Urban Water Journal 3 (3), pp. 127-143

A review of residential demand-side management tool performance and influences on implementation effectiveness.

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Abstract

There has been sparse coverage of advances in the application of Demand-Side Management (DSM) in the academic press in recent years. At the same time a number of important DSM studies have been reported on by non-academic institutions, and there is therefore a need for a comprehensive, up to date review of the impacts of DSM tools and the factors which influence their effectiveness. This paper aims to begin to address this apparent lack of coverage with a review of residential DSM tools using recent reports of DSM campaigns in the western (developed) world collected from a range of sources. The aims are, to understand the potential for residential DSM tools to save water in different types of household under varying conditions and, identify influences on implementation effectiveness. The current review will be of interest to, among others, water company professionals, policy makers, regulators and environmental agencies.

Keywords : demand-side management, water saving technology, water conservation, household water demand.

1. Introduction

Consumption or, more precisely, over-consumption, is a major driver of global environmental change (Princen, 1999). Faced with rising demands and increasing supply uncertainty there is a pressing need to engage governments, water utilities and the public on water conservation issues if future water shortages and environmental problems are to be avoided. Human drivers of increasing household and per capita water consumption include population growth (EEA, 2001; Ofwat 2000a), higher household numbers (Ofwat, 2000a; AWWArf, 2001), lower household occupancy (Mitchell, 2001; Ofwat, 2000a), and lifestyle changes related to technology, personal habits and affluence (Princen, 1999; EEA, 2001). Whilst human consumption is increasing, water availability is becoming more variable due to climate change and is forecast to decrease in many regions in the future (IPCC, 2001).

Up until recently the main solution to addressing water shortages was to exploit new sources of supply. The growing consensus that reducing human demand is a more sustainable method of addressing the imbalance between supply and demand has led researchers (see Michelson et al, 1999; Renwick and Archibald, 1998; Maddaus, 2001; Howarth and Butler, 2004) and environmental organisations (UK Environment Agency, 1997; USEPA, 2002; Read, 2005); to recommend that municipal and private water utilities adopt an Integrated Water Resource Management (IWRM) approach in which Demand-Side Management (DSM) options are employed in conjunction with conventional supply activities to address water shortages.

IWRM involves consideration of the cumulative impacts of all activities within a watershed in an effort to maintain overall watershed health. The licensing of municipal water withdrawals and wastewater discharges is considered alongside other activities in the watershed, such as intakes and outflows of other municipalities' water systems as well as land and resource uses such as agriculture and forestry (Shrubsole and Mitchell, 1997). The immediate contribution of residential DSM to IWRM is to increase the supply headroom to all sectors.

Successful implementation of DSM tools requires commitment from the local water utility and its customers (Howarth, 1999; Gumbo and Zaag, 2002) as well as the required political will and leadership from governments (Read, 2005; Gumbo, 2004; Howarth, 1999) to generate consensus and provide suitable legislation. However, it has been pointed out (Read, 2005; Howarth, 1999) that there has been a lack of willingness to participate in DSM by some stakeholders causing difficulty in providing the necessary coverage. This raises the question: if over-consumption is such an issue, why is there such hesitation in implementing DSM measures? It should be pointed out that the recommendation that DSM is a more sustainable approach to managing the imbalance between supply and demand should be seen in the context of identifying the point at which it becomes more efficient to shift from water resource reinforcement to a demand management approach (Green, 2003). This decision is often complicated by a number of factors such as the water pricing mechanism used, and the difficulty in quantifying the value of leaving water in the environment.

There has been sparse coverage of advances in the application of DSM tools in the academic literature in recent years (UK Environment Agency, 2005). A number of important DSM studies have recently been reported on by non-academic institutions, and there is a need for a comprehensive, up to date review of the impacts of different DSM tools and the factors which influence their effectiveness. This paper will begin to address the apparent lack of coverage with a contemporary review of advances in the application of residential DSM tools. Recent reports of DSM campaigns in different countries, with the focus on countries in the western, developed-world are reviewed in order to understand the potential contribution of residential DSM tools to conserve water in different types of household under varying conditions and identify influences on implementation effectiveness. The current review will be of interest to, among others, water company professionals, policy makers, regulators and environmental agencies.

The following discussion of the differences in context (i.e. Europe, USA, and Australia) will help the reader appreciate better the relative character of the results reported in this paper, particularly where results are reported as a percentage of total consumption.

Water consumption in litres per capita per day (l/c/d) for the focus regions are presented in Table 1 (below). There is a significant difference between average per capita consumption, with the highest reported in Australia (503 l/c/d), followed by the USA (409 l/c/d), and Europe (170 l/c/d).

[Insert Table 1 here]

Indoor and outdoor water consumption in Australia, USA, and European countries, disaggregated by micro-component, is presented in Table 2. The most noticeable difference is the high level of outdoor consumption in the USA and Australia.

[Insert Table 2 here]

The relative difference the outdoor component demand is the major factor that explains the higher total demand in Australia and the USA in Table 1. This difference, along with other factors such as the efficiency of existing indoor fittings, will determine to some extent the water saving potential of the different DSM tools referred to in this report.

2. Current state of knowledge on the effectiveness of various DSM tools

DSM campaigns usually involve co-implementation of several DSM tools which can be separated into five categories; technological, financial, legislative, operation & maintenance, and educational. In order to distinguish the water saving potential for individual DSM tools on water consumption, data requires a high level of disaggregation (i.e. individual indoor and outdoor components) (Michelson et al, 1999; Renwick and Green, 2000; Turner et al, 2004). A control sample is desirable in order to understand relative savings (Turner et al, 2004) because absolute savings in any one year will not prove useful as they do not account for other factors such as climate variables or restrictions which can significantly change household demand from year to year.

A number of DSM campaigns and controlled studies selected on the criteria that they disaggregate relative savings of different DSM tools are reported on below using the five DSM tool categories.

2.1 Financial tools

The use of financial tools as a DSM mechanism requires that water use is measured on a per unit basis which requires the installation of a water meter. A number of reported impacts on water demand following meter installation are reported on below, followed by a discussion of pricing effectiveness and the different application of financial tools. Some of the synergistic relationships between pricing and metering and non-price measures are in discussed in more detail in Section 4.2.

2.1.1. Metering. Metering water consumption and charging on a per unit basis produces a water bill that varies with the amount of water used, signalling in the mind of the consumer the value of clean water. Meter installation is therefore important if water utilities intend to implement water conservation pricing. The findings from a number of studies of household metering in Europe and the United States are shown in Table 1.

[Insert Table 1 about here].

The processes by which household meter installation causes lower residential water demand are not fully understood, and are likely to be due to effects other than meter installation alone. This observation is based on the assumption that secretly installing a meter in a pipe entering a person's house will have no affect on their behaviour (Thornton, 2002).

The mean reported savings from US programs (see Table 1) is 20 percent. Two separate studies (Maddaus, 2001; Linaweaver et al, 1966) found that metering has a significant impact on outdoor demand and a significantly lower impact on indoor demand. The study by Maddaus (2001) in California revealed that in the first year, metering led to an 18.9 percent reduction in residential water demand between 1997 and 1998, but only an 8.7% reduction between 1997 and 1999 indicating that water demand rebounded after the initial impact of metering. Her study also found that savings due to metering correlated positively with an increase in plot size. Savings from meter installation may also be coincidental. Mean savings from UK reports indicate a 14 percent reduction in demand with a wide variation between different areas due to seasonal demand fluctuations during the monitoring period, implementation of water use restrictions, and reductions in household and network leakage (Ofwat, 2002).

In addition to metering single occupancy houses, many multi-family dwelling units in the United States are converting to systems where each multi-family dwelling unit pays for water and wastewater services directly instead of including these charges as part of the rent. A comprehensive survey of over 10,000 multi-family residences in the United States showed that submetering and a price increase led to a 15.6% reduction (83 litres/capita/day) in per capita demand (Mayer et al, 2004). However, concerns regarding the equity of this approach have been raised because multifamily households are often associated with low-income residents (AWWArf, 2001).

2.1.2. Pricing. As already pointed out, metering water consumption and charging on a per unit basis produces a water bill that varies with the amount of water used, signalling in the mind of the consumer the value of clean water. The reliability of price incentives in reducing demand, at least in the short-term, compared to the uncertainty of other DSM options, has been cited as one of their main strengths (Campbell et al, 2004) as a conservation measure. However, research which shows water demand to be relatively price inelastic (Espey et al, 1997; Renwick and Archibald, 1998), reports which indicate the lack of persistence of price mechanism (i.e. rebounding to the same or even higher levels following an initial decrease) (Maddaus, 2001; Alitchkov and Kostava, 1996; Kanakoudis, 2002) and concerns about equity and the opposing motivation of raising prices (i.e. profit or DSM) (Duke et al, 2002; Howarth and Butler, 2004), have led many to question the efficiency and sustainability of using water price as a method of reducing water demand.

From an efficiency standpoint, the (metered) per unit water price should reflect the marginal cost of water (i.e. the change in cost per unit change in quantity sold) (AWWArf, 2001). Marginal cost pricing first emerged in the United States in the electrical industry during the 1970s and 1980s. Where marginal price structures were used in this early period (and also in some current cases) they set aside the sole, narrow focus of meeting the utility's revenue requirements in favour of a broader set of goals that also include economic efficiency and the promotion of conservation (Baumann et al, 1998). Whilst economists generally advocate residential water prices that reflect marginal costs as a means of reducing demand during periods of limited water supply availability, others argue that residential demand is only price elastic up to a certain point and thus price is a relatively ineffective DSM mechanism. This argument rests on both economic theory and empirical evidence (Dalhuisen et al, 2003; Espey et al, 1997; Chestnutt and McSpadden, 1991).

Despite the general findings that residential water demand is relatively price inelastic, disaggregated price elasticities for different regions and different income groups show significant variations. Dalhuisen et al (2003) studied 64 separate regions in Europe and the United States deriving 314 instances of price elasticity, providing one of the most comprehensive studies to date. They showed that price elasticities vary between regions. In Europe price elasticities averaged -0.28, in the Eastern United States -0.005, and in the Western United States they averaged -0.17. A separate study in Australia (Dandy et al, 1997) found that the price elasticity range was reported between -0.60 and -0.80. Price elasticities have been shown to be highly sensitive to temperature and the regional tariff structure. The magnitude of price elasticity is expected to increase in regions with higher incomes (Dalhuisen et al, 2003). In the UK it has been reported that middle income families' water consumption is more responsive to a per unit price rise than that of high income families and low income families (UKWIR, 1996). This can be explained by the fact that prior to metering low-income families in the UK are already only using enough water to fulfil basic needs so could not substantially reduce their consumption, whereas the price signal for more affluent groups is not sufficiently strong to reduce demand as it is for the middle income groups.

Other research has concluded that outdoor water use is more price elastic than indoor water use (Bruvold and Smith, 1988; Renwick and Archibald, 1998). A recent study of eight water municipalities in California has shown that aggregate demand was 25% more price responsive in the summer months, reflecting the more discretionary nature of outdoor water use (Renwick and Green, 2000). Renwick and Archibald (1998) found that low-income families in Santa Barbara are *more* responsive to price and that households on larger parcels of land had larger quantity reductions under scarcity pricing. Higher relative outdoor water use in the USA compared to the UK is the most likely reason for low-income families in the USA being able to respond to price signals.

2.1.3 Pro's and con's of different tariff structures. The use of marginal pricing may serve the purposes of efficiently meeting the costs of supplying water but not the aim of providing incentives for efficient use. The method by which changes in price are implemented (e.g. seasonal variations or step changes due to volume used) have an impact on the effectiveness of pricing strategies. Such pricing structures are suitably referred to as conservation pricing (e.g. increasing block rates or seasonal rates) because they send an amplified price signal to consumers to conserve water. To be most effective, Espey et al (1997) recommend that pricing structures need to be designed in such a way that discretionary water use in summer months is targeted. Reports detailing the implementation of different pricing structures indicate that moving from a uniform to increasing block structure can significantly impact on demand (USEPA, 1998 in UK Environment Agency, 1997). An increasing block price based on per capita consumption (rather than per household consumption) has recently been shown to effectively meet the objectives of both affordability and efficiency (Liu et al, 2003). Although this approach has shown potential within an experimental group it is yet to be reported on in a fully implemented water pricing program.

A problem experienced when moving from a uniform to increasing block structure it often increases revenue instability leading to affordability problems for the utility itself (Day, 1993; Renwick and Archibald, 1998; Baumann et al, 1998, AWWArf, 2001). For example, in 1990, following the introduction of an increasing block rate structure in the previous year, the town of Goleta in California, which suffered severe water shortages in the mid-late 1980s, moved to a relatively high uniform rate to stabilise water revenues. This was mainly due to the effects of the previous increasing block rate structure, but was also partly as a response to the financial burden of a previously implemented toilet rebate program raising questions about whether the use of an increasing block tariff combined with imposed cost of implementing technological DSM tools may increase the risk of financial insecurity for the water utility.

As already mentioned, in some regions lower-income households are less able to reduce water demand due to low outdoor water consumption, and furthermore are less able to bare the financial burden of high water prices. In summary, from the review of literature on this issue, we observe that water price elasticity varies down to the most disaggregated level (i.e. the individual), but overall, compared to other goods, water is relatively price inelastic and therefore requires significant price increases to have a major impact on demand. For these reasons, if price mechanisms are to be used as a water conservation tool, there is a need for permanent surveys and observations to monitor the paying capacity (and incapacity) of different social groups.

2.2. Technological tools

2.2.1. Indoor water use. The following table (Table 2) shows reported savings from DSM programs involving the installation of water efficient household appliances in different countries. The majority of these come from studies in the USA and Australia where household retrofit programs have been most widely implemented and reported on. The 'retrofit' column in Table 2 refers to programs involving the installation of what can be considered temporary measures such as toilet dams, faucet aerators, low-flow shower heads etc, whereas the other columns show where water appliances have been permanently replaced. The data indicates that 'retrofit' programs can reduce indoor water consumption by between 9-12 percent whilst comprehensive replacement of household appliances with more highly efficient appliances can reduce indoor water consumption by between 35-50 percent.

Achieved water savings from technology vary for a number of reasons. Predictably, they vary due to household appliance water use rate before and after refitting. Figure 1 shows savings for different household appliances as a percentage of total indoor water use from research in three US cities by Mayer et al (2000; 2003; 2004b). Their research indicates that toilet and clothes washer replacement offers the greatest water saving potential for indoor appliances. In order to understand the potential for household retrofits to reduce indoor water consumption, micro-component water use data was obtained from a sample of homes in the three cities studies; Seattle - 37 homes (Mayer et al, 2000), San Francisco - 33 homes (Mayer et al, 2003), Tampa - 30 homes (Mayer et al, 2004b). The homes were retrofitted with high efficiency toilets, clothes washers, showerheads, and faucets.

[Insert Table 2 about here].

[Insert Figure 1. about here].

One of the most important findings from the three studies by Mayer et al (2000; 2003; 2004b) is that leakage, which was mainly caused by faulty toilet valves, accounted for the majority of savings in the Tampa (20.2%) and San Francisco (19.8%) retrofits, but significantly less for the Seattle program (6.6%). This was due to differences in the initial level of leakage in the different municipalities which were 29.7%, 24.3%, and 10.4% respectively.

The importance of toilet leakage for water saving potential has also been pointed out in reports of retrofit programs in New York (Ostrega, 1994) and Jordan Valley Water Conservation District (JVWCD) (Mohadjer and Rice, 2004). Under New York City's Toilet Rebate Program, at least 70% of the toilets in apartment buildings were required to be replaced. About 50,000 apartment buildings had their toilets replaced under the program, and a 'before' and 'after' monitoring project by the Department of Environmental Protection in a sample of 39 retrofitted apartment buildings reported that water consumption had declined, on average, about 37%. These particularly high levels of savings were probably mainly due to the high levels of leakage prior to the retrofit (California Urban Water Use Bulletin, 1994). In the JVWCD case the reduction in leakage resulting from toilet replacements accounted, on average, for 44% of the water savings. In the San Francisco study (Mayer et al, 2003) the removal of leakage from the overall savings data showed that the actual impact of the retrofit of appliances was a demand reduction of 27.9 percent (39% including leakage reduction). Furthermore, during the pre-program data collection period, it was found that only 10 houses (38 percent) in the San Francisco study were responsible for more than 85 percent of the total household leakage.

Results from the Sydney Water Company Every Drop Counts (EDC) program which involved the largest ever DSM study in Australia were recently reported by Turner et al (2004). For research purposes a large sample of over 24,000 randomly selected single residential household participants (out of a total participating population of 200,000) and an equal number of non participants (representing the control group) were used for the analysis. Between July 2000 and July 2002 the control group increased demand by 80 litres/household/day (l/hh/d) and participants increased demand by 22.7 l/hh/d. Hence both the controls and participants increased demand in absolute terms, which the authors point out is likely to be associated with the fact that 2002 was a hot dry year compared to 1999. Participants have ultimately reduced demand relative to the control group, and the 'relative savings' attributable to the program so far are 57.3 l/hh/d indicating that the program has achieved savings of approximately 8% of average household demand and 12% of estimated indoor demand.

However, not all retro-fit programs result in savings and, as a number of experiences in the UK and USA where ultra-low flush toilets (ULFT) were installed have shown, the type of technology used can have a major impact on both the potential savings and customer receptivity (Mayer et al, 2003; UK Environment Agency, 1997). Offsetting behaviour, discussed in Section 3.1 of this paper, can also be a major factor in the success of campaigns involving water saving devices.

2.2.2. Outdoor water use. As noted above, previous research has found that outdoor water use is more price elastic than indoor water use (e.g. Foster and Beattie, 1979; Bruvold and Smith, 1988; UKWIR, 1996; Renwick and Archibald, 1998) due to the more discretionary nature of the former. Irrigation is the major component of outdoor water use and lawn reticulation systems can contribute a significant proportion of variance to external usage values (Chestnutt and Mcspadden, 1991; Renwick and Archibald, 1998). In a recent study, households with more sophisticated lawn reticulation systems were found to have used more water externally than those with manually operated irrigation systems (Syme et al, 2004). The researchers suggest that a reason for this may be a tendency to set timing devices for longer periods or more frequently than other irrigation modes. This is supported by research in the USA by Chesnutt and McSpadden (1991) who found that single family households in Los Angeles with automatic sprinkler systems consumed on average 11.2 percent more than those households using manually controlled sprinkler systems or watering by hand. This poses a significant challenge to the standard promotion of reducing water usage by installing automatic reticulation systems. Because the ownership of automatic reticulation systems has increased rapidly over recent years, Syme et al (2004) point out that it will be crucial for the water agencies to introduce educational programs to ensure that the systems are used appropriately and that water efficiency outside the home is achieved.

2.3. Educational tools

Engaging the public on water conservation issues is important for the objectives of any DSM campaign (Bruvold and Smith, 1988; Lant, 1993; Howarth and Butler, 2004). The difficulty involved in disaggregating the impact of consumer awareness campaigns from other DSM tools means that they are often reported as a combined saving with other measures. A number of programs however have reported disaggregated results which are shown in Table 3 below.

[Insert Table 3 about here].

Public awareness campaigns (e.g. media broadcasts) are generally expected to reduce demand by 2-5 % (Baumann et al, 1998); (USEPA, 1998) and are usually a temporary measure (Wang et al, 1999). A study of an education campaign in southern Arizona for example showed that water use as a function of publicity about water problems had an average elasticity of -0.05 suggesting that a 10 percent increase in the amount of publicity about the need to conserve water would produce a 0.5% reduction in water use. The researchers do not explain how this was measured but conclude that the publicity variable in their study showed ‘no significant lagged effect, thus indicating that the effect of publicity exists only as long as publicity continues’ (Billing and Day, 1989). Longer term awareness can be achieved through education and by encouraging participation with the local community, a good example being the case of Zaragosa in Spain. The initial emphasis in the Zaragosa public education campaign was identifying the suppliers of water efficient devices and bringing them in contact with the public and second, informing the wider public through exposition, school visits, and community presentations on the merits and practicalities of water saving. After one year an evaluation was carried out showing a decrease in the city's annual water consumption of 5.6%. The program also recorded an increase in awareness among 28% of Zaragosa's population (UK Environment Agency, 1999)

Adopting a different form of public education, the Artesian Water Company in New Castle County, Delaware (U.S.A) (Wang et al, 1999) used bill inserts and pamphlets as an information source among a sample group of the population. Demand reduction of 4.8% in the summer months was recorded between 1992 and 1997.

Research indicates that the impact of education campaigns may vary for regions with different xeric regimes. Using an American Water Works Association (AWWA) survey of 430 U.S. water utilities, Nieswiadomy (1992) estimated the impacts of public education campaigns on water conservation for four different regions in the United States – North Central, Northeast, South and West. His results showed that public education programs which urge people to conserve water significantly reduce water demand only in the western USA which is more prone to water scarcity. This finding is supported by other examples such as those provided by Renwick and Green (2000) who used a cross-sectional monthly time series econometric model to study the effects of DSM tools including education in eight water supply areas in the western USA. The study estimated that public information campaigns reduced demand by an average of eight percent. In contrast, a study in Swindon in the UK by Thames Water and the Environment agency among 8000 residences found that a campaign involving direct mailing, newspaper and radio advertisements, and posters had no impact on demand and only 5% of the population questioned indicated that they had noticed the campaign (Howarth and Butler, 2004).

2.4. Operation and maintenance tools

Losses due to leakage in water networks can account for a significant fraction of water demand. Losses for water networks vary in different countries and in different regions in different countries. For example research by the EEA (2003) has reported major losses of water due to leakage in Italy of 30 percent and in Bulgaria of 50 percent. The potential for reducing water demand by reducing leakage is therefore significant. In the UK, leakage reduction has led to a reduction in demand since 1997, when water companies were given mandatory leakage targets based on their economic level of leakage (i.e.

the cost of repair weighed against the cost of losses) and also offered free supply pipe leakage detection and repair service for their customers (Ofwat, 2000b). Data on the precise savings achieved are not available, but since its peak in 1994-95, leakage among UK water companies has fallen by 31 percent from 228 litres/property/day to 174 litres/property/day (Ofwat, 2000b). The fact that reducing infrastructure leakage can reduce overall demand so significantly means that it is often considered to be more effective and therefore more important than other DSM tools.

Saegrov et al (1999) have identified a need for greater international collaboration, particularly in Europe and North America relating to the exchange of current practices relating to static, dynamic and operating factors which can affect leakage. This is also relevant to the sharing and exchange of results and ideas about other DSM tools.

2.5. Regulatory rules and legislation,

Complementary legislation can be used both to encourage implementation of other DSM tools and to impose restrictions on water consumption. Restrictions can be characterised on an increasing scale (i.e. voluntary to mandatory measures). An example of how legislative tools can be combined with other DSM tools and implemented as a cascade of measures to address short-term water scarcity is presented below in Table 4 showing relevant cumulative savings as reported in the UK (UKWIR, 1998).

In both Australia (White, 2001) and the USA (USEPA, 1998) the introduction of plumbing codes combined with a labelling approach for water efficient goods has been introduced with results indicating overall savings for the water utility of 5-10 percent over a 10 year period. In Goleta, California, a mandatory allocation policy was introduced where households were charged based on historical water use with significant marginal price penalties for households exceeding their allotment; this approach reduced the average household consumption by 28.2 percent (Renwick and Archibald, 1998). Renwick and Archibald also found that the allocation policy reduced demand more among low density respondents with larger landscaped areas (57 l/hh/d) than high density respondents (27 l/hh/d) with smaller amounts of landscaping. Restrictions applied to certain water uses, such as washing down pavements or driveways, car-washing, and banning landscape irrigation during peak evapo-transpiration hours has also been shown to reduced consumption, by 29 percent in California (Renwick and Archibald, 1998) and 25-35% in Greece (Kanakoudis, 2002).

[Insert Table 4 about here].

3. Identified influences on the effectiveness of residential DSM tools

In the previous section the reported savings of different types of DSM tools in different regions have been discussed. In the following section we give examples of how the conditions of implementation (e.g. environmental and demographic factors) can influence the effectiveness of different DSM tools.

Research shows that indoor household water consumption is dependent upon a number of factors, the most important of which are household occupancy (Mitchell, 2001; Turner et al, 2004), household income (Jones and Morris, 1984; Moncur, 1987), and the type of water intensive household appliance installed (Mayer et al, 2004a; Decook et al, 1988). Outdoor water use is affected by climate or the evapo-transpiration rate (Maddaus, 2001; California Urban Water Use Bulletin, 1994), plot size or population density (Renwick and Archibald, 1998; Maddaus et al, 1996) irrigation method (Syme et al, 2004; Renwick and Archibald, 1998) and also local cultural norms (Maddaus et al, 1996). Collection of disaggregated data regarding these factors is a high priority when specifying and targeting DSM tools for a specific region because it will affect the water saving potential, and therefore the relative returns, from implementation.

There is a high variation in per capita demand between different countries around the world, in different cities within different countries, and in different neighbourhoods in different cities, and this in turn affects the potential for different DSM tools to reduce consumption. For example in the EDC campaign in Sydney, Australia, analysis of the savings of participants in different Local Government Areas (LGA) shows that participants in 22 out of 40 LGAs achieved significantly higher relative savings when compared to their controls (Turner et al, 2004). The range of savings for LGA's varied from the highest (183.5 l/hh/d) in the Lane Cove area, to the lowest (41.1 l/hh/d) in the Sutherland area.

This indicates that the targeting of some LGAs could be more beneficial to provide high relative savings than others.

The relative savings accruing to three income groups were also analysed by Turner et al (2004). The results of their analysis indicated that it would be beneficial to seek higher uptake amongst low-income groups who have high average relative savings of 69.9 l/hh/d. Targeting of low income groups would not only provide high relative savings, thus increasing the overall level of savings of the program, but also lead to added social benefits for low income households in the community. Furthermore, of over 200,000 participants 38% were exempt from paying for the retrofit due to proof of low income status whereas the Australian Bureau of Statistics states that only 22% of households in the Sydney came from this low-income group (Turner et al, 2004) indicating a relatively higher uptake of DSM tools among low-income households. An explanation for this might be that low income householders have higher indoor water demand than other groups due to higher occupancy, so installing water saving devices free-of charge would be more advantageous.

Urbanisation can be a major cause of unsustainable water consumption due to the impact on population size. As well as increasing total domestic demand, an additional difficulty that water planners face due to in-migration is that newcomers may bring attitudes and behaviours more suitable to less arid areas and will initially be less aware of water conservation issues (Trumbo and O'Keefe, 2005).

Research into how social perceptions of water conservation measures might affect the implementation of DSM is reported on in the following section discussing offsetting behaviour.

3.1 Offsetting behaviour. In 1975, Peltzman's work on automobile safety regulation raised the spectre of offsetting behaviour decreasing policy effectiveness – and perhaps even leading to perverse outcomes – when people consume more of a good than they usually would (Peltzman, 1975). There is also evidence of offsetting behavioural responses to water conservation policies (Geller et al, 1983; Campbell et al, 2004). Geller et al (1983) found evidence of offsetting behaviour in their experiment involving educational, behavioural, and engineering strategies for inducing residential water conservation (and all combinations of the three in their 2 x 2 x 2 design). Their findings strongly suggest that people engage in offsetting behaviour when they know devices are causing conservation. For example, if people know that their showerhead is low-flow, they may feel free to take longer showers.

Furthermore, a study of the trade-offs between prices, people, devices, and rules, in Phoenix Arizona of 19,000 households over six years (Campbell et al, 2004) found empirical evidence that offsetting behaviour is dependent on the mode of water saving device implementation. Summarising the study, Campbell et al (2004) make a number of observations that we consider to be central to the aims of this review.

The city officials tried to legislate for the use of water-saving devices, to randomly give people water-saving devices, to invite people to pick up water-saving devices, and had individual people work with individual households to install water-saving devices. These different settings helped illuminate the conditions under which offsetting behaviour appears and what can be done to ameliorate it. One indication was that ignorance prevents offsetting behaviour (Geller et al, 1983), though this has grave implications for citizenship and governance. Whether people picked water saving devices up or were given them randomly, it was obvious that people knew that the fixtures were water-saving, and this tactic at best had little effect, at worst induced water consumption. Taking the results for devices alone, the results for these programs suggest that personalized communication can enhance the water saving potential of implementation and decrease the effect of offsetting behaviour. They also infer that communication is even more important than self-selection. The possibility of offsetting behaviour should be kept firmly in the mind of the policy analyst and public administrator.

The cooperation literature (Ostrom, et al, 1993). tends to support the importance of repeated communication—a brochure is a one-shot communication; billboards and radio messages may be heard many times. Depending on how the program is designed, education to children may combine personal communication with multiple messages (Campbell et al, 2004).

The durability of effects of conservation programs may decline over time. However, this is true of all policy interventions. Hardware devices themselves wear out over time. Price increases are overtaken by inflation. Engineering-focused regulations, such as those used here, become obsolete as technology improves, and so on. Thus, all of these concerns just remind us that policies cannot be static—we cannot expect to find the best one and then move on; we must revisit even policies that have been effective (Campbell et al, 2004). This supports the need for the setting up of an organisation specifically to design, implement, and continuously monitor DSM programs, a suggestion that is widely supported by other DSM commentators (e.g. Gumbo 2004; Turner et al, 2004; Read, 2005, White, 2001).

Campbell et al (2004) also make an important point regarding 'coercive types of regulation' which is mentioned here because of its relevance to the overall conclusions in her study. The most coercive types of regulation—command and control rules—have been much criticized in recent years because they are not market-like and therefore, at least in principle, are less efficient. In addition, there is some evidence that people in particular do not support them for water conservation (Avalos & De Young, 1995). However, Weimer & Vining (1999) state, "While it is fashionable to focus on the disadvantages of rules . . . , rules may provide the most efficient method for dealing with market failures in some contexts." They further point out that such regulation can provide higher certainty of outcomes.

In sum, Campbell et al (2004) conclude that in the trade-offs between prices, people, devices, and rules, prices and rules are the most certain and, because they can be applied generally to all households, their cumulative effects can be great. Simply giving households engineered devices is not effective. Offsetting behaviour may be so strong that effectiveness is swamped; here, non-market provision by government is a poor choice, unless mediated by direct communication. However, programs that must be administered one-on-one to individual households will tend to have a smaller impact overall, even if they have a greater impact per affected household— but these techniques do have the advantage of inducing cooperation, which is in keeping with participatory democracy. Prices and rules are administratively more inexpensive with high effectiveness; cooperative programs educate citizens but require more resources and are less effective overall.

We observe that offsetting behaviour is linked to awareness of the installation of water saving devices, as well as the high certainty regarding rules is a strong argument for introducing water efficiency rating schemes along the ‘white goods’ supply chain, to include, for example, manufacturers and wholesalers of white goods, plumbers, and building contractors.

4. Identified influences on the adoption of residential DSM tools

Achieving coverage of DSM tools depends on a number of factors. These include financial factors such as the cost of installing vs. the potential savings, willingness to make lifestyle changes, access to suitable technology etc. In order for DSM tools to reach the target population it may be necessary to introduce specially designed policies to encourage uptake. A number of instances where implementation policies have been relatively successful are given below.

In a 1991 customer survey, the City of Los Angeles learned that poor customers were receptive to conservation programs but less likely to participate than wealthier customers (Pollyea, 1993) probably because of the initial investment required. Research in Sydney, Australia (Turner et al, 2004) and Austin, USA (Poch, 1995) has shown that the indoor water saving potential of DSM in low income residencies is 18% and 34% greater respectively than in other socioeconomic groups as shown below in Figure 2. The results of the two studies also show that if DSM strategies are offered free-of-charge for low income households, the potential uptake can increase significantly (i.e. 100% in Austin Texas and 16% higher than other socioeconomic groups in Sydney). The Austin Ultra Low-Flow Toilet Outreach Program provided free toilets, showers and leakage repair to residents in traditionally low- income zip-codes. Program eligibility took into account family size and income with different thresholds for residents under and over 60.

[Insert Figure 2. about here].

The majority of program participants had incomes less than US$25,000. The program objective was to encourage uptake in low-income households because low-income households had not participated in the previous toilet rebate program because of the initial investment required.

Although uptake figures were not available the program anticipated replacing 15,000 toilets, with a saving of 2.2 M/litres per day, and 100 percent coverage (AWWArf, 2001). Water municipalities in both Australia and USA have used computer mapping software to identify postcodes or regions which are suitable for a certain type of DSM strategy (e.g. low income, low density, high evapo-transpiration rate). A mapping approach can be useful to target identified social groups with relevant policy tools, thereby utilising identified influences on adoption.

4.1 Synergistic relationships between price and non-price mechanisms

A number of authors have suggested that pricing and metering might raise citizen's awareness of the need for water conservation (Bruvold and Smith, 1988; Van Vugt, 2001; Campbell et al, 2004). Pricing can be regulatory if prices are intentionally set in a regulatory process to achieve policy goals, but pricing still allows an element of voluntary behaviour as it allows people to make their own decisions faced with the administered price; as such pricing induces rather than requires change.

In preparing this review no studies were found that specifically focus on the link between pricing-metering and the uptake of specific non-price mechanisms. This is indicative of the difficulty in distinguishing between people's different motivations for displaying conservation behaviour. One study in the USA (Hamilton, 1983) developed a causal model of water conservation behaviour, and results indicated that 'economic motives seemed to be common among poorer, less well educated households, with more children and high baseline use levels'. This repeats the findings among low-income households in the USA by Renwick and Green (2000). Hamilton (1983) continues that 'concerns with the economic aspects of water consumption are obviously quite realistic for such households, though the concern did not translate into substantial savings'. This low level of responsiveness among low-income households to pricing and metering would indicate that synergistic relationships between price and non-price mechanisms are limited to non-price mechanisms and those that citizens can implement free-of-change (e.g. behavioural changes or freely available water saving technology).

Metering has the advantage of improving customer's knowledge about their consumption, particularly when combined with specific tariff structures. Previous research (Bruvold and Smith, 1988; Trumbo and O'Keefe, 2005) has shown that customer knowledge about consumption is significantly related to lower demand and is more important than their beliefs about water conservation in reducing water consumption. Furthermore, a number of researchers, (e.g. Bruvold and Smith, 1988; Van Vugt, 2001) conclude that the use of an increasing block structure coupled with an information campaign designed to inform customers of their consumption under each block will have a synergistic effects in improving customer knowledge about water consumption, and awareness of the need for reduction.

The relationship between price elasticity and willingness to participate in non-price DSM programs raises an important point relating to the observation made in the previous section regarding the difference between price elasticity among low-income households in the UK and USA (i.e. price elasticity is higher among low-income households in the USA due to higher outdoor water use which can be reduced through voluntary behavioural adaptations prompted by price). Because it is relatively more expensive for a low-income family to change its appliances than for a high-income one, if technological DSM tools were offered free of charge to low-income households (as they were in the examples in the Sydney Water Company EDC and Austin ULFT outreach campaigns discussed previously) then we might expect low income families to be better able to reduce their indoor consumption. This relationship is particularly relevant in the design of DSM campaigns in sections of the community characterised by low-income households.

4.2. Mediating processes and DSM implementation

In regions with a high proportion of domestic use DSM can play a major role in addressing water stress. In an earlier paper Bruvold (1988) identified three mediating cognitive processes and one mediating structural processes that affect water conservation behaviour which have been referred to either singly or collectively by subsequent researchers (e.g. Syme et al, 1999). Due to the wide-range and different scale of influences on DSM, the link between wider socio-economic and environmental influences and these mediating processes are often difficult to discern.

In the earlier sections of this paper drivers of increasing per capita consumption and associated water stress were identified and these, along with the connected mediating processes suggested by Bruvold (1988) are presented in a conceptual model in Figure 3 (below).

[Insert Figure 3. about here].

5. Discussion

The following section explores a number of challenges relating to prior and post evaluation of DSM and its role in the DSM implementation decision process.

5.1 The role of evaluation in DSM implementation

Because the decision to implement DSM has wide-ranging social impacts, and also inevitably requires financial intervention from the water sector or local government, the case for DSM needs to be rigorously tested and proven. It requires evaluation of social, economic, and environmental impacts and, where possible, should to be supported by historical evidence.

One of the problems faced in using data collected from previous studies to make prior-evaluations of the potential impacts of DSM is (lack of) transferability of trends between regions. For example, the success of a DSM program in one region may not be reflected in another region due to the situation specific socio-demographic / socio-economic water demand trends. In another region, the impact of other factors, e.g. climate, will come to bear on water availability and demand trends. Climate also inevitably affects the water culture of local citizens, complicating further the interface between society and agencies responsible for water governance. This last point in particular means that policy mechanisms need to be carefully crafted to handle cultural sensitivities on a regional basis. Furthermore, ‘region’ can, in some instances, be replaced by ‘neighbourhood’, if there is low resolution of socio-demographic and socio-economic variation.

To understand the relevance of the lack of transferability of DSM program performance data on policy-making it may be helpful to distinguish between using ‘theoretical’ and ‘actual’ DSM program performance data. Theoretical evaluation based on ‘expert’ forecasts is often the only accessible information that policy makers have, in the first instance, on which to base their decisions. However, the lack of transferability of trends, even at the household scale, means that in the first instance uncertainty is usually high in DSM forecasting, and this is a possible barrier to commitment by relevant institutions. A prior evaluation only becomes credible as actual (empirical) evidence is gathered (e.g. through pilot-scale DSM projects). For this reason the lack of transferability of trends is problematic because, given the lack of credible proof, even pilot-scale studies will still require the existence of ‘champions’ of DSM. This point is relevant to the discussion in Section 5.2 (below).

Prior evaluation of DSM inevitably involves economic appraisal and there has been much debate about the economic method used. An early study in the USA (Hirshliefer et al, 1960) criticised the then prevalent practice of comparing water projects by measuring the ratio of the present worth (PW) of benefits (PWB) to the PW of costs (PWC). The authors demonstrated that it was in fact the NPV (net present value), the absolute difference between the two (i.e. cost-benefit analysis – CBA), that should (i) determine whether a given one-off water scheme should go ahead or not and (ii) form the basis of scheme ranking.

The authors put their ideas to work in the context of New York’s then ‘water crises. They compared various suggested options for the “improvement of existing supplies” (leakage reduction, domestic metering extension, and price increase for metered consumers) with the new (Cannonsville) dam supply project which had already begun. This led the authors to a comparison, based on present worth calculation, of the costs of the three demand-management options (respectively $1, $148, and $267 per million US gallons saved, using an annual discount rate of 6%) with the estimated Cannonsville cost of $459 per million US gallons supplied. The case for DSM options were concluded to be, respectively, “overwhelming”, “impressive”, and “arguable”.

However despite the apparent advantages afforded to DSM indicated in the above studies, nearly ten years later Steve Hanke (1981) spent a hectic decade publicising the application of CBA (via NPV) to improve decision-taking in the US water industry, covering both the formulation of marginal cost based pricing techniques and the assessment of a wide range of demand-management measures (Herrington, 2006).

In the UK increasing interest in these matters found practical expression in a contract let out by UK Water Industry Research and the Environment Agency (UKWIR & EA) to NERA (London) in 1995 (Herrington, 2006). The framework developed (Economics of Demand Management – EDM) had to be acceptable to the economic and environmental regulators – the Office of Water Services, and the Environment Agency, respectively. The 'Practical Guidelines' report put into practice least-cost planning, the agreed formal planning objective being to minimise the net social cost of balancing the supply and demand for water into the future. This could be achieved by calculating the average incremental social cost (AISC) for each of the supply and demand options, which then need to be "selected and timed in increasing order of AISC to form an initial solution: a programme of options which balances supply and demand over the horizon (Baker et al, 1996).

Within four years it was claimed in a second NERA report commissioned by UKWIR/EA that there was (i) significant variability in the use made of the 1996 report and Guidelines, (ii) some misinterpretations of the suggested approaches and (iii) key outstanding methodological issues (Atkinson & Jones, 2001).

The New York example is one of many reporting the economic efficiency of demand-side management (e.g. see for the USA - Maddaus, 1996; 1999, and for Australia – Burn et al, 2002). A more recent study in Australia, comparing the economics of demand vs. supply-side options (Fane et al, 2002), reports the importance of the methods used to make economic evaluation. Fane et al (2002) conclude that the use of annualised unit cost for large scale supply schemes is inherently misleading. The unit cost calculated by this method does not represent the true cost of supply. Excluded are periods when demand can be expected to be significantly less than safe yield. The result is a systematic under representation of the cost of supply from large scale supply projects such as new dams (Fane et al, 2002). Using Levelised cost significantly altered the ranking of the options, in particular, decreasing the cost effectiveness of building new dams because "annualised cost does not reflect the fact that with projected rate of demand increase, it would be nearly 70 years before the safe yield from this project was fully utilised".

Residential water savings can lead to a number of quantifiable benefits for water utilities which are overlooked in some economic evaluation methods. Advantages include: reduction in operation and maintenance costs, deferral or downsizing of capital facilities, and reduced water purchases from wholesale providers (Maddaus, 1999). Least cost planning has emerged as the way forward for water utilities in regions where water conservation has become an objective or where ongoing supply expansion is constrained (Fane et al, 2004). Least cost planning originated in the energy sector in the United States during the 1980's for comparing energy conservation programs with increased generation from sources of supply (Beecher, 1996). In the Australian water sector water conservation is based on the key ideas that: demand is for the services water provides rather than the actual volume supplied; and that a drop of water saved is equal to a drop supplied (Fane et al, 2004).

The above discussion about economic evaluation highlights the importance of the methods used, as well as the unfortunate scope for ambiguity, particularly with regard to deciding which externalities to include in economic evaluations.

In this section we have described two major factors (non-transferability of trends & legitimacy of economic appraisal methods) which potentially undermine both the validity and legitimacy of projects aimed at evaluating the potential impact and efficiency of demand-side measures in managing water scarcity. Because evaluation is used by policy-makers to design suitable regulatory instruments, and regulatory instruments inevitably determine the timing of implementation of DSM to ameliorate water scarcity, we recognise these two factors as being a priority for future research in the scientific community.

The following section discusses different institutional setting that require different types of regulatory instruments to probe water utilities to engage in DSM. We discuss the timing of implementation of DSM and cite examples of how regulatory instruments can on the one hand help avoid, but on the other may induce an anachronistic tendency in responses to water scarcity.

5.2 Engaging governments and water utilities in DSM

The level of engagement (or non-engagement) by governments and water utilities in DSM planning is probably the most important factor in determining whether DSM is used as a reactive response or as a long-term pro-active measure. In the case of the USA, the debate regarding the timing of responses to water scarcity is best summed up by Elisabeth Graffy (2006) in her recent article ‘Expert Forecasts and the Emergence of Water Scarcity on Public Agendas’ who comments that:

> “the institutional fragmentation of water expertise and prevailing patterns of communication about water scarcity militate against the formulation of a common public definition of the problem and encourage reliance on crises to stimulate social and policy agenda setting. Expert forecasts of worldwide water scarcity suggest the need for preventive, coordinated, and comprehensive public agendas, but existing approaches remain crisis driven and ad hoc”.

With regard to recent policy changes in the USA she comments that:

> “Local and national agenda setting since 2002 provides fresh opportunities for expert networks to become engaged. In the absence of such efforts, further agenda setting is likely to rely on catastrophic events, rendering the preventive function of expert forecasts largely moot”.

The commitment and advances in DSM in Australia, reported earlier in this paper, are reflected in the 2004 national drought policy which has already started to adopt a risk management, as opposed to crisis management, approach to ameliorating water scarcity in the domestic sector (Wilhite, 2005).

In Europe, Article 14 of the Water Framework Directive promotes the “active involvement of all interested parties” which is important in the context of demand management because water conservation/efficiency programmes are unlikely to succeed in the absence of public involvement and support (Howarth, 2006).

In the UK the Water Act received Royal Assent in 2003, and water conservation is addressed in specific sections addressing ‘efficient use of water resources’ (Section 81), ‘requirements on relevant undertakers’ (Section 82) and ‘water conservation by public authorities’ (Section 83). As Howarth

(2006) points out, in the UK, 'sticks' have played a greater role than 'carrots' in introducing water efficiency, and we may hypothesis that this is partly a result of comprehensive privatisation and subsequent heavy regulation in the UK water sector.

6. Conclusions

Evidence indicates water price elasticity for indoor use is relatively low meaning that large increases in price are required to significantly reduce indoor water consumption, which could be economically counterproductive for low-income groups. On the other hand, outdoor consumption is more responsive to changes in price and mandatory restrictions. Accordingly, if used, we suggest that pricing structures should be accompanied by a number of complimentary DSM policies including

- a 'lifeline' rate to accommodate low-income groups.
- sufficient opportunities for water consumers to reduce their indoor water consumption without excessive costs, and
- seasonal rates to reflect variations in seasonal demand.

We have reported research showing that offsetting behaviour is linked to water consumer's awareness of the installation of water saving devices. We suggest that this observation, and the high certainty of water savings achieved by policy 'rules', suggests that there is a strong argument for introducing water efficiency rating schemes along the 'white goods' supply chain, to include, for example, manufacturers and wholesalers of white goods, plumbers, and building contractors.

From this review it can be concluded that indoor consumption in existing housing can be reduced by 35 - 50% if water intensive appliances are comprehensively replaced. An important caveat to this conclusion is that potential water savings might be significantly less in regions where domestic water consumption is already relatively low (e.g. if water intensive appliances are not widely used). Replacement of old toilets offers the greatest water saving potential and this is, in part, due to the incidental repair of leaking toilet valves. Substantial indoor savings are possible amongst low income households but water efficient appliances need to be offered and installed free of charge to achieve significant coverage. Regulatory measures such as upgrading of water efficient technology when a change of household occupancy occurs has been shown to be a successful method of achieving uptake of water meters. This approach might be transferable to improve coverage of technological DSM tools and requires further investigation.

Overall, DSM programs can be expected to reduce water consumption by 10 to 20 percent over a 10 to 20 year period depending on type of approach used, and, as already mentioned, the level of residential per capita consumption before implementation of DSM measures. From the reported findings it can be concluded that in general, relatively moderate (5-15%) reductions in aggregate demand can be achieved through modest price increases and voluntary alternative DSM policy instruments, but to achieve larger reductions in demand (greater than 15%), policymakers will likely need to consider either relatively large price increases, or more stringent mandatory policy instruments (Renwick and Green, 2000; Maddaus, 1999).

6.1 *Recommendations for future research*

6.1.1 Metering and consumer engagement in water conservation. Research shows that consumer knowledge about water consumption is the most important cognitive process in driving consumer interest in reducing water demand (Lant, 1993), but such knowledge is currently lacking. Metering has the potential to engage consumers in DSM programs by improving their knowledge about personal water consumption. It is concluded that metering is currently under-utilised in this respect and future research could explore innovative methods to allow consumer's to access their water consumption on a daily basis (e.g. via the internet, special purpose LCD)

6.1.2 Pricing mechanisms. Innovative pricing mechanisms (e.g. increasing block price based on per capita consumption (Liu et al, 2003) which achieve both efficiency and affordability require further research in the form of large scale pilot studies.

6.1.3 DSM policies to compliment the use of conservation pricing. As already mentioned, if pricing mechanisms are to be used as part of a DSM strategy they should be accompanied by a number of other DSM policies. Combinations of pricing and complimentary policies that achieve the goals of efficiency, equity, and sustainability require further research.

6.1.4 Raising awareness of water scarcity on public agendas. DSM can lead to a number of quantifiable benefits for water utilities including reduced operation and maintenance costs, deferral or downsizing of capital facilities, and reduced water purchases from wholesale providers. However, implementation of DSM tools (e.g. in all new developments) requires participation by relevant stakeholders, most importantly from local and national government. There is scope for future research into participatory methods of evaluation that engage all stakeholders in DSM.

6.1.5 Investigation of the use of 'stick's (regulation) and 'carrots' (incentives). It is possible to observe an interesting, if somewhat abstract, connection between the predominant role of 'sticks' as regulatory instruments in the UK (Howarth, 2006), Elisabeth Graffy's observation that "further agenda setting is likely to rely on catastrophic events", and the phenomenon of offsetting behaviour. This connection is a tension between lack of willingness to engage, possibly due to the potential socio-psychological, as well as political risks of using 'command and control' rules, and the potential risks of not acting at all to forecasts of water scarcity. There is certainly scope to explore the different coping mechanisms in different cultural and institutional settings in future cross-country, comparative research.

6.1.6 Analysis of the DSM implementation decision-processes and methods to manage uncertainty. We recommend that more carefully designed and monitored pilot-scale studies are required during evaluation

The decision process involved in DSM implementation inevitably begins with a feasibility study to investigate the potential impact of the specific measure (s), against forecasts of water scarcity. The combination of the forecasts of demand and availability, particularly using long-term projections is characterised by high uncertainty, and one might therefore wonder how the much needed commitment to DSM, necessary to achieve comprehensive implementation, can ever be attained. We hope that this review has begun to address this issue by presenting data showing the real (as opposed to potential) impact of DSM in a western, developed-world context. However, we observe that further work is needed in developing decision support tools that manage uncertainty both of water availability and demands, to address the non-transferability of trends & legitimacy of economic appraisal methods.

Acknowledgements

The work on which this paper is based was supported by the European Commission 6th Framework Project – Aquastress, Contract No. 511231-2. The contents of this publication do not necessarily reflect the views and policies of the European Commission.

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Table 1 Reported values of water demand (l/c/d)

Literature source	Daily water consumption (l/c/d)	Region	Country	Region	Description
White 2002	503	Australia	Australia	Sydney	Actual level
Madsen 1995	186	Europe	Denmark	National	
Madsen 1995	167	Europe	Denmark	Copenhagen	
Kloss-Trebaczkiewicz 2000	206	Europe	Poland	Warsaw	
Kloss-Trebaczkiewicz 2000	123	Europe	Poland	Bialystok	
Kloss-Trebaczkiewicz 2000	154	Europe	Poland	Average	
Madsen 1995	205	Europe	Poland	Lublin	
Butler and Memon 2006	150	Europe	UK	National	
Dietemann 1998	476	USA	USA	Seattle	Peak season
Nelson 1992	475	USA	USA	North Marin	13200 single-family homes
Schutte and Pretorius 1997	276	USA	USA	Average	

Table 2 Household uses in different countries (%) (Ofwat, 2002)

	England and Wales	Scotland	Finland	Switzerland	US	Australia
Toilet flushing	33	31	14	33	11	20
Bathroom (bathing and sho	20	32	29	32	8	26
Kitchen (washing, dishwasl	17	35	34	19	16	20
Miscellaneous	27	<1	21	14	7	-
External	3	1	2	2	58	34

Table 3. Household savings from metering

COUNTRY	REGION	SAVINGS (%)	CONDITIONS UNDER SHICH SAVINGS WERE MADE	SOURCE
Bulgaria	Sofia	10	Assuming 2.7 person household	*Alitchkov & Kostava, 1996*
Canada	Ottawa	10-40		*Brooks & Peters, 1988*
UK	National	7	Whole summer period	*UKWIR, 1996*
UK	National	15	Peak week	*UKWIR, 1996*
UK	National	22	Peak day	*UKWIR, 1996*
UK	National	11	High users (>400 l/cap/d)	*UKWIR, 1996*
UK	National	20	Middle income bracket (250-400 l/cap/d)	*UKWIR, 1996*
UK	National	none	Lower income bracket (<250 l/cap/d)	*UKWIR, 1996*
UK	National	7.2	Metering all users	*UK Environment Agency, 1999*
UK	National	1.4	Metering sprinkler users	*UK EA, 1999*
UK	National	11		*UKNMT, 1993*
UK	Isle of Wight	21		*UKNMT, 1993*
USA	California	18	1998 compared to 1997	*Maddaus, 2001*
USA	California	8.9	1999 compared to 1997	*Maddaus, 2001*
USA	Austin	25	Compared to previously unmetered	*USEPA, 1998*
USA	National	20		*USEPA, 1998*
USA	National	20		*AWWArf, 2001*
USA	Baltimore	30	Leakage and waste	*Linaweaver et al, 1966*
USA	Baltimore	none	Indoor demand	*Linaweaver et al, 1966*
USA	Baltimore	56	Outdoor demand	*Linaweaver et al, 1966*
USA	Baltimore	34	Total demand	*Linaweaver et al, 1966*

Table 4. Water savings achieved using indoor technological tools

CITY	COUNTRY	SAVINGS (l/hh/d)	SAVINGS (%)	RETR0-FIT	TOILET	SHOWER	BATH	FAUCET	DISH WASHER	CLOTHERS WASHER	LEAKS	SOURCE
Seattle	USA	228	37.2 **(2*)**		•	•	•	•	•	•	**(5*)**	*Mayer et al, 2000*
San Francisco	USA	325	39 **(2*)**		•	•	•	•	•	•	**(5*)**	*Mayer et al, 2003*
Tampa Bay	USA	419	50 **(2*)**		•	•	•	•	•	•	**(5*)**	*Mayer et al, 2004*
Austin, Texas	USA	146 **(1*)**	~		•	•						*AWWArf, 2001*
US cities	USA	227	~		• **(3*)**	• **(3*)**			•	•	•	*Maddaus, 1984*
US cities	USA	158	~		• **(4*)**	• **(4*)**						*Maddaus, 1984*
US cities	USA	40-65	~	•								*Maddaus, 1984*
San Jose	USA		11**(2*)**	•								*Wang et al, 1999*
Delaware	USA		10 - 15 **(2*)**	•	•						•	*Wang et al, 1999*
8 California cities	USA		9	•								*Renwick and Green, 2000*
Sofia	Bulgaria	109			•	•		•				*Alitchkov and Kostava, 1996*
Sydney	AUS	57	12 **(2*)**	•							•	*Turner et al, 2004*
East Sussex	UK		5		• **(6*)**							*Keeting and Styles, 2004*
East Sussex	UK		16		• (7*)							*Keeting and Styles, 2004*

1* *Targeted at low income households*
2* *On indoor use only*
3* *Installation of 3 litres per flush toilet or 3 litres per minute showerhead*
4* *Installation of 15 litres per flush toilet or 15 litres per minute shower-head*
5* *leaks fixed inadvertently due to replacement of faulty toilets*
6* *Total savings in new construction*
7* *Total savings in old houses*

Table 5. Educational tools

COUNTRY	REGION	SAVINGS (%)	PERIOD OF MEASUREMENT	SOURCE
USA	California	8	Annual	*Renwick & Green, 2000*
USA	Austin	2-5	Annual	*USEPA, 1998*
Spain	Sargossa	5.6	Annual	*Kallis et al, 2001*
UK	National	7.6	Annual	*UKWIR, 1998*
UK	National	12.3	Peak 7 days	*UKWIR, 1998*

Table 6. Cumulative savings from short term measures (%) (UKWIR, 1998)

	APPEALS	PRESSURE REDUCTION	SPRINKLER BAN	HOSEPIPE BAN	NON-ESSENTIAL USE BAN	ROTA CUTS	STANDPIPES
Peak 7 days	12.3	12.3	20.2	32.6	32.6	55.4	85.5
Annual	7.6	7.6	7.9	9.8	9.8	42.2	76.4
Variation	0 to -6%	na	na	0 to -37%	0 to -12%	30 to -49%	

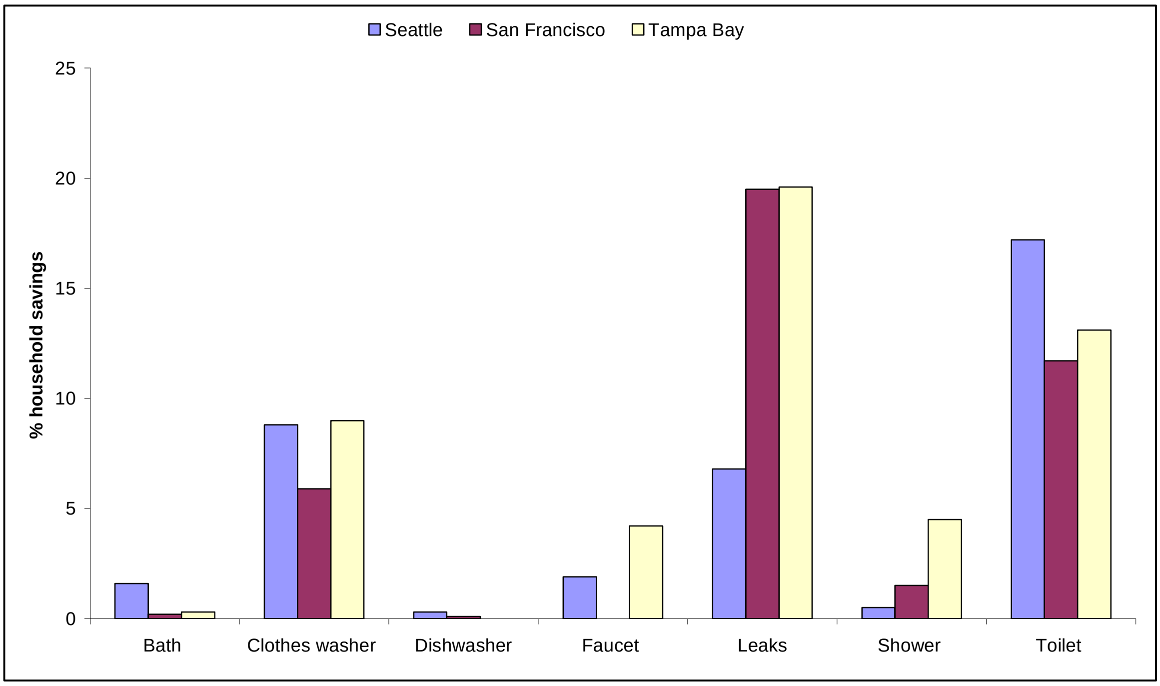

Figure 1. Water savings for different household appliances as a percentage of total indoor water use in Seattle, San Francisco and Tampa Bay - adapted from Mayer et al (2000; 2003; 2004b)

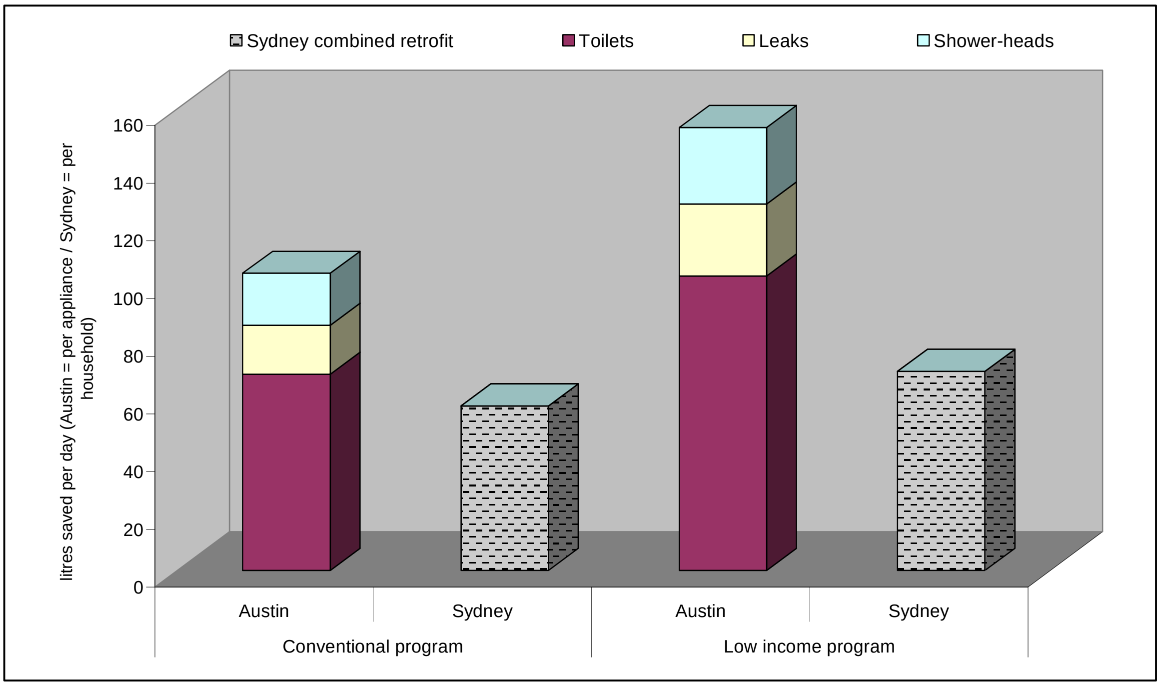

Figure 2. Water savings in low-income groups compared to average in Austin and Sydney retrofit programs – adapted from AWWArf (2001) and Turner et al (2004).

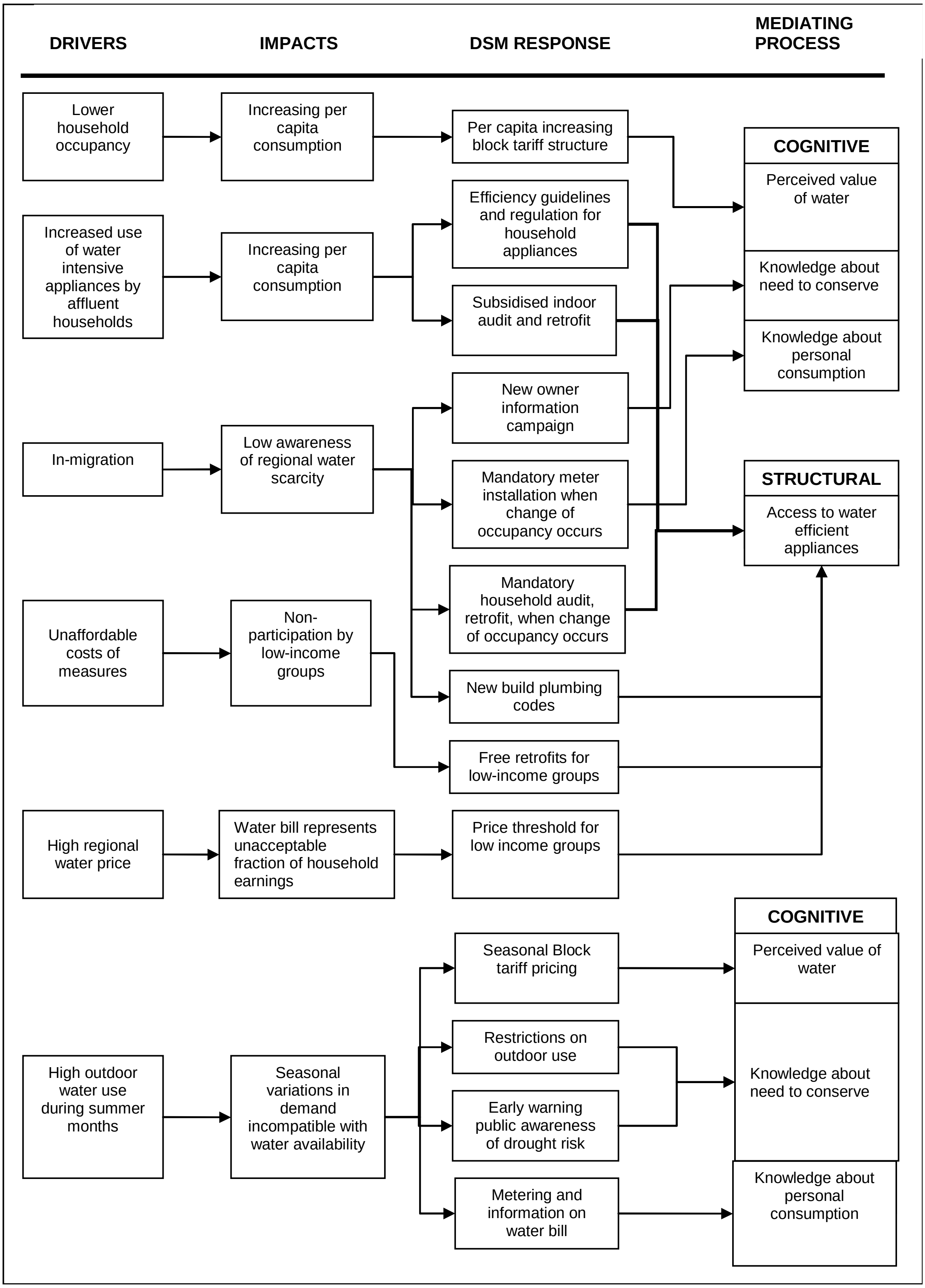

Figure 3. A conceptual model of mediating processes involved in mitigating water stress using residential DSM tools

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