmentally responsible intervention to implement

(Billi et al., 2007). Even as these technologies become standard in new buildings, considerable scope exists for greater uptake and use of water efficient technologies across much of Europe. Far more can and should be done in reducing water use across Europe. The European Commission estimates that overall European consumption can decrease by 40 percent (Howarth, 1998; EEA, 2012). However, it should be taken into account that many European WDSs are over-dimensioned, and as such any reduction in water demand could have severe system impacts (T. Wintgens, personal communication, October 2013).

In cases where replacing household appliances may not be cost-effective, simple behavioural changes can be made and low-cost and easy to fit retrofit devices with short pay-back periods are available. Retrofit devices such as cistern displacement and variable/interruptible devices can be used where WC use more water than it needs. Showers will use about a third of the water used in baths when used responsibly, and can therefore represent a water saving alternative to baths. Taps can be retrofitted with readily available aerators and flow restrictors to limit and regulate flow rates. The water and energy efficiency gains of white goods can be improved by full loads and control of detergent dosing. It is also possible to have a beautiful and productive garden without using mains water with good design and appropriate planting and the use of rainwater simple grey water diversion systems.

Alternative systems such as GWR and RWH systems can also be used to reduce water consumption by limiting the amount of potable water use for non-potable uses such as toilet flushing, garden watering, and clothes washing; thereby reducing the dependence on mains water supply. Water savings can also be incentivised through economic instruments such as water pricing, metering and innovative tariffs schemes, which can act as incentives or disincentives for householders and WSPs to save water (EEA, 2001a; EEA 2012), by either providing financial rewards for desired behaviour or imposing penalties for undesirable behaviour (Stratos Inc., 2003). Substantial water savings can also be achieved by using soft interventions which aim to modify personal water use habits through education and awareness campaigns. Fundamentally, behaviour in both in the style of water use and the nature of the water-using facilities installed must be modified. At the crudest level, this can, in theory be driven by price through tariffs, but this can only have an impact if water is metered and is linked to an escalating tariff such as the rising-block tariff (McDonald et al 2011).

However, not all water produced reaches customers, which implicitly limits the extent of savings that can be made from customer-side WDM interventions. Leakage in WDSs results in not only the loss of water, which undermines gains made from other WDM interventions, but also the waste of energy and material resources used in abstraction and treatment of water treatment (EEA, 2012). Leakage reduction is therefore an essential component of any comprehensive WDM intervention, and can be used to save both water and energy as water lost from leakage will have already required a substantial energy input in terms of treatment and pumping.

Ultimately, it may be that the only incentive for households to reduce their water use may be a reduction in the bill (Howarth, 2006), although this could only apply in countries where water is widely metered and the water charge is related to the volume of water consumed (EEA, 2001a; Walker, 2009). The impact of water pricing and metering on water use is difficult to separate from other factors, as the introduction such interventions is usually accompanied by other interventions such as water efficiency, leakage reduction, and soft interventions. It is also questionable for behavioural changes, whether the size of financial gains will be worth the effort involved, although on current evidence it would appear that payment by volume does result in reductions in water use (Howarth, 2006). Moreover, given that the successful implementation of some WDM interventions may have a negative impact on the WSP's revenue through the reduction of sales and turnover, it may be necessary that adequate mechanisms are put in place to compensate for this (EEA, 2001a).

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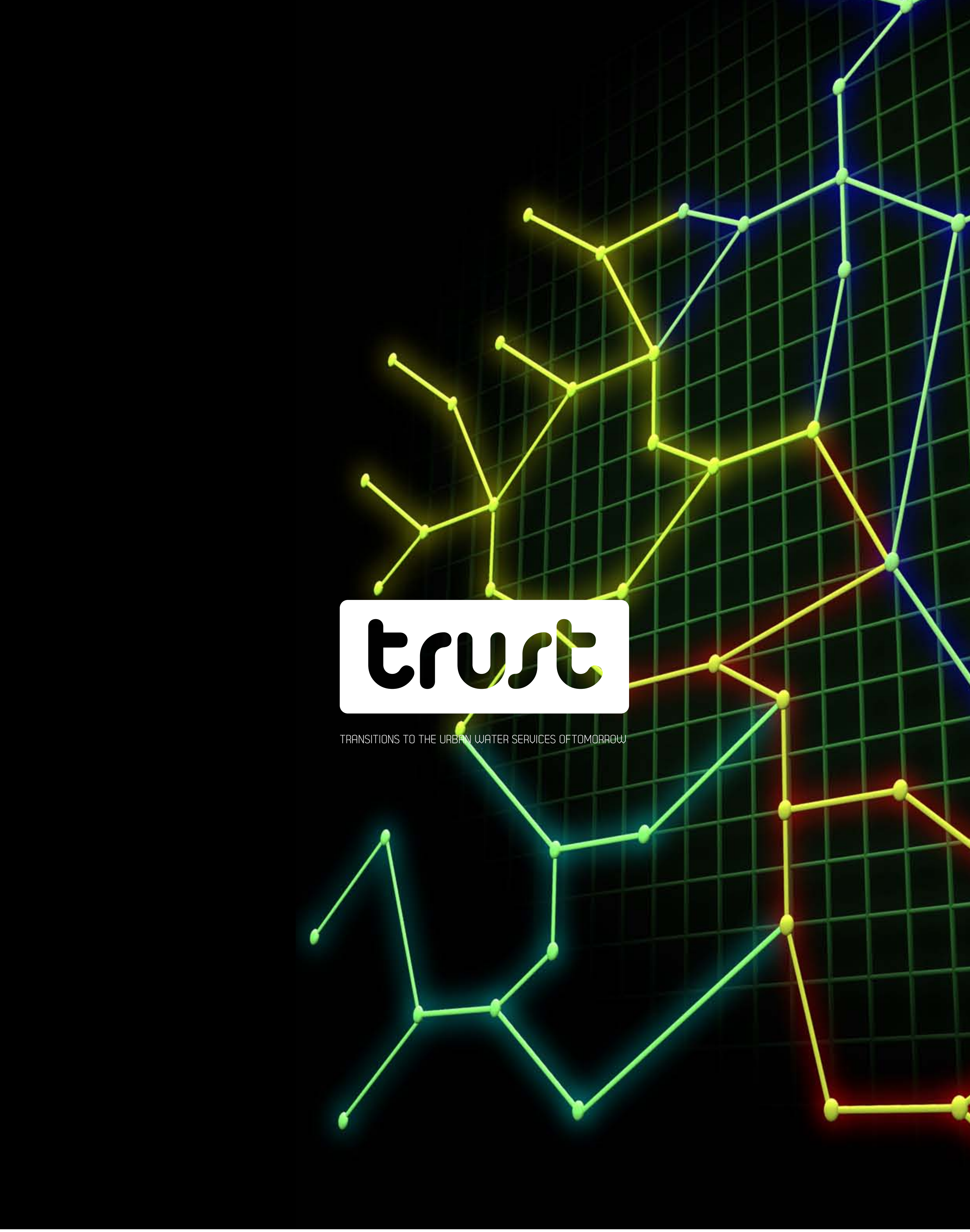

Guidance on evaluation and
selection of sustainable water demand
management technologies **D 42.1**

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