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Article

Future Water Demands: The Role of Technology and User Behaviour

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Abstract: The traditional water supply management approach focuses on (perceived) community requirements that must be met, but not on community demands, which are variable. Therefore a paradigm-shift is required to the way water is considered. In this paper the impact of two distinct approaches for managing the urban water demand, thus daily water consumption, within residential and office buildings are examined through a futures framework. The two fundamental management measures to influence water demand are: 1) structural and technical measures (via adopting water-saving devices); and 2) socio-political measure (via changing users' behaviour). Both align well with UK policy drivers and results show each in isolation has similar impacts (i.e. 55% reduction) on domestic water consumption per capita, although the ranges over which user behaviour can operate appears to be far more diverse. Most strikingly, when these measures are considered in combination greater impact (i.e. 80% reduction) could be achieved. Conclusions are drawn as to how far water demand management, through a dual track approach, can go in terms of reducing indoor water consumption of both residential and office users. The paper then discusses what else is needed in this respect to contribute to securing sufficient, sustainable supplies within a 'liveable' future.

Keywords: urban water demand management, user behaviour, water saving devices

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1. Introduction

The traditional emphasis in the approach to water supply has been on developing new infrastructure to further exploit currently available sources, most of which are already overexploited. As pressure on urban water demand escalates, due to population growth, rapid urbanization and climate change, a more strategic approach to planning for public water supplies is required. A paradigm shift is required from managing water supply to managing water demand. Water demand management (WDM) generally takes three main forms (Vairavamoorthy, 2009):

(i) structural and technical means (e.g., the use of water-saving devices, leakage control, water meter management, etc.),
(ii) economic and financial means (e.g., water pricing, taxes, rebates, etc.), and
(iii) socio-political means (e.g., promoting water conservation, educational programmes, awareness campaigns, water benchmarking, etc.).

There is now a large and growing body of evidence around the world that, compared with other options, water conservation is the way to safeguard our ability to supply cities most cheaply with water and it is faster, cheaper and better to augment the efficiency of water use than to continue relying exclusively on new supplies to meet the growing water demand (Haddad and Lindner, 2001; Vairavamoorthy, 2009). One other commonly adopted WDM measure is the use of water saving devices that can have significant impact in both domestic and office settings (Butler, 1991; Barreto, 2000; Hunt et al., 2012; Zadeh et al. 2013a, b). These devices are commercially available in different forms; ultra-low flush toilets, low flow shower heads, low flow or infrared taps, etc. Unfortunately, in some cases a lack of awareness exists amongst designers, planners, engineers and in particular consumers of the potential for reducing water demand that these water-saving devices can offer in conjunction with future changes in water use behaviour.

This paper examines, individually and together, and in alignment with the UK's policy drivers (e.g., the Code for Sustainable Homes and BREEAM), the impacts of changes in technology and in user behaviour on water demand in domestic residences and offices. Section 2 describes a generic methodology that has been used to assess dual driver impacts through a futures framework approach. The resulting water demands are shown in Section 3 with future implications discussed in Section 4. Conclusions are subsequently drawn.

2. Methodology

The methodology adopted within this paper consists of 5 clear steps shown below. These are subsequently applied to domestic dwellings and offices and, although generic, they are not inappropriate to urban city centre landscapes.

1) Establish the role of 'user behaviour (UB)' and 'technological efficiency (TE)' in current average UK water demands.
2) Collate a UK database for existing ranges of UB and TE.

3) Establish appropriate variations in demand profiles (i.e. incremental levels of change based on 2 above) for:
   a) UB;
   b) TE.
4) Use a full 'futures framework' to establish the resulting impact of:
   a) UB;
   b) TE;
   c) UB and TE combined.
5) Make future recommendations.

Steps 1 to 3 are discussed in this section, Step 4 is discussed in Section 3.0 and Step 5 is discussed in Section 4.0.

Step 1: The role of 'user behaviour (UB)' and 'technological efficiency (TE)' in current average UK water demands.

Step 1 is used to identify typical (i.e. average) UK water consumption figures for residential and office buildings and identify the dual role of technological performance and user behaviour. These are presented in Tables 1a and 1b respectively and are based upon the previous work of Hunt et al., (2012) and Zadeh et al. (2013). The total water demands are directly in line with those reported by Environment Agency (2010) for domestic properties and Waggett and Arotsky (2006) for offices. It can be seen that the total water use (far right column) is directly dependent upon the water using performance of the technology (e.g. a shower flow rate measured in lit/min) and user behaviour (e.g. how often the shower is used and for how long it is used). In contrast the total water use for a bath is dependent on the volume of the bath, how much it is filled (i.e. assumed half-full in an average case) and how often it is used. The duration of use, unlike a shower, has no bearing on total water use. This is the same for WC flushing or a dishwasher or washing machine where a set volume is used (although for the latter two options water use can be influenced directly by user settings, i.e. short eco-cycles versus long intensive cleaning cycles).

Step 2: UK database for user behaviour and technological efficiency.

This step identifies the water use behaviour of, and water efficient devices used by, domestic and commercial consumers and forms the basis of the assumptions used in this study. The behaviour(s) of domestic users (Table 2) are derived from past monitoring studies amongst water users. Those figures highlighted in bold show current average UK values. This helps to identify, for example, the variation in reported values for frequency of WC flushing (6.3 and 2.2 flushes / day, with an average value of 4.8). Its shows also that showering times are highly variable and have a much broader range (3 to 30 minutes, with an average of 8). In addition showering appears also to be more prevalent than bathing. Frequency of tap / hand basin use does not vary significantly, although the duration does vary significantly from 0.33 minutes to 6 minutes. There is unfortunately a lack of behavioural data for office employees, therefore the average figures adopted in Table 1b would have to form the baseline for a sensitivity type of analysis (see Step 3). In offices, the frequency of appliance use has been shown also to be different for males and females as it is assumed that there is a notable difference in the frequency of washroom appliance use between the genders. This assumption is supported by the findings of Thames Water's "Watercycle" project at the Millennium Dome in London (Hills, 2001). Table 3 shows commercially available water efficient devices that are applicable to both domestic and office settings.

Table 1 (a). Breakdown of water use in residential dwellings

Water use	Technology	User behaviour		Total water use
	- i – Water consumption *(units)*	- ii – Duration of use *(minutes per usage)*	- iii – Frequency of use *(per day & person)*	iv = I × ii × iii *(Litres/day/person)*
WC flushing	6 *(lit/usage)*	-	4.8	28.8
Hand basin	8 *(lit/minute)*	0.33	3.5	9.2
Kitchen sink	8 *(lit/minute)*	0.33	3.5	9.2
Wash. Machine	80 *(lit/load)*	-	0.21	16.8
Shower	12 *(lit/minute)*	8	0.6	57.6
Bath	116 *(lit/usage)*	-	0.16	18.6
Dishwasher	24.9 *(lit/usage)*	-	0.23	5.7
Other	2 *(lit/day/person)*			2
Total daily water consumption *(l/person/day)*				148

Table 1(b). Breakdown of water use by office employees
(*Italics* show where water use by females differs from that for males) (Zadeh at al. 2013)

Water use	Technology	User behaviour		Total water use
	- i - Water consumption *(units)*	- ii - Duration of use *(minutes per usage)*	- iii - Frequency of use *(per day & person)*	iv = I × ii × iii *(Litres/day/person)*
WC flushing	6 *(lit/flush)*	N/A	1 *(2)*	6 *(12)*
Urinal	3.6 *(lit/employee)*[a]	N/A	1 *(0)*	3.6 *(N/A)*
Hand basin	8 *(lit/min)*	0.2 *(0.2)*	2 *(3)*	3.2 *(4.8)*
Kitchen sink	8 *(lit/min)*	1	0.1	0.8
Cleaning	N/A	N/A	N/A	1.0 *(1.8)*
Canteens	N/A	N/A	N/A	1.0
Total daily water consumption (l/employee/day)				15.6 *(20.4)*

[a] Male urinals have a certain flush volume per urinal bowl (i.e. there is typically one water cistern that will service multiple bowls – when it flushes all bowls are flushed simultaneously). The bowls are then (typically) flushed at set time intervals during the day. 2011 UK Building Regulations specify urinals should use no more than 7.5 litres / bowl / hour and should be considered to operate 12 hours per day, 5 days per week (assuming water saving timers is fitted) and not 24/7 based on UK Water Regulations pre 2011.

Table 2. Domestic user behaviour: frequency (F) of use and duration (D) ranges. (**Bold** figures represent UK average values).

WC	Washing Machines	Taps / hand basins		Showers		Bath	Dishwasher
F	F	D	F	D	F	F	F
6.3 [19]	0.37 [12]	6 [7]	**3.5 [20]**	30 [20]	0.65 [12,16]	0.34 [6,9]	0.71 [19]
5.25 [1,17]	0.34 [5]	1 [20]	3 [11]	15 [21]	**0.6 [6,11,14]**	**0.16 [21]**	0.4 [21]
4.8 [5,3,21]	**0.21 [21]**	**0.33 [11]**	2.25 [7]	10 [19]		0.12[12]	**0.23 [21]**
4.3 [6,18]	0.18 [1]			**8 [16]**			0.214 [7]
4[9,10]	0.16 [2]			5 [3,6]			0.14 [12]
3.7 [2,15]	0.157 [6]			3 [19]			
3.3 [4]	0.05 [19]						
2.8 [19]							
2.2[19]							

References: 1.SODCON, 1994; 2.Butler , 1991; 3.Chambers et al., 2005; 4.Thackray et al. 1978; 5.DCLG, 2007; 6. EA, 2001; 7. Butler and Memon, 2006; 8. Mays, 2010 ; 9. European Commission, 2009; 10. EU Eco-Lable, 2011; 11. Green building store, 2011, 12.Aquacraft, 2003; 13.Loh and Coghlan, 2003; 14. Shimokura et l., 1998; 15. Otaki et al. 2008; 16. Barreto, 2000; 17. Gleick et al. 2003; 18.DCLG, 2010; 19. Hunt et al. 2012; 20. DeOreo et al. 2011; 21. Zadeh et al., 2013a,b

Step 3: Water demand profile variation – assigning levels of performance.

In the future one might envisage that the UK would continue to strive toward reducing total water demands. One way to achieve this could be to target and benchmark each individual water demand within the home or office. Figure 1 illustrates how any reductions in water demands for showering are dually influenced by the two key drivers of ‘User behaviour’ (x-axis) and ‘Technological efficiency’ (y-axis). The resulting plot, referred to here as a partial ‘futures framework’ (see Hunt et al., 2013 for further details of future frameworks), shows the existing (average) UK demand from daily showering of 57.6 l/day/person in the top left-hand corner. Reductions in demand can be achieved through either changes in user behaviour (moving horizontally to the right) or technological efficiency (moving vertically downwards) or through a combination of both. For example a demand of 34.6 l/day/person (40% reduction from UK average) can be achieved by a reduction in shower use (i.e. from 4.8 to 2.9 min/day/person) or adoption of a reduced flow rate shower (i.e. from 12.0 to 7.2 litres/min). Equally it could be achieved through a multitude of combinations of both (i.e. a 4 minute shower and a flow rate of 8.7 litres/min). In this case the dotted curves represent contours of equal demand, located at 20% reduction intervals – Level 5 to 1 respectively represent zones in-between these reduction contours, i.e. Level 5 represents a 0 to 20% reduction in demand and so forth.

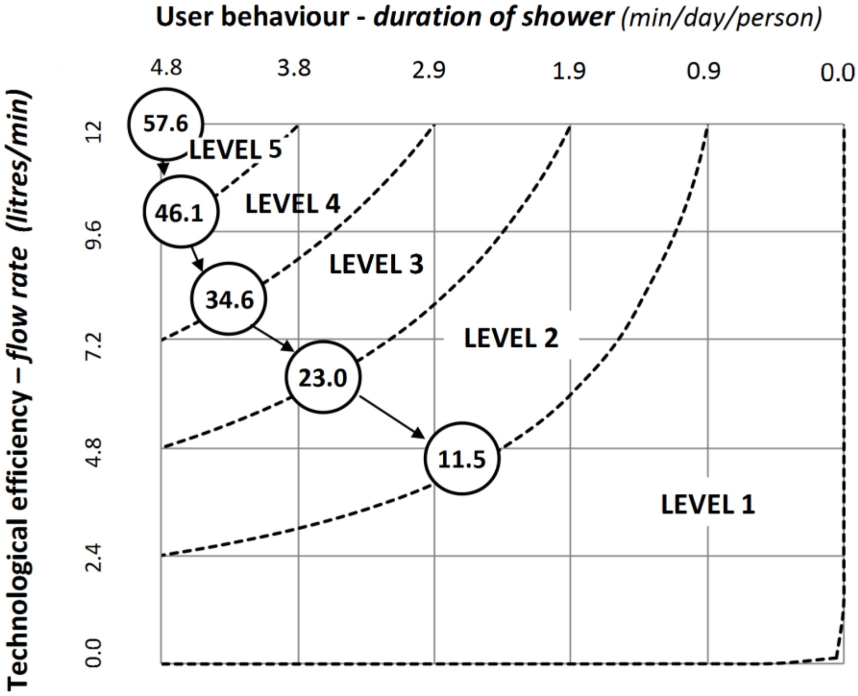
The impact of adopting a range of reported user behaviour profiles and technological efficiencies (drawn from Tables 2 and 3) is used to show how current domestic water demands can be changed significantly, not only below average figures (as just illustrated) but also above.

Table 3. Technologies: Range of water usage from existing and modern indoor technological appliances (**Bold** figures represent UK average values).

WC		Hand Basin	Washing Machines		Showers	Bath	Kitchen taps	Dishwasher	Urinal flush [d]
(lit/flush)	**Type**	*(Lit/min)*	*(lit/use)*	*(Lit / kg)*	*(Lit/min)*	*(litre)*	*(Lit/min)*	*(lit/load)*	*(Lit/bowl/hr)*
9 [26]	Single	15 [23]	110 [8 a]	27 [2]	24 [25]	230 [24]	12 [15]	56.78 [17]	7.5 [5]
6 [2,5,6,7]	**Single**	12 [14,15]	100 [1]	**12 [16]**	15 [23]	140 [16]	10 [13]	**24.09 [10]**	6 [17]
6/4 [9]	Dual	10 [12]	**80 [4]**	7 – 8 [7 b]	**12 [13,15]**	**116 [4]**	9 [13]	20 [17]	**3.6 [5]**
6/3 [7,9]	Dual	**8 [13]**	65 [6]		10.8 [20]	88 [17]	**8 [20]**	16.75 [15]	1.7 [15]
4.5 [7]	Single	7.5 [14]	55 [6]		9.5 [12]	65 [17]	7.5 [21]	14 [17]	0.75 [5]
4 [6,7,9]	Single	6 [13,16]	49 [5]		8 [12]		5 [21]	13 [15]	0 [16]
4/2 [6,9]	Dual	5 [16,17]	45 [3,22]		6.5 [15]		4 [4]	12 [17]	
2-3 [7]	Single	4 [16]	40-80 [6,18]		6 [9]				
1.5 [10]	ULFT [c]	3 [16]			5.11 [19]				
1.2 [7]	Vacuum	1.7 [16]			4.5 [16]				
0 [6,11]	Composting				3.5 [21]				

References: 1.SODCON, 1994; 2.HMSO, 1999; 3.Lallana et al. 2001; 4.Butler and Memon, 2006; 5.DCLG, 2007; 6. EA, 2001b; 7. Grant, 2006; 8. Mays, 2010 9. Grant, 2003; 10.Milan, 2007; 11. Anand and Apul, 2011; 12. EA, 2003; 13. Australian Eco-Label, 2008; 14. Kaps and Wolf, 2011; 15. EU Eco-Lable, 2011; 16. Green building store, 2011; 17.EU water saving potential, 2007; 18.Bricor, 2010; 19. Friedman, 2009; 20. Aquacraft, 2003; 21. BREEAM, 2009; 22. British standard, BS 8525-1, 2010; 23. Jamrah et al. 2008; 24. MTP, 2008; 25. A power shower; 26. Standard flush in 1970's dwellings and exist in some older houses today; [a] Referred to as Lit/load (it is assumed here that 1 load = 1 use), [b] Actual reference reads 35-40 litres / 5 kg; [c] Referred to as Ultra Low Flush Toilet; [d] Assuming 2 or more urinals.

Figure 1. '**Futures framework' analysis for showering (partial framework).



This forms the starting point for a full 'futures framework' analysis which in turn is used as a proxy to represent the impact of future plausible changes / fluctuations in water demands. Six different user behaviour profiles (Levels A – best performance to Level E – worst performance) are adopted for residential (Table 4a) and office buildings (Table 4b) within this study.

Table 4a. Assumed User behaviour in domestic buildings:
Level A (best performance) to Level F (worst performance)

Water use	User behaviour levels											
	Level A		Level B		Level C		Level D - Typical UK -		Level E		Level F	
	D [1]	F [2]	D	F	D	F	D	F	D	F	D	F
WC flushing	-	2.2	-	2.8	-	3.7	**-**	**4.8**	-	5.25	-	6.3
Hand basin	0.33	2.25	0.33	2.25	0.33	3.00	**0.33**	**3.5**	0.33	3.5	1	3.5
Washing machine	-	0.05	-	0.12	-	0.16	**-**	**0.21**	-	0.34	-	0.37
Shower	3	0.6	5	0.6	7	0.6	**8**	**0.6**	10	0.65	15	0.65
Bath	-	0.11	-	0.16	-	0.16	**-**	**0.16**	-	0.3	-	0.34
Kitchen tap	0.33	2.25	0.33	2.25	0.33	3.00	**0.33**	**3.5**	0.33	3.5	1	3.5
Dishwasher	-	0.14	-	0.23	-	0.23	**-**	**0.23**	-	0.4	-	0.71

1. Duration of use in minutes, 2. Frequency of use per day per person

Table 4b. Assumed User behaviour in office buildings: Level A (best performance) to Level F (worst performance). *Italics* show where water use by females differs from that for males.

Water use	User behaviour levels											
	Level A		Level B		Level C		Level D -Typical UK -		Level E		Level F	
	D	F	D	F	D	F	D[1]	F	D	F	D	F
WC flushing	-	0.25 *(0.5)*	-	0.5 *(1)*	-	0.75 *(1.5)*	**-**	**1** ***(2)***	-	1.25 *(2.5)*	-	1.5 *(3)*
Urinal	-	0.25 *(NA)*	-	0.5 *(NA)*	-	0.75 *(NA)*	**-**	**1** ***(NA)***	-	1.25 *(NA)*	-	1.5 *(NA)*
Hand basin	0.05	0.5 *(0.75)*	0.1	1 *(1.5)*	0.15	1.5 *(2.25)*	**0.2**	**2** ***(3)***	0.25	2.5 *(3.75)*	0.3	3 *(4.5)*
Kitchen sink	0.025	0.25	0.05	0.5	0.08	0.75	**0.1**	**1**	0.125	1.25	0.15	1.5

In the case of offices the lack of behavioural data meant that ranges were assumed in order to form a sensitivity type analysis. A 50% increase in behaviour (above average UK values) was assumed in Level F and a 75% reduction in behaviour is assumed in Level A. Likewise six different profiles (Levels a – best performance to Level e – worst performance) are adopted for technological efficiency as shown in Table 5. Section 3 discusses the impact of each level on total water demands when adopted in isolation and combination.

Table 5. Technologies in Domestic and Office buildings:
Level a (best performance) to Level f (worst performance)

Water Use	*Units*	User Technology levels					
		Level a	Level b	Level c	Level d Typical UK	Level e	Level f
Urinal *	*lit/employee*	0.0	0.75	1.7	**3.6**	6.0	7.5
WC	*Lit/flush*	1.5	3	4.5	**6**	6	9
Hand basin	*Lit/ min*	3	5	6	**8**	12	15
Kitchen tap	*Lit/min*	4	5	6	**8**	10	12
Shower **	*Lit/ min*	6	8	10	**12**	15	24
Bath **	*Litre*	65	88	116	**116**	140	230
Washing machine **	*Lit/ use*	35	49	49	**80**	110	110
Dishwasher **	*Lit/load*	12	14	16	**25**	25	57
* Applies to offices only, **Applies to domestic only							

3. Results and Discussion

3.1. Step 4a: The influence of 'User Behaviour'

3.1.1 Domestic

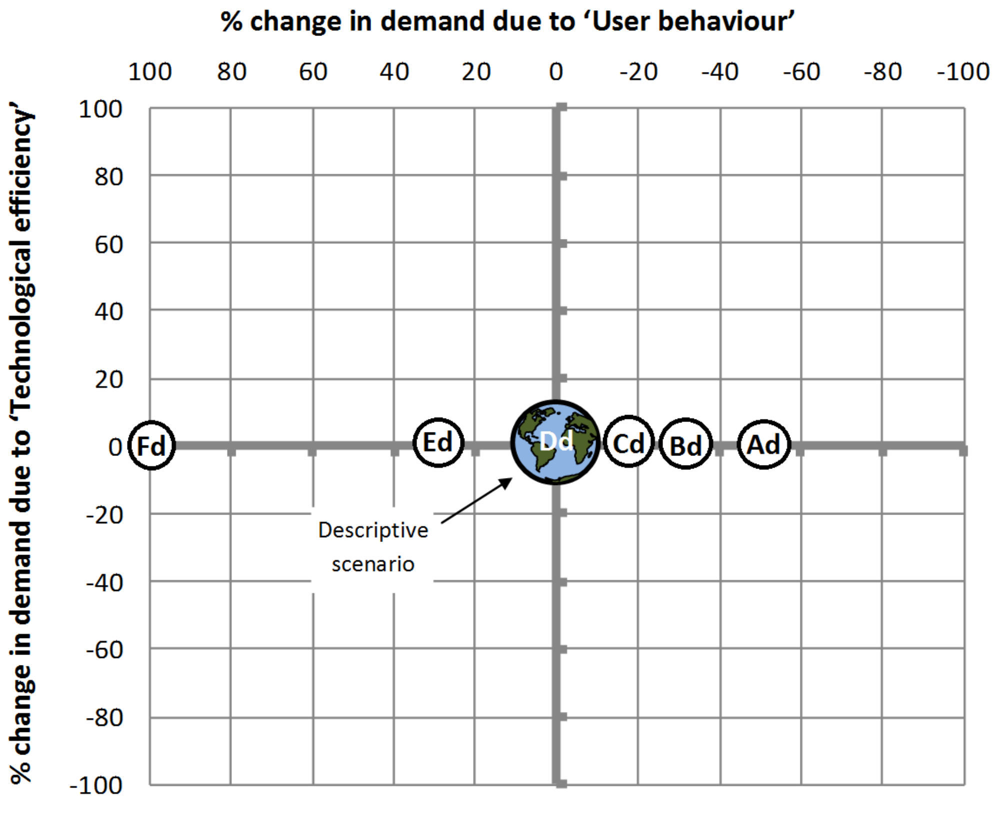
Table 6a shows the water demands that can be achieved by altering residential user behaviour (Levels A to F) whilst keeping technological efficiency constant (i.e. at Level d). For simplicity these are plotted on a full futures framework in Figure 2. Any fluctuations in demand, due to changes in user behaviour are represented along the horizontal axis. Changes in demand due to changes in technological efficiency are represented along the vertical axis and for this step are assumed unchanged – hence all points lie on the horizontal axis. Case Dd represents typical UK practice. Cd represents a reduction in demand of 14% to 128 lit/person/day. This is achieved (see Table 4a) through WCs being flushed less (on average 3.7 times per day), water is run into hand basins 3 times per day, whilst shower (for 7 minutes on average) and baths are taken at the same frequency as the UK average.

Dishwashers similarly match the UK average rate of use, but care is taken to limit kitchen sink use to 3 times per day and reduced frequency of washing machines from roughly once every 5 days to once every 6 days. For Bd further reductions in user behaviour occur (i.e. WC flushing is reduced to 2.8 times per day and showers are 1 minute shorter at 5 minutes). The frequency of use for dishwashers, baths and showers is unchanged. Ad combines the lowest level of user behaviour with standard efficiency technologies. The WC is flushed only 2.2 times / person / day. It is not inappropriate to assume that this low number of flushes is most likely to be possible in homes with professional occupants who are at work during the day and use the WC at home once each morning and once each evening, with a marginal increase at weekends. Or alternatively the toilet is not flushed each time it is used. Baths are limited to one every 8 days and showers are limited to 3 minutes providing a significant source of water saving. In this case it is assumed also that washing machines are used (per person) approximately once every 3 weeks. This requires an appreciation by users of the need to run the washing machine on a full load or perhaps to wear clothes for longer. This attitude to using washing machines can be encouraged by education and the use of incentives as described later. [It should be noted that the above narratives, and values of frequency and duration for indoor water use, are firmly based on current western values and way of life. A radically different outcome might be achieved if values drawn from overseas countries experiencing water scarcity (e.g. Australia) or from past UK experience (e.g. rural or post-second World War) are considered as discussed later.] Taps feeding kitchen sinks were assumed to run for 20 seconds, twice a day per person in all Levels except Level F where 1 minute is assumed. This assumption is based on the existence of a dishwasher which, in the lowest case, is used once per week – this is in agreement with the work of Butler and Memon (2006). Should it be the case that no dishwasher were adopted, the duration and (likely) frequency of kitchen tap use would increase accordingly; this may be influenced by culture. For example, according to one method of washing dishes the kitchen sink is filled with water and washing liquid, dishes are washed (with a sponge) and not rinsed with water afterwards.

Table 6a. Domestic demands achieved through changes in user behaviour alone: 'Technological efficiency' unchanged

Technology / User behaviour mix	Demand (lit/person/day)	Equivalent UK Water benchmark	% change compared to Dd
Ad	69	None	-54
Bd	101	None	-33
Cd	128	None	-14
Dd	**148**	**Typical UK**	**0**
Ed	202	None	+37
Fd	322	None	+102

Figure 2: Domestic demands through behavioural change (Futures Framework approach)



However, an alternative method is one in which the kitchen tap is kept running and dishes are washed under running water and a sponge impregnated with washing liquid and then rinsed again with water. Therefore the duration of use of the kitchen tap increases from 1 to around 6 minutes (Table 2).

3.1.2. Offices

Table 6b shows the water demands that can be achieved by altering office user behaviour (Levels A to F) whilst keeping technological efficiency constant (i.e. at Level d). Changes in total water demands for offices are achieved in a broadly similar manner to the domestic case. For example, in order to achieve the 4.7 (*6.2*) lit/employee/day in Ad (the most water efficient option in Table 6b), it is assumed that daily WC flushing and urinal flushing are reduced to 0.25 times per male employee (Table 5b). On the face of it this could be criticised for being an over-ambitious assumption since during a typical working day (8 hours) employees would almost certainly find such restrictions impossible, even were they to value water to such a high degree so as to seek positively to minimise their water usage. Moreover, in presenting this assumed goal without changing the technology, it raises the question of how low can you 'realistically' go in terms of user behaviour? Perhaps Level D (Table 4b) already defines this threshold, particularly for human bodily functions. Alternatively perhaps it highlights where office technology could be redesigned so as to eliminate the 'user' element from water flushing. This is already the case for 'timer driven' male urinals and unisex hand basin taps.

Table 6b. Office Demands achieved through changes in user behaviour alone: 'Technological efficiency' unchanged: (*Italics* show where water use by females differs from that for males)

Technology / User behaviour mix	Demand (lit/person/day)	Equivalent UK Water benchmark	% change compared to Dd
Ad	4.7 *(6.2)*	None	-70
Bd	7.8 *(10.2)*	None	-50
Cd	11.5 *(14.2)*	None	-27
Dd	**15.6 *(20.4)*** [a]	**Typical UK**	**0**
Ed	20.3 *(26.6)*	None	+ 30
Fd	25.4 *(33.4)*	None	+ 63

3.2. Step 4b: The influence of Technology

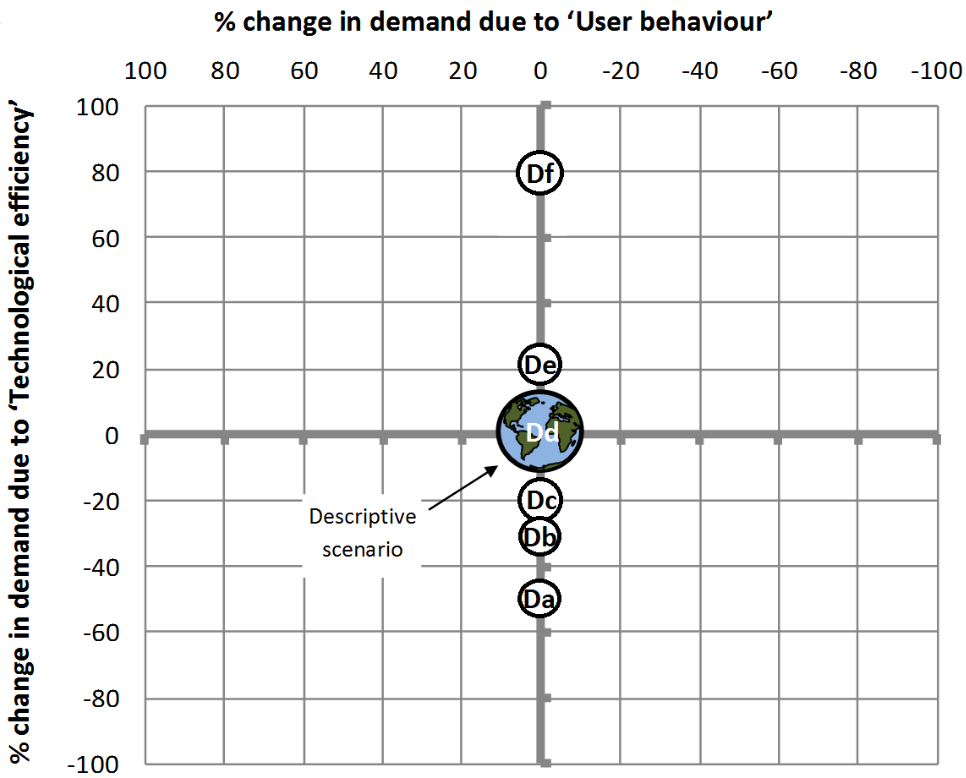
3.2.1 Domestic

Consider now the water level usage being achieved by progressive adoption of water saving devices in domestic buildings (i.e. not changing user behaviour at all, this remains at level D – Table 4a), as shown in Table 7a and, through a futures framework, in Figure 3. In this case, in direct contrast to Figure 2, data points are restricted to the vertical axis as user behaviour is assumed unchanged. For case Dc (equivalent to a Code for Sustainable Homes, CSH, 1&2 rating), with a daily usage of 120 litres per person, lower flow rates than those in the Typical UK case were adopted for showers (10 lit/min) and the kitchen and hand basin taps (6 lit/min), and a smaller WC cistern (4.5 lit/usage), in addition to a more efficient washing machine and dishwasher.

Table 7a. Domestic demands achieved through changes in technology alone: 'User behaviour' unchanged

Technology / User behaviour mix	Demand (lit/person/day)	Equivalent UK Water benchmark	% change compared to Dd
Da	67	CSH level 5&6	-55
Db	94	CSH level 3&4	-37
Dc	120	CSH level 1&2	-20
Dd	**148**	**Typical UK**	**0**
De	179	None	+21
Df	265	None	+79

Figure 3: Domestic demands through technological change (Futures Framework approach)



For case Db (equivalent to CSH 3&4, 94 lit/p/d) the same washing machine as case Dc has been assumed, but with further reductions in the size of the WC cistern and the flow rates of shower (8 lit/min) and kitchen and hand basin taps (all uses in Table 5 except urinal). For case Da (equivalent to CSH 5 and 6, 67 lit/p/d) the lowest demand was achieved, 55% lower than current typical UK practice, and the most efficient technologies were adopted. Likewise the highest demand (265 lit/p/day, 79% > typical UK practice) was achieved by using the most inefficient technologies (all uses in Table 5 except urinal).

3.2.2. Offices

In offices, the changes to water saving devices are implemented in a similar manner to domestic properties (first four technological uses in Table 5 only). The resulting demand changes can be seen in Table 7b: In case Dc (11.2 lit/employee/day) a smaller WC cistern, urinal and lower flow rate taps, as compared to the UK average, are adopted. In Db (8.3 lit/employee/day) these are decreased further. The highest possible technological efficiencies, including waterless urinals, were adopted in the most water efficient case (Da, 5.6 lit/employee/day) and this is 56% lower than typical UK practice. In case De (19.8 lit/employee/day) demands were increased through a decrease in technological efficiency as compared to Typical UK, for example both urinals and taps were less efficient and use more water. The most inefficient case (Df, 25.7 lit/employee/day) adopted the most inefficient technologies resulting in the highest water demand, some 65% higher than case Dd.

Table 7b. Office demands achieved through changes in technology alone: 'User behaviour' unchanged (*Italics* show where water use by females differs from that for males)

Technology / User behaviour mix	Demand (lit/person/day)	Equivalent UK Water benchmark	% change compared to Dd
Da	5.6 *(9)*	None	-64 *(-56)*
Db	8.3 *(12.3)*	None	-47 *(-40)*
Dc	11.2 *(16)*	None	-28 *(-22)*
Dd	**15.6 *(20.4)***	**Typical UK**	**0**
De	19.8 *(23)*	None	+27 *(+13)*
Df	25.7 *(31)*	None	+65 *(+52)*

3.3. Step 4c: The dual influence of 'Technology' and 'User Behaviour'

3.3.1 Domestic

In order to have a robust perspective on the dual impact to (and future options for) water demands the various levels of water saving devices and various levels of user behaviours are combined using a full futures framework (Figure 4). The values of the demand contours, as in Figure 1, are at 20% spacing – 100% represents no change in total water demand. This can be compared to a traditional plotting approach in Figure 5.

Through combining the most efficient technology options with behaviour options (point Aa), the lowest level of water demand of 31.9 lit/person/day is obtained. This represents almost an 80% reduction in water demands compared to typical practice and is lower than the level which could be achieved in isolation by considering user behaviour (53.4% in Ad) or technologies (55.6% in Da).

Figure 4: Domestic demands through behavioural and technological changes (Futures Framework approach, contours at 20% intervals)

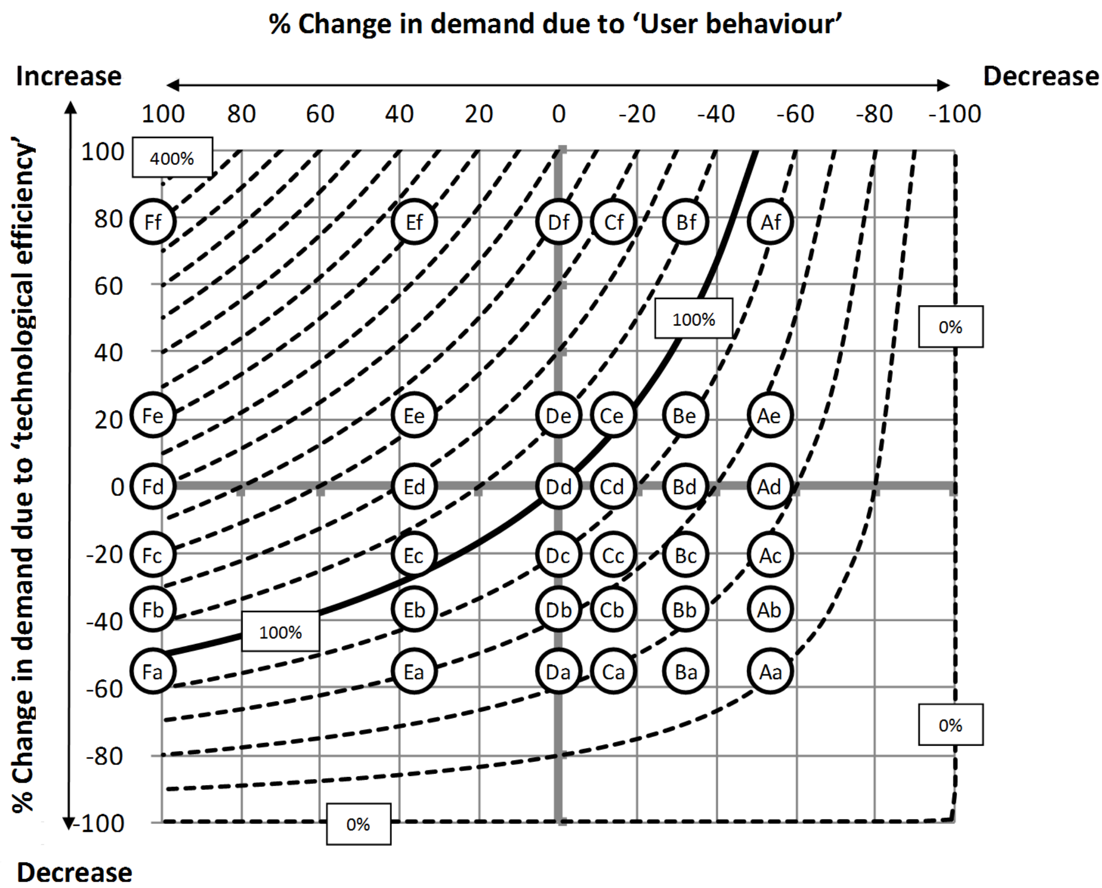
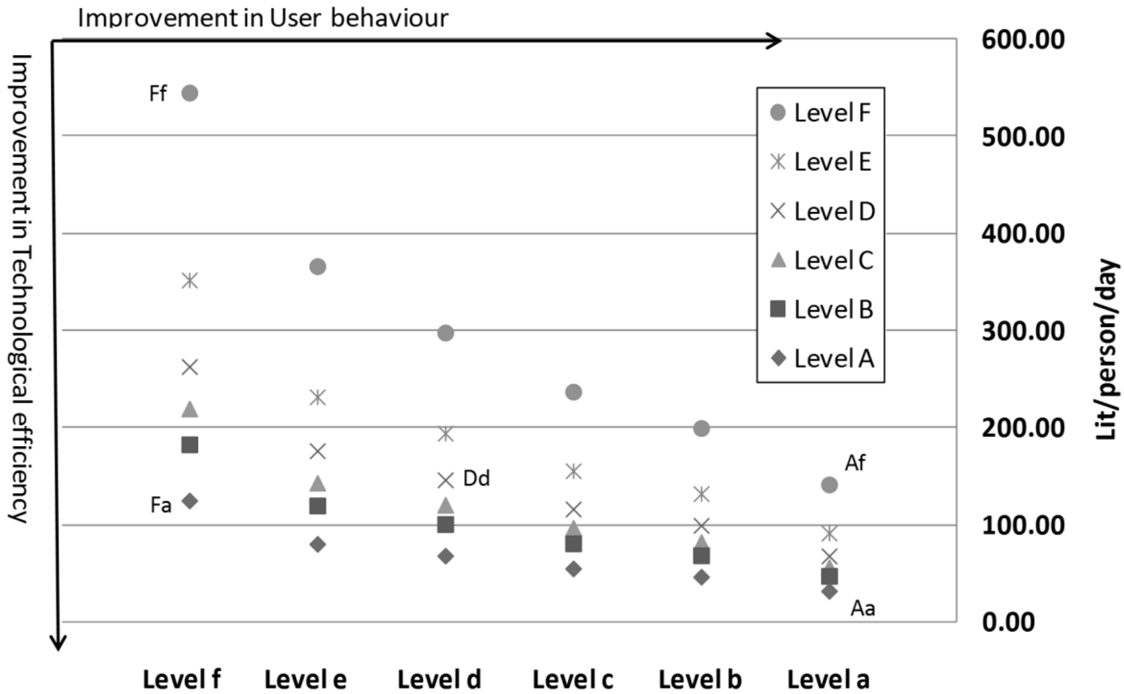


Figure 5: Domestic demands through behavioural and technological change (conventional representation)



The breakdown of demands in litres shows the high consumption for basic hygiene practices (WC, 3.3, Hand basin, 2.2, Washing machine, 1.75, Shower, 10.8, Bath, 7.15, Kitchen tap, 2.97, Dishwasher, 1.68). The total is identical to that suggested for Level 3 of living (Table 8), but still twice the minimum basic human need (Level 0). Even achieving this minimal level of water consumption in Aa is an ideal probably far from what could be achieved in practice, as the assumed toilet cistern size in this case is 1.5 lit/flush, which is believed not to be very widely acceptable (i.e. user *perception* comes into play), and is not high enough to allow for conventional sewered systems. In addition there is a possibility that users opt for the higher flush setting on dual flush toilets due to a misconception of malfunctioning of this type of toilet. In other cases users may flush low flush units more than once each use. The duration of shower usage should also be limited to 3 minutes with 6 lit/min showers in order to achieve such dramatic reductions. Given the significant step-change from the current situation it might be expected that shower duration would be influenced by switching to a low-flow showerheads. However, three American Water Works Association (AWWA) end-use studies (see EBMUD, 2003; also Seattle, Tampa) indicated that the duration of showers was similar with and without a low-flow showerhead (McMahon, 2006) and thus it would be possible to achieve these dual reductions in water usage.

At the opposite end of the scale the highest water demand (546 lit/person/day; point Ff in Figure 4 and 5) is achieved in the case where the most inefficient user behaviour (Level F in Table 4a) is combined with the most inefficient water using technologies (Level f in Table 5). This represents a 270% increase above Typical UK practice and demonstrates how significant the demand can become when both drivers remain unchecked. The futures framework shown in Figure 4 is particularly useful for identifying how broadly similar levels of water usage can be achieved in very different ways (e.g. Fa, Eb,Dc, Cd, Be, Ef).

3.3.2. Offices

Figures 6 and 7 shows the total water consumption (per male employee) in a typical office building when combining the various levels of user behaviour and user technology.

Table 8. Summary of water required for domestic activities of different level of living

Levels of living *(water needs)*		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Survival	• *Drinking and Cooking*	3	3	3	4	5	4	4	4
Utensil washing	• *Dish washing*	2	2	2	3	4	6	10	15
Hygiene	• *House washing*	1	1	1	1	2	2	3	5
	• *Clothes washing*	2	3	3	4	4	5	6	8
	• *Bathing/Showering*	7	15	16	20	15	60	92	163
	• *Toilet use*	0	0	0	0	20	30	30	40
Total (litres per day)		15 [a,b]	24[a]	25[a,c]	32[a]	50[a,d,e]	82[a]	143[a]	235[a]
Reference: a) Van Schalkwyk, 1996; b) Sphere. 2011; c) RSA DWAF,1998; d) Gleick 1996; e) WHO,1987									

Figure 6: Office demands through behavioural and technological changes (Futures Framework approach, contours at 20% intervals)

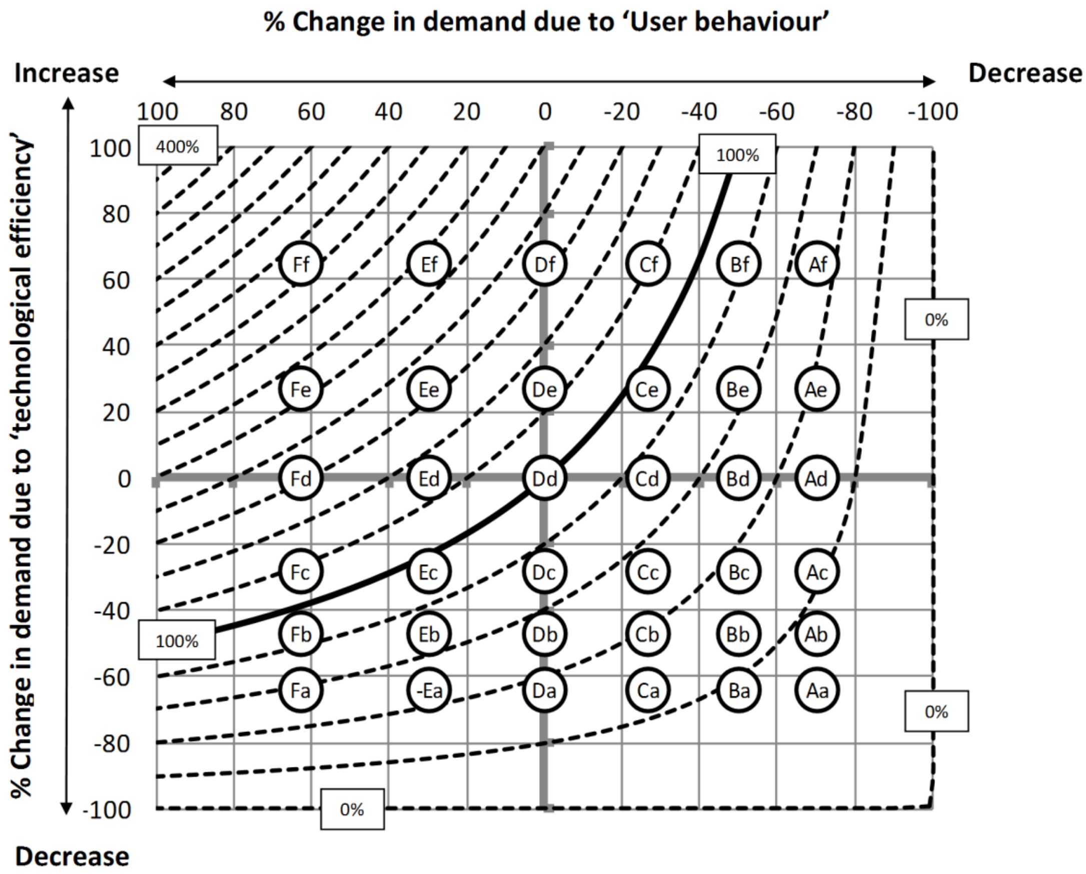
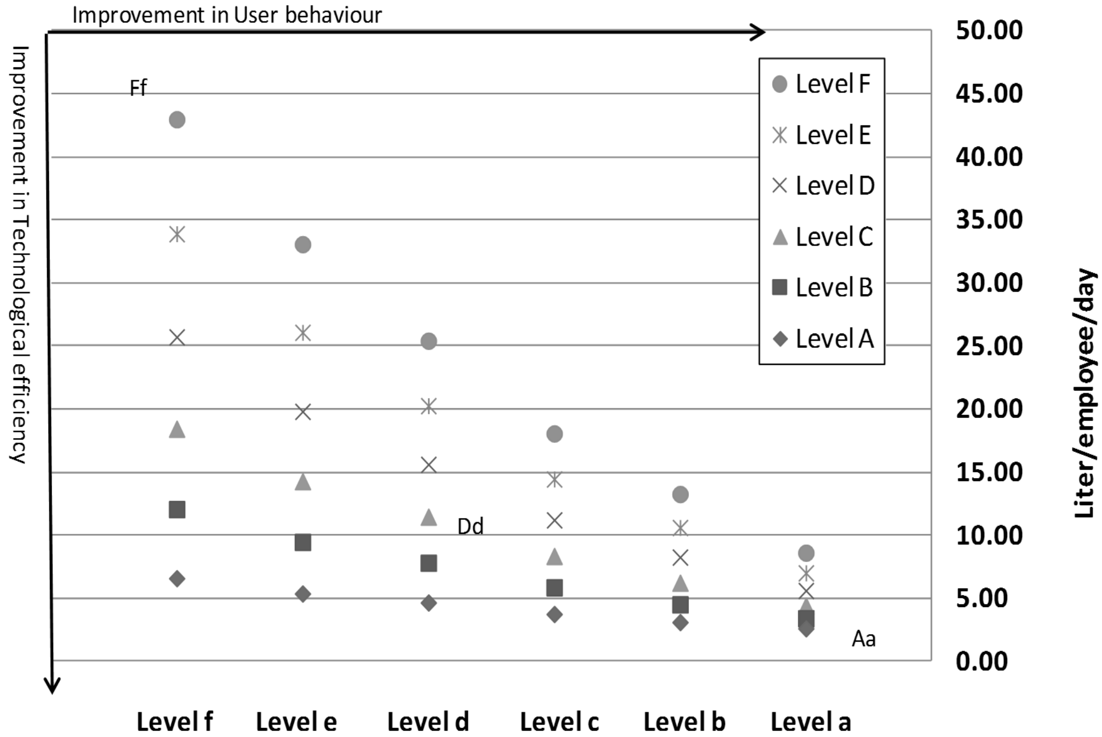


Figure 7: Office demands through behavioural and technological change (conventional representation)



Adopting the most efficient user behaviour (Level A in Table 4b) in conjunction with the most efficient user technologies (Level a in Table 5) results in the lowest daily water demand per employee (point Aa, 2.6 litres for male and 3.9 litres for females). This represents 80% of typical UK office consumption. Likewise the highest water demands (Point Ff, 43 litres for male and 53 litres for females) are achieved through combining the worst efficiencies. This represents a 159% increase.

3.3.3. Domestic and Offices

The results for both residential buildings and offices show that changing the technology adopted in buildings is a more efficient means of actually reducing water demand rather than relying solely on changing user behaviour, which has been shown to be highly variable. Figures 4 to 7 show that the consumption envelope is smallest where the most efficient water-saving devices are adopted and even profligate use of them results in relatively low water consumption values. In case Da, even with a significant increase in user behaviour the rate of water use is still restricted to lower than typical UK average values. This buffer obviously diminishes as the technological efficiency worsens.

Whilst a range of demands have been achieved through many combinations, the outcomes and choices are wide-ranging but not exhaustive. For example, when considering household options the user may wish to combine user behaviour levels and technological efficiency levels in very different ways (i.e. Level a and Level B for showering, Level b and Level D for WC flushing, etc.). Refreshingly, any of these perturbations can be explored within the Futures Framework.

4. Discussion

Accepting the premise that water demand management, rather than water supply management, is required, then the results presented above demonstrate both what might be achievable and what actions are necessary to achieve these favourable outcomes. It also raises ethical and moral issues alongside issues related to governance, regulation, legislation, finance, and individual and societal aspirations and practices, some of which are discussed here.

4.1 Socio-Political Approaches

Taking the societal issues first, the amount of water used in the shower by domestic users accounts for a significant proportion of the total per capita water consumption per day. Water consumption in the shower depends on the flow rate that the shower requires (technology) and the amount of time the shower is kept running (user behaviour). People typically spend far more time in the shower than they need. For example a troll that was posted on one of the biggest social networking websites (Facebook) contended that of every 27 minutes of showering 2 minutes is spent on washing and rinsing and the rest on thinking. While this does not constitute a reliable quantitative evidence-base, the fact that almost 35,000 users agreed that they did this in the shower does show that unsustainable water use behaviour wastes an enormous amount of clean water and energy. The latter constitutes a significant political driver for change when considering the UK Government's commitment, enshrined in legislation, to an 80% reduction in carbon emissions from 1990 levels. [An 80% reduction in water flow, as in case Aa, will reduce the embodied carbon emissions accordingly. However any associated carbon emissions within the home would require additional consideration of the energy using efficiency of the water using technologies; for example, the adoption of an electric water heater (e.g. a 9kW electric shower) versus a gas powered combi-boiler. Moreover user behaviour, once again, influences this water-energy equation (e.g., the influence of water temperature – 41 degrees or hotter – is important).]

It is a critical obligation to encourage people to behave more efficiently in their use of water, and one means of doing this would be via media such as Facebook to encourage change in individual, and societal, practices. A perhaps more deep-seated concept is that of societal and individual aspirations – 'wants' as opposed to 'needs' – and changes here require a fundamental adjustment to how water is valued. An appreciation of the complete sequence of the processes involved in water harvesting, purification, delivery, removal, treatment and transmission back into the environment, and the energy, greenhouse gas emissions and chemicals embodied in these processes, should help in this. Similarly an appreciation of the concepts of potential future water scarcity at home (shorter-term hosepipe bans during droughts and long-term national or regional water shortages as populations increase and the climate change), the current serious water scarcity in different parts of the world (along with some of the, what to us might appear extreme, measures being taken to mitigate the effects, even in developed countries), and the adverse effects on the environment of over-abstraction might help in getting the message accepted.

It is undoubtedly true that water supply restrictions, such as temporary bans applied in serious droughts, are effective in reducing water consumption, but this is a scenario that is highly undesirable, and unnecessary, if the other measures reported herein are adopted. Indeed, there is evidence to suggest that (mandatory) water restrictions reduce consumption over the short-term, when consumers are motivated to comply (e.g., the acceptance of responsibility for the problem, perceptions of institutional trust, environmental values, etc.). Water conservation is more apparent when individuals believe that water is scarce and when they perceive that other consumers are also conserving water (intensive social and moral awareness, perceptions of inter-personal trust; Corral-Verdugo *et al.*, 2003). This can be achieved via TV and other media advertising, and education campaigns including schools, leafleting and displays at water recreational sites such as reservoirs.

4.2. Economic Incentives

Economic incentives provide a second, more immediate, means of changing behaviours and encouraging the adoption of water saving technologies. Numerous studies by the European Environmental Agency (EEA) have proven that price signals (economic incentive) have a significant impact on water use in households. Indeed, water consumption generally correlates negatively with water prices (White and Fane, 2007). For example, when the Hungarian government progressively increased water prices (from 10 to 140 HUF), it led to a decline in the country's water consumption from 160 to less than 100 lit/person/day over a ten-year period (European Commission, 2000). Germany likewise introduced economic incentives, leading to a 17% decline in daily water consumption over 20 years to reach 122 lit/person/day. Of course when the true value of water is not reflected in the price, consumers in the past often used it inefficiently and irresponsibly. But the question is how much does the pricing matter?

This policy raises two issues: one is that those who are wealthy will continue to use water unsustainably and inefficiently, in the interests of a luxurious life style, while most of the pressure to economise will be on low income users. If prices are raised to high levels to correct this imbalance it will become progressively harder for many to afford enough water for one's basic needs. The second issue is that increasing the price of water gives people an excuse not to feel guilty if they do consume more water and might discourage them from applying simple indoor water saving practices. Moreover the above analysis and discussion has neglected outdoor uses such as car washing and outdoor garden irrigation or powered washing of hard surfaces, all of which consume very large quantities. Employing arguments of social equity and human rights, and perhaps invoking the need for strong governance or legislation, a very different pricing structure might be adopted. Accepting that access to clean water can be considered as a human right, it can be argued that minimum level to satisfy human needs should be provided at a reduced rate or (for those who cannot afford it) free of charge, and that a 'rising block tariff' is adopted for quantities above this minimum level, such that profligate usage will cost the end-user many times more than that of reasonably constrained end-use. Interestingly this approach was trialled in 1000 households by South West Water in the UK using three blocks: a low-cost 'essential use' block which varies with household size (73% of standard unit cost); a standard price 'safety net' block (standard unit cost) and a premium price block for non-essential use (181% of standard unit cost). The idea was not subsequently pursued because the trials failed to produce significant behaviour change, though this might simply be because the differentials were insufficient.

4.3. Benchmarking and Metering

The analyses performed here using the futures framework suggests that benchmarking should be based on water use (i.e. a mix of user behaviour and technological efficiency) rather than a reliance of technology alone. From the results obtained using the futures framework, best practice user behaviour and a modest investment in water-saving devices for domestic users would suggest that this level of free usage might be fixed at a 50 lit/person/day benchmark. [It should be noted here that the absolute minimum basic survival water need is reported to be 15 lit/person/day (Van Schalkwyk, 1996; Sphere, 2011). However, in westernised developed societies, much of which is urbanised, this level is not currently deemed adequate for a healthy and productive life, i.e. 'liveability', hence the suggested benchmark.] The cost for usage above this level could then be increased, perhaps exponentially for incremental increases in volumes used, such that the pricing structure produces an acceptably profitable business model for water companies. Moreover this pricing structure could be adjusted annually as user behaviours and/or technology adoption causes usage volumes to fall and water company profitability to change; there is a role for the regulator here to ensure fairness on both sides. The moral imperative for such an action that would result in progressive reductions in water wastage would not only reflect a right to clean water, but embrace protection of the environment, protection of sources of water for future generations, a reduced need for an expanded water infrastructure as the population grows (and reductions in the embodied carbon and natural resource consumption that this necessarily entails), reduction in energy demands, and so on. This intervention would yield multiple benefits and perform well in futures analyses (Rogers *et al*., 2012), as well as delivering greatly improved resilience to this essential service provision (Lombardi *et al*., 2012). An important corollary here is the need for all households and offices to be fitted with a water meter and a readily accessible means of viewing and recording water use in real times. Figure 1 could be used to show how an individual case of water use (in this case showering) can be benchmarked and as a decision-making tool it allows the user to decide upon how their water is used. In essence therefore the user is free to apply their own 'liveability' lens (which includes costing) to each water option.

4.4. Combined Incentives

In light of the discussion above, the roles of other incentives (social and moral) seem indispensable for changing users' behaviour. For example, the decline in water consumption in Hungary and Germany was not only the result of increasing water prices (Figure 3). Increasing water charges was merely one of the strategies in reducing water demand, being allied with consumer awareness campaigns and encouraging the use of water-saving devices. In effect, social and moral incentives were aligned with an economic incentive which helped these countries to significantly drop their per capita water consumption. Social and moral incentives via education to reinforce the dual ideas of "shortage of precious clean water" and explain the ways of "helping to save this vital resource" can motivate and encourage water users to behave more sustainably and efficiently. Creating an environment in which "we're all in this together and we have a collective duty to behave responsibly" is perhaps best achieved via TV and radio advertising, backed up by education campaigns, leaflets and national and local news stories.

5. Conclusion

This paper clearly demonstrates the need for a combination of all of the potential interventions – technological improvements, user behaviour change, societal and individual value and aspiration adjustments, financial incentives, ethical and moral imperatives, and governance/ legislation/regulation change – if water demands are to be greatly reduced and the UK is to be assisted in moving towards the commonly stated aspirations of being resource secure and meeting our environmental targets (which include the 80% CO_2 reduction enshrined in UK law). All are influential in making a success of strategies for managing household water demand, which ultimately depends on how people think about and use water. As this paper has shown, even a sub-set of the possible measures in the two most evident approaches (technology and behavioural change) can make a very marked difference. An approach based on an alternative business model that recognises a minimum level of clean water supply as a human right and charges progressively greater costs for incremental use above this minimum level could result in a sea change in how water is valued and used.

More specifically the results in this study show that structural and technical measures (i.e. the adoption of water saving devices) have just as great an impact on reducing per capita water consumption as does changing user behaviour towards more efficient use. Furthermore implementing water saving devices in buildings in conjunction with changes in user behaviour can very considerably reduce the domestic water demand in urban areas and readily meet sustainability code levels, such as levels 1&2 and levels 3&4 of the Code for Sustainable Homes, without adopting any recycling or reuse systems. However, in order to achieve levels 5&6, there is a need to implement the most efficient water devices that the public will accept. However the degree of user acceptance of the more radical water-saving devices and the impact of installing them on changing user behaviour is still unknown.

Water is an undeniable essential requirement for life, health and human dignity. The quantities of water needed for basic human needs may vary depending on cultural practices, religious practices, the climate, people's habits (individual and societal norms), the food they cook, the clothes they wear and the sanitation facilities available. While the absolute minimum basic survival water need is reported to be 15 lit/person/day, in westernised developed societies, much of which is urbanised, this level is not currently deemed adequate for a healthy and productive life (or 'liveability') and a minimum level for essential needs might be fixed at 50 lit/person/day. However, any such establishment of a baseline benchmark is dependent on the context – can we assume that the availability of water per capita that we currently are used to will remain into the near and far future, and thus might the context radically change? Adopting the 'futures framework' described herein allows for a twin track approach to be considered and for 'liveability' options to be accounted for. The framework can be used to manipulate performance based on levels we currently accept and achieve, or it can be used to specify a level of performance and work backwards to establish the technological and user behaviour performance (in isolation or combination) required to achieve this specified level of performance, whether within a building, a neighbourhood or a city. Questions can be asked about how 'liveable' certain options might be. We might envision a future where all our demands are met and unlimited resources flow freely, or alternatively (as we know to be the case currently) we might envision the opposite. Underlying all of this argument is a fundamental question: if we were only allowed 50 litres of water per day, how might you spend yours? The 'futures framework' enables us to consider our options and answer the question.

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Conflict of Interest

The authors declare no conflict of interest.

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