Demand-side management for supply-side efficiency: modeling tailored strategies for reducing peak residential water demand

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Abstract

Increasingly, the water sector is exploring the value of applying demand management strategies to reduce peak water use through behavioural and technical solutions. Literature suggests that using behavioural interventions may be a useful approach in changing the daily peak demand patterns to reduce the pressure on network pumping energy costs during peak use times. There is a lack of studies, however, that have investigated the role of social based marketing or behavioural intervention studies on specifically reducing and shifting residential peak diurnal daily water end-use demand. This concept is modeled in this current study through the application of longitudinal experimental end-use data to predict how reduced demand through behaviour change can impact on overall peak residential demand. Notwithstanding the acknowledged limitations of the study, results illustrate a range of potential peak hour flow savings that can be realised from reducing total demand, or shifting the peak demand in households. The study provides preliminary evidence that water businesses can use demand-side strategies to also achieve efficiencies in the distribution of urban water (e.g. reduced energy for pumping in pressurised water system, pipe augmentation deferrals, peak energy demands).

Keywords: end-use studies, infrastructure optimization, smart meters, behavioral interventions, demand management, peak demand

1 Introduction

Like many regions around the world, Australia's climate is dictated by drought and flood cycles, making management of climate-dependent water supplies complex, uncertain and often costly. Demand-side water management is historically associated with the onset of the drought cycle with the aim of securing drinking water supplies during low recharge periods (Arbues et al. 2003). During more plentiful water supply conditions, demand management strategies are being increasingly recognised as a useful tool to reduce short term costs associated with peak water supply and long term costs associated with infrastructure augmentation (Beal and Stewart, 2014, van Staden 2011). The costs not only relate to direct economic costs of supplying water but also to the indirect costs for the energy requirements to treat, pump and maintain the water supply network. The energy sector has long recognised the value of implementing demand management strategies for the purpose of reducing peak grid energy load (Suganthi and Samuel 2012, Nadel 1992). Increasingly, the water sector is exploring the value of applying demand management strategies to reduce peak water use through behavioural and technical solutions such as time-of-use tariffs (Cole and Stewart, 2012), customer feedback from smart metering systems (Beal and Flynn 2015, Fielding et al. 2013) and options for alternative off-grid water sources (Gurung et al. 2014, Dolnicar et al. 2012). As such, the main aim of this present study was to model a range of estimated savings from the implementation of behaviourally-driven water demand management strategies.

The study will draw upon previous data from SEQ households that has shown how different behavioural approaches can reduce not only total household consumption, but targeted end-uses such as shower, clothes washer and outdoor irrigation (Fielding et al 2013). This information will be applied to known peak demand patterns to predict how peak usage can be reduced through promotion of similar behavioural approaches to the wider community. The scope of the study does not extend to testing the predicted peak water demand reductions but seeks rather to provide an indicative range of savings that may be achieved from behavioural interventions that have been shown to be successful on average water demand for SEQ households. Based on this study scope, the research aim was to determine the likely range of potential reductions to peak water demand arising from targeted water demand management strategies (e.g. behavioural interventions). Such information may assist utilities with reducing peak demand flows in pipe networks, which may subsequently accrue infrastructure or pump energy efficiencies for water utilities.

2 Background

2.1 Demand management for water conservation

Water demand management broadly defines any actions or strategies that aim to promote and improve water conservation or efficiency (Brooks 2006). Following the historical Millennium drought, research into water demand management become a focal point in Queensland, Australia (e.g. Beal et al. 2013, Fielding et al. 2012, 2013, Makki et al. 2015, 2013, Turner et al 2009). The chief aim of this research effort was to understand how best to reduce residential water consumption and promote water conservation in a bid to reduce demand on the exceptionally low water supplies at that time (Beal and Stewart 2011, Walton and Hume 2011, Turner et al. 2009). There are a wealth of studies worldwide that compellingly demonstrate the effectiveness of demand management strategies in reducing potable water demand through: technical approaches such as installation of water-efficient devices (e.g. Willis et al. 2013, Fidar et al. 2010, Millock and Nuages 2010), voluntary and behavioural approaches such as tariff structures (Cole and Stewart 2012, van Vugt 2001, Nieswiadomy 1992), social-based marketing (Fielding et al 2012, Walton and Hume 2011, Athanasiadis and Mitkas, 2005) and mandatory behavioural approaches such as water restrictions (e.g. Grafton and Ward 2008, Syme et al 2004). The effectiveness of water restrictions, while not always a favoured demand management approach for water utilities, has been shown to be very effective at reducing residential demand (Beal et al. 2014, Syme et al 2004). However, by understanding the factors that drive upward or downward trends in water consumption, managers can adopt a proactive approach to demand management and potentially circumvent the need for restrictions or other mandatory approaches (Giurco et al 2011).

2.2 The role of demand management beyond water conservation

In the absence of drought, there can be a different focus for applying demand management strategies. For example, in post-drought south-east Queensland (SEQ), a different political landscape exists with the security of supply now much more resilient due to new climate-independent sources such as the Tugun desalination plant and the Western Corridor Recycled Water Scheme (Traves et al 2008). Along with this infrastructure and two substantial flood events (leading to full water supply dams across the region), the promotion of urban SEQ water conservation and efficiency programmes have all but disappeared off the local and state government agendas. It could even be argued that in some cases residents have been subtly encouraged to increase their water consumption, particularly outdoor use, to assist in the cost-recovery (through additional revenue) of

the many billions of dollars of capital investments in bulk water infrastructure for securing the SEQ water supply during the drought (Thompson and Solomans, 2012).

The water price cost increases to SEQ customers has been rising well above inflation in the past five years in order to service the additional debt taken on by the government-owned SEQ bulk water agency to fund such drought security infrastructure. In response to the necessity to increase water prices but at the same time respond to political pressure to reduce prices, the bulk and distribution water business of the SEQ region have shifted their focus from demand management and managing water scarcity, to system efficiency in order to reduce the future price acceleration of water. Thus, there has been a marked shift in SEQ toward investigating how changes to domestic potable water demand can assist in revenue forecasting, optimising future water network infrastructure, leak management, and reducing peak usage – rather than water conservation *per se*. Some examples include Gurung et al. (2014, 2015), who discuss the application of smart metering technology to improve our understanding of peak demand patterns and subsequent network optimisation, including non-traditional water supply systems. Cole and Stewart (2012) combined diurnal consumption patterns and their peak demands to inform system flow rates and the subsequent calibration of network distribution models. Beal and Stewart (2014) demonstrated how smart meter enabled water end-use data can identify the key indoor and outdoor end-uses that contribute to peak hour, day and month demand.

2.3 Behavioural strategies for reducing peak demand

In the current context where surface water supplies are secure in the SEQ region, water utilities have not been focused on reducing the current overall water consumption of its customers, but instead have focused more on reducing peak demand, which can in-turn reduce network pumping costs and defer trunk infrastructure upgrades (Gurung et al. 2015). That is, during times where peak water demand coincides with the highest energy tariff period for pumping to supply reservoirs, a reduction in residential peak demand can substantially reduce operating costs (van Staden et al 2011). In terms of using social marketing strategies to achieve this, encouraging behaviour change in peak water use activities such as irrigation and other outdoor water uses could be promoted (Browne et al. 2013). Time of use tariffs is one approach that can encourage behaviour change during peak demand times but would require a smart metering system with billing and customer feedback technology to be in place which may not be achievable or desired by water service providers at this time (Cole and Stewart 2012). Encouraging behaviour changes that shift water consumption outside the peak period

would be a more affordable and politically palatable long-term strategy for reducing utility pumping costs and deferring the costly upgrades of pipe distribution infrastructure (Beal and Flynn 2015).

A wealth of energy policy literature, evolved from the need to reduce peak network demand and the transition to smart metering, demonstrates the reduction of peak and total energy use arising from the application of behavioural change programs in the energy sector (Steg and Vlek 2009, Abrahamse et al. 2005, Stern and Gardner 1981). This knowledge, gained from over two decades of research in the area of energy demand management and consumer response, has yet to fully translate across to the water sector, particularly regarding the role of smart metering and real-time feedback data as a mechanism for behaviour change. Nevertheless there is mounting evidence demonstrating how behavioural strategies targeting water efficient behaviours are an effective tool to promote water efficient behaviour in the community (Browne et al. 2013, Fielding et al. 2013, Millock and Nauges 2010, Russell and Fielding 2010).

A large social-based marketing campaign during the SEQ drought in the mid to late 2000s was aimed at behavioural shifts in water consumption prompted by community and government media messaging, such as the “Target 140” campaigns and promotion of water-efficient devices. This approach, together with water restrictions, was widely acknowledged as being highly effective in significantly reducing demand from the pre-drought use of around 300 litres per person per day (L/p/d), to less than 130 L/p/d during the height of the drought (Walton and Hume 2011). Fielding et al (2012, 2013) demonstrated how voluntary demand management strategies can further reduce (already below average) water consumption in households representing a range of different socio-demographics. The study went on to describe how tailored interventions, such as feedback of household water end-uses and water conservation information influenced how people interacted with certain end-uses (e.g. shower, clothes washing) in a manner that significantly reduced the demand for those end-uses. Tortajada and Joshi (2013) describe the water demand management approaches taken by the Singaporean Government to successfully promote improved water conservation practices in the residential and industrial sectors. They explain that the increased level of public engagement, information, education and communication campaigns are central to achieving sustained attitudinal change amongst the consumers towards efficient water use. Strategies over the years have included slogans in public places urging consumers to save water, exhibitions, media campaigns, and more recently the introduction of the Water Efficiency Labelling Scheme (WELS) and water use targets (e.g. the ‘10 l challenge’) (Tortajada and Joshi 2013).

The above are just some examples from the literature that suggest that using behavioural interventions may be a useful approach in reducing residential water consumption. However, there is a dearth of published studies to date that have investigated the role of social based marketing or behavioural intervention studies on specifically reducing or shifting residential peak diurnal daily water end-use demand.

3 Methods

3.1 Overview

An overview of the methods used to determine the estimated savings from various water-efficient strategies is presented in Figure 1. Baseline water end-use consumption has been used which represents the average water end-use consumption from four years of monitoring data taken from residential properties in SEQ (Beal and Stewart 2011, Carragher et al 2012). Water demand varies during the day, with demand generally lowest during the night and highest in the morning and early evening hours, resulting in double peaks concentrated over these two periods; the higher of which is termed a daily peak demand. This variation in water demand is also referred to as a diurnal demand curve. Diurnal demand patterns were developed for each of the three water demand parameters typically used by water distribution network modelling engineers for planning and design tasks, namely: average day (AD), peak day (PD) and mean day in maximum month (MDMM).

Figure 1. Overview of the method used to estimate water demand savings from various intervention strategies

Each of these diurnal demand curves have been normalised to reflect the current utility-assigned AD consumption of 220 L/p/d (SEQ Code 2013). Although this per capita usage is above that reported by Beal et al. (2014) and the recent weekly updates from Seqwater (typically range between 165 and 180 L/p/d - see <http://www.seqwater.com.au/latest-updates/news/>), it is a prudent approach for water supply planning and takes into account some degree of demand growth, demand estimation uncertainty, population growth, to name a few. Once the datasets were normalised, a water-use reduction factor was then applied to the baseline data for each of the AD, PD and MDMM patterns.

3.2 Smart meter-enabled end-use data

The data for the current study is generated from the completed SEQREUS funded through the Urban Water Security Research Alliance (<http://www.urbanwateralliance.org.au/>). Households from four local authority boundaries located in the south east corner of Queensland took part in the SEQREUS study ($n=252$). The participating households were selected from a large sample of over 1000 homes that originally participated in a larger baseline survey of household water use (Spinks et al 2011). Of this sample, around 100 homes were randomly selected for partitioning into three different intervention strategies. The participants did not self-select for the interventions themselves. The water consumption profiles that were monitored over 4-5 years for the SEQREUS (a sub-sample of 252 households taken from the Spinks et al. 2011 study) were consistently similar to the government-sourced water use data for the SEQ region. This suggests that the water use behaviours and practices of the sub sample were in general representative of the larger SEQ region as a whole. Upon completion of recruitment, standard council residential water meters were replaced with modified Actaris CTS-5 water meters. These 'smart' meters measure flow to a resolution of 72 pulses/L or a pulse every 0.014 L. The smart meters were connected to Aegis Data Cell data loggers programmed to record pulse counts at five second intervals. Data was wirelessly transferred to a central computer and stored in a database for subsequent analysis. A representative sample of received data was extracted from the database and disaggregated into all end use events associated with the sampled residential households using flow trace software (Aquacraft 2010). Concomitantly with meter and logger installation, a water fixture/appliance stock survey was conducted at each participating home in order to investigate how householders interact with such stock. This facilitated the disaggregation of trace flows from each home and also provided a valuable snapshot of the daily water consumption habits within each home. For detailed explanations and method descriptions on obtaining the South East Queensland Residential End Use Study (SEQREUS) data and creating end-use level diurnal demand patterns please see the Stage 1 Report authored by Beal and Stewart (2011) as well as Gurung et al. (2014).

3.3 Diurnal water end-use demand pattern creation

Diurnal water end usage patterns can be generated from high resolution micro-component data. Diurnal usage patterns have been used to identify trends and peaks in water (e.g. Willis et al. 2013) and energy (e.g. Firth et al. 2008) consumption over time. A software tool was specifically developed to cluster water demand from individual water end use events contained in a database into daily diurnal demand patterns at the end use level. The software facilitates the creation of diurnal patterns at various time intervals. An MS Excel™ spreadsheet is then used to obtain an average day and peak hour consumption. Further details of the diurnal pattern formulation approach and application are found in Gurung et al (2014).

3.4 Determining total daily diurnal consumption reductions from social marketing

Aligned work completed by Fielding et al (2012, 2013) provided a basis for determining the potential savings that can be achieved from using behavioural intervention strategies for reducing water consumption. In their research, various interventions were applied to segmented sub-groups of the total sample participating in the SEQREUS study, in order to evaluate the influence of different behavioural approaches to a reduction in household water demand. Three strategies were trialled by Fielding et al. (2012), which are briefly described below.

The first was an *information only* intervention in which households were sent monthly water saving tips about how to reduce water use in the bathroom, laundry, kitchen, and through fixing leaks. The second intervention group received the water saving tips as well as *descriptive norm* information. This was information that described how households of similar household makeup (e.g. young children, 2 adults) have actually done to save water around the house. The third intervention group received the water saving tips and *water end-use feedback* information. Households in this group were advised of their average daily water usage and they were provided with a pie chart that showed the proportion of water their household used on water using activities (e.g. shower, taps, clothes-washing). The three intervention groups were compared to a control group which did not receive any information. The inclusion of a control group allowed an assessment of whether changes in water use can be attributed to the interventions or whether any changes that occur in water use may have resulted because of being part of the study or because of external events (Fielding 2012). Due to the roughly comparable results between each intervention group in terms of water demand reductions, results were combined and an average was taken for each end-use. From this, the average

daily demand reduction was calculated based on the difference of the water use volumes for each end-use category before and after the behavioural intervention period was carried out in the study by Fielding et al. (2012). These reduction factors, along with the before (baseline) and after end-use values, are presented in Table 1.

Table 1: Parameters used for estimating diurnal water savings from behavioural interventions

	Before intervention	After intervention	Reduction	Volume	Reduction
	L/hh/d		factor	(L/hh/d)	%
Dishwasher	6.5	4.3	0.66	2.2	34%
Bathtub	7.7	4.9	0.64	2.8	36%
Tap	66.4	61.1	0.92	5.3	8%
Toilet	58.7	55.5	0.95	3.2	5%
Clothes Washer	86.3	65.3	0.76	21	24%
Shower	110.1	85.8	0.78	24.3	22%
Outdoor	14.9	8.6	0.58	6.3	42%
TOTAL	350.6	285.5		65.1	

3.5 Determining shift in peak day consumption from social marketing

As mentioned previously, not a lot of research has been done on encouraging a behavioural shift in how people interact with their water use activities, although this has been well studied in the energy sector (Hargreaves et al 2010, Fischer 2008, Abrahamse et al 2005). Reduction ‘factors’ were formulated from concepts presented in the energy sector literature, and a number of scenarios targeting a shift in the peak water use behaviours of householders were developed with some underlying justification and assumptions (Table 2).

There are a number of factors that would contribute to the success of encouraging shifts in behaviour including: season, family size (e.g. difficult to change shower routine with high demand for shower) and composition (e.g. children needing baths before bed), water use attitudes (e.g. environmentally aware households may be more likely to readily adopt shifts in peak water use) and employment factors (e.g. shift workers). For this reason, there are two uptake rates that have been assumed in the modelling: a low uptake where fewer households engage in the water use shifts, and a high uptake, where it is assumed that twice as many targeted households engage in the behaviour (Table 2). The

uptake rates also represent the percentage of reduction that would be expected from the baseline end-use value for each scenario. For example, if a 10% rate was applied to shifting clothes washing to early morning, this scenario indicates that 10% of the targeted population would engage in this strategy and 10% of the total change in baseline clothes washer consumption resulting from the behaviour shift strategy would be achieved.

Peak energy tariffs in Queensland are typically between 16:00 and 20:00 hours, thus this is the target time that the modelling has focussed on (e.g. to shift key end-use peak water use to late evening or early in the morning). Similar to energy consumption (Gatersleben 2001), it is most likely quite difficult to encourage a behavioural shift in water use activities that are strongly associated with routine and quality of life (e.g. showers and tap use) (Russell and Fielding 2010). It may be easier to encourage clothes washing and outdoor watering to occur out of peak times as these activities can be automated and may be undertaken at any time of the day.

Table 2: Scenarios for encouraging water use behavioural shifts away from peak times

Behaviour change in water use activity	Peak time to target shift / reduce	Shift to new time	Low uptake rate (%)	High uptake rate (%)	Notes
Set clothes washer in early morning	07:00 – 11:00 AM 16:00 – 20:00 PM	0:00 - 06:00 AM	10	20	This would require the clothes washing machines to be set automatically to operate at hours between 0:00 and 06:00 hrs.
Shower later in evening	16:00 – 20:00 PM	20:00 - 22:00 PM	5	10	To prolong people's shower use until after 20:00 hrs. Difficult to control discretionary behaviour that also incorporates quality of life aspects.
Set dishwasher in early morning	18:00 – 22:00 PM	0:00 – 6:00 AM	10	20	This would require the dishwasher to be set automatically to operate at hours between 0:00 and 06:00 hrs.
Reduce kitchen tap use	16:00 – 20:00 PM	20:00 - 22:00 PM	2.5	5	Aims to encourage people to minimise their tap use during 16:00 to 20:00 hrs where possible.
Outdoor watering	07:00 – 09:00 AM 16:00 – 20:00 PM	0:00 - 06:00 AM	15	30	This will have the most impact on peak day diurnal pattern since much of the peak is typically attributed to outdoor use.

4 Results and Discussion

Total water savings, along with morning and afternoon peak hour demand reductions are shown for AD, PD and MDMM (Table 3). (Note there is no total estimated water demand savings for the peak load shifting scenarios as a shift rather than a reduction in water consumption was the aim of these scenarios – see note below Table 3).

Over an annual analysis period, water utilities define certain peak demands to assist in infrastructure design. Peak hour (PH) demand exists in a peak day which is the maximum day demand over a 12-month period, and is utilised mainly in the design of pipe infrastructure. Additionally, in Queensland, the average of the highest moving average 30-day water demand, the mean day at maximum month (MDMM), is utilised to consider demand variance in response to seasonal changes (DERM, 2010). This MDMM is used mainly in the sizing of pumps and reservoirs in Queensland, hence the inclusion of these figures in the summary table (Table 3).

Table 3: Summary of estimated peak hour demand savings from baseline demand scenarios for SEQ

Demand management scenario	Demand curve type	Morning peak hour		Afternoon peak hour		Total daily (24 hour) estimated water demand
		L/p/hour				kL/p/year
Social marketing strategies aimed at reducing total daily diurnal consumption (Table 1)	AD	4	(22%)	5	(27%)	19 (24%)
	PD	9	(28%)	15	(35%)	45 (30%)
	MDMM	7	(26%)	10	(33%)	34 (29%)
Social marketing strategies aimed at encouraging shift in peak day consumption – <i>Low uptake assumed</i> (Table 2)	AD	1	(5%)	1	(8%)	See notes
	PD	2	(8%)	5	(12%)	
	MDMM	2	(7%)	3	(11%)	
Social marketing strategies aimed at encouraging shift in peak day – <i>High uptake assumed</i> (Table 2)	AD	2	(10%)	3	(17%)	See notes
	PD	5	(15%)	10	(23%)	
	MDMM	3	(14%)	6	(21%)	

Notes: data in parentheses denotes a percentage reduction from the baseline peak hour or baseline daily total. No daily water demand change is assumed for the social marketing strategies for peak demand shift.

4.1 Impact of social marketing strategies on total daily diurnal consumption

This modelling scenario explored the potential reduction in total daily water demand arising from the implementation of behavioural strategies for residential water use. This section is not focussed on shifting peak demand to other parts of the diurnal demand curve, but on the *overall reduction* of water consumption across the curve. As previously outlined in the methods section, water use reduction factors were applied to each end-use (except leaks as they are not considered a human element of water use) to determine the estimated reduction after implementation of behavioural strategies.

Results are presented as end-use diurnal demand curves for the critical PD scenario as baseline (Figure 2a) and adjusted after reduction factors have been applied (Figure 2b). Savings estimates from these demand curves are also presented for the PD (Table 3). The baseline total daily water pattern for PD diurnal consumption illustrates the high proportion of outdoor use contributing to overall total daily demand (Figure 2). This is typical of a PD demand curve, where outdoor use is the driver of high peak hour and PD demand (Beal and Stewart 2014, Gurung et al. 2014, Lucas et al. 2010).

Notes: In Figure 2b, dashed line represents baseline total for comparison.

Figure 2 Estimated total end-use peak day demand pattern from implementation of behavioural strategies showing (a) baseline prior to implementation, (b) after implementation.

Morning showers and clothes washing activities comprise a large proportion of the indoor peak use. Once the reduction factors are applied to the baseline PD curve, there is a clear reduction in outdoor usage predicted as a result of behavioural prompts to residents to conserve water (Figure 2a). The reduction in peak hour PD demand is estimated at 28% (9 L/p/h) and 35% (15 L/p/h) for the morning and afternoon, respectively (Figure 2b). Overall, a reduction in daily PD diurnal demand is predicted to be around 30% less than the baseline demand at 45 kL/p/y (Table 3). To provide an example of the cumulative impact on peak reduction that behavioural strategies may have, a combined household savings estimate of 604 giganlitres per year (GL/y) has been determined from 475,000 homes in the SEQ region (Queensland Treasury and Trade, 2013) assuming a 2.8 persons per household occupancy rate. This represents a very substantial and valuable reduction in PD demand.

In terms of specific end-uses of residential peak demand, outdoor water use activities are a key discretionary end-use that is strongly behaviourally driven; with frequency, duration, timing, and nature of outdoor use (e.g. trigger hose vs soaker hose) all important factors (Russell and Fielding

2010, Syme et al. 2004, De Oliver 1999). Climatic cues such as duration of low or no rainfall, temperature and humidity are also likely to be influencing factors (Makki et al. 2015, Beal and Stewart 2014). Wider macro cues such as water restrictions, political ‘encouragement’ via media messaging (e.g. “it’s OK to water your garden again, the dams are full” or “it is socially unacceptable to be seen to waste water in the garden during the drought”) will also moderate the behaviour of individuals on how they use their water, particularly outside their house (Russell and Fielding 2010, Corral-Verdugo and Frias-Armenta 2006). Fielding et al (2012) compared three social marketing (or also termed behavioural intervention) strategies to a control condition (no information at all) and found that all three voluntary strategies were effective in reducing household water use, even in the context of low pre-existing levels of household water use and high levels of rainfall during the intervention period. Behavioural cues for discretionary uses such as outdoor, tap use and to a certain extent shower use, can be effective as shown in the results here and reported elsewhere (Fielding et al. 2012, Syme et al. 2004).

4.2 Impact of social marketing strategies on peak hour demand

This modelling scenario focused solely on peak periods rather than daily diurnal demand as presented in the above section of this paper. In comparison to the PD diurnal curves at baseline (Figure 2), modelling results in Figure 3 illustrate the potential opportunity for reducing peak flows at high energy tariff times of the day (e.g. morning and evening peaks). Both the low uptake (Figure 3a) and high uptake (Figure 3b) of marketing strategies scenarios demonstrate that they can shift demand (mainly from outdoor use) away from the peak demand period and thus reduce peak hourly flow rates in the water distribution pipe network. Figure 3 illustrates that a reduction in the PD peak hours, for morning and afternoon, is substantial at 8% (low uptake) and 15% (high uptake) and 12% (low uptake) and 23% (high uptake), respectively. The curve is also notably altered compared to the typical curve with early morning activity up to nearly 12 L/p/h, at 2:00am, compared to the baseline for the same time of around 1.6 L/p/h. The shift of demand to earlier in the morning tends to flatten the curve out somewhat, particularly for high uptake rates. Since outdoor use is known to strongly influence the quantum of the PD diurnal curve, and most specifically the peak hour demand, even a small shift in outdoor use can have a notable impact on flattening the afternoon peak demand.

Notes: baseline total also shown for comparison – direction of arrows indicates the change in water use

Figure 3 Peak Day end-use demand for homes receiving social marketing material to shift peak hour demand for (a) low uptake by residents and (b) high uptake by residents

4.3 Potential versus practical uptake of social marketing strategies to shift peak demand

In theory, modelling results showed that based upon empirically-derived reduction factors, behavioural strategies to reduce daily total end-use demand and peak hour demand shifts, can be effective. The modelling exercise for the second objective of the study represents a separate set of social marketing objectives and strategies to the work presented. The social marketing strategy objectives for some local and state governments would be to maintain the same amount of water which is sold to customers, but for this consumption to occur outside peaks hours as much as possible to reduce infrastructure upgrade and pumping energy costs. However, for this marketing strategy to be successful, there would have to be some incentives from the customer's perspective to engage in different water use behaviour activities, especially if they are discretionary and/or involve a degree of lifestyle change (e.g. showering at a later time, setting clothes washer on in the early hours of the morning, using an irrigation timer). If perceived to be too restrictive, such strategies will not be popular or encourage high uptake (Jones et al. 2011). Amongst other psychological and social factors, the effectiveness of an environmental policy or strategy is connected to the level of social acceptability (Dolnicar et al 2012, Jones et al. 2011) and the suggestion of shifting shower times, outdoor water activities and clothes washing may be an unacceptable burden for many. The attitudes (intentions), beliefs and habits or routines of consumers will also be a key factor that influences the degree of uptake of behavioural strategies (Dolnicar et al 2012, Russell and Fielding 2010).

Context and perception of water supply security is also likely to influence the success of behavioural interventions that are aimed solely at shifting demand rather than reducing total daily consumption – especially if there is an absence of environmental cues such as drought (Fielding et al. 2012, Gilbertson et al. 2011). For example, based on current water demand trends in SEQ for example, where there are presently (i.e. in 2015) no restrictions, regular rainfall and perceived security of water supply, these marketing strategies would potentially be a 'hard sell' to customers. While this paper provides evidence that there are genuine savings to be made off the peak hour demand, this may be unlikely to be realised without, for example, time-of-use tariffs (TOUT), determined through smart metering, which can then incentivise customers to reduce water use (e.g. showering and irrigation) during peak periods of the day. This latter example of TOUTs involves a paradigm shift in water utilities' current level of uptake of smart metering, billing and customer feedback technology that may not yet be achievable, affordable or desired by water service providers at this time. Nonetheless, such technologies and the associated industry changes will inevitably be widespread within a decade.

Thus, there are many critical social and psychological factors to consider when designing and promoting the type of social marketing strategies suggested in this paper. Notwithstanding this, the concept of using tailored demand strategies to shift peak or critical water use periods to other times of the day has strong implications for practice in advanced economies. It may offer a potentially cheaper, politically attractive, and more long-term community-based solution to peak demand management than alternatives such as financial incentives through TOUTs or mandatory strategies such as outdoor water restrictions.

5 Study limitations

Given that the herein described concept is relatively new and there is limited empirical evidence available in the literature on the link between social marketing strategies and shifts in peak hour water demand on the peak day of the year, a number of estimates have had to be formulated. For example, in the modelling process we have had to carefully estimate the types of scenarios that may be used to shift peak water demand and also the actual level of engagement (uptake) from households. As there is no prior literature on this, the results provide an indicative range of savings that could be expected based on measured water end-uses and demand curves. We have also assumed that all individuals in each household will have the same degree of uptake (i.e. either low or high), but in reality water consumption behaviours involve the actions of multiple household members and they will not all be homogeneous actions (Gilg and Barr 2006). There are several key drivers of water conserving behaviour (intentions, attitudes, behaviour, personal capability, context) of which each person will respond individually, and this must be considered for a large scale analysis of the likely behavioural responses to social marketing strategies (Russell and Fielding 2010).

For the peak demand shifting scenarios, there is an assumed absence of actual reduction of total daily water demand in those households that engage in the interventions. This may not reflect reality, as people who are likely to engage in the demand shifting behaviours are more likely to have intentions and attitudes towards water conservation in general (Dolnicar et al. 2012, Russell and Fielding 2010) and thus may reduce consumption as well as change the timing of water use behaviours for certain end-uses.

The modelling methodology has intentionally been kept simple in order to understand what diurnal demand patterns might look like with reduced daily and hourly peak demand. A future larger scale study using more sophisticated modelling techniques (e.g. regression based analysis) together with

a set of qualitative survey data from the public on the preferred type of behavioural interventions and their willingness to uptake each strategy would overcome many of the limitations discussed here.

6 Conclusions and future applications of research

This paper reports on a modelling exercise to gauge the range of theoretical reductions to peak water demand arising from targeted social marketing strategies. The results suggest that applying behavioural interventions in the form of social marketing strategies to householders on specific ways to save water, can achieve substantial savings off a baseline case, in some cases over a third reduction in peak hour demand. Outdoor water use behaviour change can potentially result in some marked changes to the PD and MDM demand curves, particularly in the afternoon. In the current environment (in SEQ at least) where water supply security is presently high, social marketing strategies alone are unlikely to gain much traction without some level of incentive for the customer. For example, this may be rebates on irrigation timers to encourage very early morning watering, or at the other scale, the introduction of time-of-use tariffs (TOUTS). The reality of achieving these reductions from behavioural strategies will be dictated by the type and mode of communicating these messages, the situational context for the householders, the external environment (drought conditions or not) and a suite of psychosocial factors (e.g. attitudes, beliefs, habits of consumers).

Notwithstanding the acknowledged limitations of the study, results illustrate a range of potential peak hour flow savings that can be realised from reducing total demand, or shifting the peak demand in households. Reduced peak hour flow rates have a number of implications for water distribution businesses internationally. The most notable benefits are deferred requirements for trunk main infrastructure upgrades in densifying urban areas and reduced pump station energy costs to maintain desired standards of service (i.e. mandated certain level of water pressure to customers) in a pressurised water delivery system. Reducing the operational cost to supply water to customers will ultimately lead to a reduced cost of potable water supply for customers.

Specifically related to the goal of shifting peak demand, but not reducing overall water consumption, some carefully targeted social marketing strategies are required to ensure sufficient participant uptake. As Steg and Vlek (2009) and Russell and Fielding (2010) observe, successful intervention strategies are more likely to be the ones that focus on the most important drivers of the desired behaviour change. With the penetration of efficient devices and fixtures in SEQ homes approaching saturation point (both from retrofits and new building code requirements), the key drivers of peak

water and water-related energy use will become increasingly focussed on behaviours rather than technology. This may be particularly so for shifting, rather than reducing, water use activities. This paper seeks to lay the foundations for future research in this area of behaviour change.

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