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Article

Socio-Technological Influences on Future Water Demands

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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 two fundamental management measures to influence daily water demand and therefore conservation are considered: (1) Technological efficiency measures (*i.e.*, via adopting water-saving devices); and (2) User behaviour (*i.e.*, how users interact with and use the technologies). Through a newly developed futures framework, the individual and combined impact of these approaches within residential and office buildings are examined. 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 within the UK. The paper provides philosophical arguments for what else is needed in order to secure sufficient, sustainable water supplies within a "liveable" future.

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

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. In many countries (including the UK) it has been apparent for some time that a paradigm shift is required in Water Demand Management (WDM). In general terms WDM takes three main forms [1]:

(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 (e.g., new reservoirs, new water treatment plant, desalination) 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 [1–6]. One commonly adopted WDM measure is the use of water saving devices that can have significant impact in both domestic and office settings [7–11]. 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 current and future changes in water use behaviour. For example, work from Australia, New Zealand, USA and UK is showing that behaviour and attitudes toward water consumption and conservation are at least as important, if not more important, in terms of encouraging long-term water conservation habits [12–15]. Unfortunately in the UK consumers are typically unaware of water scarcity or the environmental impact of water use and behaviour change is only temporarily at the time of droughts when hosepipe bans are in place [16]. Water saving initiatives within the UK are focused on pushing (e.g., technological efficiency improvement through Code for Sustainable Homes—CSH), pulling change (e.g., wider adoption of water metering) or nudging change (e.g., encouraging improved user behaviour) [17]. Therefore when future water demands are being assessed a range of water consumption scenarios need to be considered.

This paper examines, individually and together, the impacts of changes in technological efficiency and user behaviour (high use to low use) on water demand in domestic residences and offices within the UK. Section 2 describes a generic methodology that has been used to assess these dual driver impacts. The novelty in this research is the way that user behaviour and technological efficiency are viewed in parallel through an innovative futures framework approach that allows a range water use scenarios to be explored. This is a paramount requirement if the UK is truly to prepare for an uncertain future. 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 five 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 and Step 5 is discussed in Section 4.

2.1. 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 Table 1 respectively and are based upon the previous work of Hunt *et al.*, and Zadeh *et al.* [9,10]. The total water demands are directly in line with those reported by Environment Agency [18] for domestic properties and Waggett and Arotsky [19] for offices. These demand profiles were based on actual data from extensive monitoring studies for water use within domestic properties the UK. 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 L/min) and user behaviour (e.g., how often the shower is used and for how long it is used). (Whilst the preferred flow rate is undoubtedly a key factor it is not included in the assessment—it is accepted that a user may be using a 12 L/min shower head and may not use it at this rate.) 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. Duration may be influential in terms of topping up bath water as it runs cold. Automated water using appliances such as WC, dishwasher, and washing machine are less discretionary in use than a bath. There is typically a set volume 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). Whilst "Duration-D" and "Frequency-F" of water end-use are the only two key measurable influences shown in Table 1 they are not the only influences and are not the only parameters that define user behaviour. However, research in the UK suggests that the complex relationships influencing household water use make underlying patterns of behaviour are difficult to detect [20]. Not least because there are so many other outside influences (e.g., age, weather patterns, household income, household make-up, household culture, perceived behavioural control *etc.* [21,22]) that are not all purely behaviourally-driven. In the UK the only way to record an individuals' water use behaviour has been through qualitative means (*i.e.*, diary based questionnaires and interviews) combined with micro-component data and this can be subjective when it comes to identifying actual *vs*. perceived (or intended) user behaviour [20,21].

Table 1. Breakdown of water use in residential dwellings and by office employees [9,10]. *Italics* show where water use by females differs from that of males.

Water use	Technology	User behaviour		Total water use
	i—Water consumption (units)	ii—Duration of use (min/use)	iii—Frequency of use (N/person/day)	iv = i × ii × iii (L/person/day)
Breakdown of water use in residential dwellings				
WC flushing	6 (L/usage)	-	4.8	28.8
Hand basin	8 (L/min)	0.33	3.5	9.2
Kitchen sink	8 (L/min)	0.33	3.5	9.2
Wash. Machine	80 (L/load)	-	0.21	16.8
Shower	12 (L/min)	8	0.6	57.6
Bath	116 (L/usage)	-	0.16	18.6
Dishwasher	24.9 (L/usage)	-	0.23	5.7
Other	2 (L/day/person)			2
Total daily water consumption (L/person/day)				148
Breakdown of water use by office employees				
WC flushing	6 (L/flush)	N/A	1 (*2*)	6 (*12*)
Urinal	3.6 (L/employee) [a]	N/A	1 (*0*)	3.6 (*N/A*)
Hand basin	8 (L/min)	0.2 (*0.2*)	2 (*3*)	3.2 (*4.8*)
Kitchen sink	8 (L/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*)

Notes: [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 L/bowl/hour and should be considered to operate 12 h per day, 5 days per week (assuming water saving timers is fitted) and not 24/7 based on UK Water Regulations pre 2011.

2.2. 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. Whilst there are many compelling international datasets that could have been used based on smart metering approaches [14,20,21] the focus of this study is for the UK. The behaviour(s) of domestic users (Table 2) are derived from past monitoring studies where empirically derived data has been collected from water users within the UK. This helps to identify, for example, the variation in reported values for frequency of WC flushing (6.3 and 2.2 flushes/day). Its shows also that showering times are highly variable and have a much broader range (3 to 30 min., 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 min to 6 min. There is unfortunately a lack of behavioural data for office employees; therefore the average figures adopted in Table 1 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 [23].

Table 2. Domestic user behaviour of an individual: frequency (F) of use and duration (D) ranges.

WC	Washing machines	Taps/Hand basins		Showers		Bath	Dishwasher
F1	**F1**	**D2**	**F1**	**D2**	**F1**	**F1**	**F1**
6.3 [9]	0.54–0.72 [14]	6.7 [13]	3.5 [24]	30 [24]	1.8–2.1 [14]	0.34 [18,25]	0.71 [9]
5.25 [26,27]	0.37 [24]	6 [28]	3 [29]	15 [1,11]	0.65 [8,24]	0.16 [1,11]	0.4 [1,11]
4.8 [1,11,13,30,31]	0.34 [31]	1 [24]	2.25 [28]	10 [9]	0.6 [13,18,29,32]	0.12 [24]	0.37–0.67 [14]
4.5–6.5 [14]	0.31 [13]	0.33 [29]		8 [8]		0.1–0.13 [14]	0.28 [13]
4.3 [18,33]	0.21 [1,11]			5.7–6.5 [14]			0.23 [1,11]
4 [3,25]	0.18 [26]			5 [13,18,30]			0.214 [28]
3.7 [7,34]	0.16 [7]			3 [9]			0.14 [24]
3.3 [35]	0.157 [18]						
2.8 [9]	0.05 [9]						
2.2 [9]		-					

Notes: 1. Duration of use in minutes; 2. Frequency of use per day per person.

Table 3 is a database of actual available water using technologies and related water efficiency data which has been drawn from the literature. It reflects technologies which have been used, are being used or could be used and encompasses those which are very water inefficient (first in column) and very water efficient (last in column).

Table 3. Technologies: Range of water usage from existing and modern indoor technological appliances.

WC		Hand basin	Washing machines		Showers	Bath	Kitchen taps	Dishwasher	Urinal flush [g]
(L/flush)	**Type**	**(L/min)**	**(L/use)**	**(L/kg)**	**(L/min)**	**(L) [f]**	**(L/min)**	**(L/load)**	**(L/bowl/hr)**
9 [a], [13]	Single	15 [5]	150 [36]	27 [37]	24 [e]	230 [38]	12 [3]	56.78 [39]	7.5 [31]
6 [4,18,31,37]	Single	12 [3,40]	110 [41] [c]	12 [29]	15 [5]	150 [13]	10 [42]	24.09 [43]	6 [39]
6/4 [44]	Dual	10 [18]	100 [26]	7–8 [4] [d]	12 [3,42]	140 [29]	9 [42]	20 [39]	3.6 [31]
6/3 [4,44]	Dual	8 [42]	92 [13]		10.8 [24]	116 [28]	8 [24]	16.75 [3]	1.7 [3]
4.5 [4]	Single	7.5 [40]	80 [28]		9.5 [18]	88 [39]	7.5 [45]	14 [39]	0.75 [31]
4 [4,18,44]	Single	6 [29,42]	65 [18]		8 [18]	65 [39]	5 [13,45]	13 [43]	0 [29]
4/2 [18,44]	Dual	5 [29,39]	55 [18]		6.5 [3]		4 [28]	12 [39]	
2–3 [4]	Single	4 [29,46]	49 [31]		6 [44]			8 [13]	
1.5 [43,47]	ULFT [b]	3 [13,29]	45 [48,49]		5.11 [31]				
1.2 [4]	Vacuum	1.7 [29]	40–80 [18]		4.5 [29]				
0 [18,50]	Composting				3.5 [13,27]				

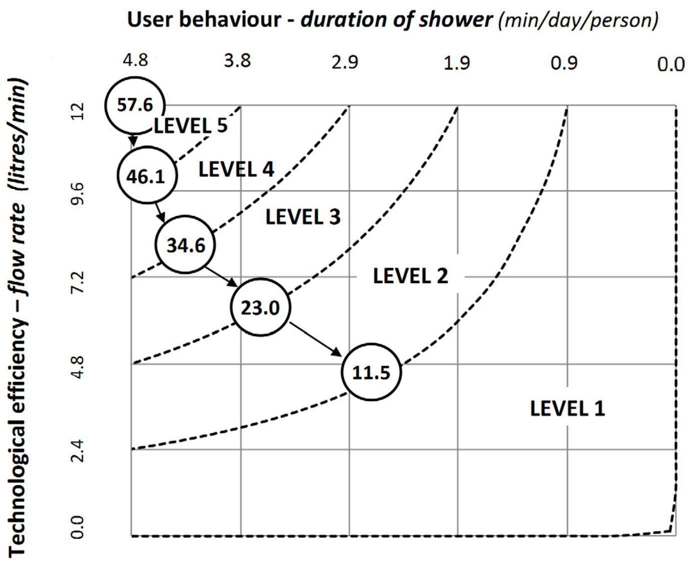
Notes: [a]: Standard flush in 1970's dwellings and exist in some older houses today; [b]: Referred to as ultra Low flush toilet; [c]: Referred to as Lit/load (it is assumed here that 1 load = 1 use); [d]: Actual reference reads 35–40 litres/5 kg; [e]: A power shower; [f]: Assuming 2 or more urinals; [g]: Bath capacity.

2.3. 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.* [51] 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 L/min). Equally it could be achieved through a multitude of combinations of both (*i.e.*, a 4 min shower and a flow rate of 8.7 L/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.

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 and office buildings (Table 4) within this study. In Table 4 data is taken directly from Table 2. Level A adopts low values and Level F adopts high values from each water use. Values in Levels B to E are then selected trying to keep a relatively even spread between these lowest and highest values. In all cases it has been assumed that values in Level D are identical to those in Table 1 for residential and offices respectively.

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

Water use	User behaviour levels											
	Level A		Level B		Level C		Level D *		Level E		Level F	
	D [1]	F [2]	D	F	D	F	D	F	D	F	D	F
Domestic buildings												
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	8	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
Office buildings												
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

Notes: [1] Duration of use in minutes; [2] Frequency of use per day per person.

Whilst the user is free to allocate whatever values they choose within this framework the overarching philosophy is that it should capture a sufficient range so as to encompass profligate and water efficient users. 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 water use (above Level D) was assumed in Level F and a 75% reduction in water use 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. Data is taken directly from Table 3. "Level a" adopts low values and "Level f" adopts high values from each water use. Values in Levels b to e are then selected trying to keep a relatively even spread between these lowest and highest values. In all cases it has been assumed that values in Level D are identical to those in Table 1 for residential and offices respectively Whilst the user is once again free to allocate whatever values they choose within this framework the overarching philosophy is that it should capture technologies (and related efficiencies) that exist or are being conceived and reflect a sufficient range so as to encompass profligate and water efficient efficiency. 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**	**Level e**	**Level f**
Urinal *	*L/employee*	0.0	0.75	1.7	3.6	6.0	7.5
WC	*L/flush*	1.5	3	4.5	6	6	9
Hand basin	*L/min*	3	5	6	8	12	15
Kitchen tap	*L/min*	4	5	6	8	10	12
Shower **	*L/min*	6	8	10	12	15	24
Bath **	*L*	65	88	116	116	140	230
Washing machine **	*L/use*	35	49	49	80	110	110
Dishwasher **	*L/load*	12	14	16	25	25	57

Notes: * 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

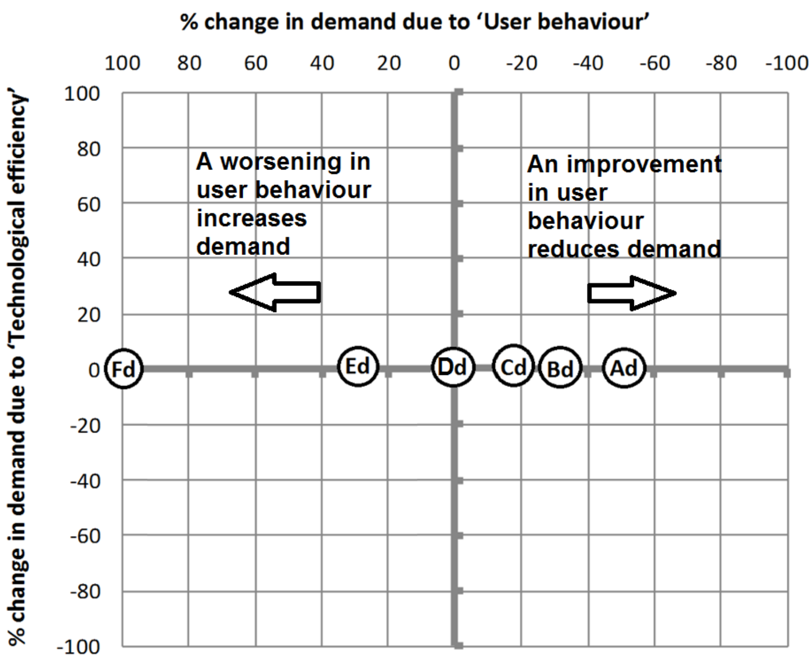
Table 6 shows the water demands that can be achieved by altering residential user behaviour (Levels A to F) whilst keeping technological efficiency constant (*i.e.*, at Level d). For simplicity these are plotted on a full futures framework in Figure 2. Any fluctuations in demand, due to changes in user 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 L/person/day. This is achieved (see Table 4) 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 min 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 min. shorter at 5 min.). 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 may be inappropriate to assume that this low number of flushes is possible even in homes with professional occupants who are at work during the day unless the toilet is not flushed each time it is used. Baths are limited to being a quarter full and showers are limited to 3 min 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. Whilst not everyone in the world has the luxury of a new set of clothes everyday It would be extremely difficult to have a successful social marketing strategy to "wear clothes for longer" because the perceived quality of life for the average Westerner would surely be seriously compromised. Although an appreciation by users of the need to run the washing machine on a full load would be equally helpful. 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, [12]) or from past UK experience (e.g., rural or post-second World War, [3]) are considered as discussed later). Taps feeding kitchen sinks were assumed to run for 20 s., 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 [28]. Should it be the case that no dishwasher is 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. However, an alternative method is one in which the kitchen tap is kept running and dishes are washed under running water and a sponge soaked with washing liquid and then rinsed again with water. Therefore the duration of use of the kitchen tap increases from 1 to around 6 min (Table 2).

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

Technology/User behaviour Mix	Demand (L/Person/Day)	% Change compared to Dd
Ad	69	−54
Bd	101	−33
Cd	128	−14
Dd	148	0
Ed	202	+37
Fd	322	+102

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



3.1.2. Offices

Table 7 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*) L/employee/day in Ad (the most water efficient option in Table 7), it is assumed that daily WC flushing and urinal flushing are reduced to 0.25 times per male employee (Table 4). On the face of it this could be criticised for being an over-ambitious assumption since during a typical working day (8 h) 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 4) 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 7. Office demands achieved through changes in user behaviour alone: "Technological efficiency" unchanged: (*Italics* show where water use by females differs from that of males).

Technology/User behaviour mix	Demand (L/Person/Day)	% Change compared to Dd
Ad	4.7 *(6.2)*	−70
Bd	7.8 *(10.2)*	−50
Cd	11.5 *(14.2)*	−27
Dd	15.6 *(20.4)*	0
Ed	20.3 *(26.6)*	+30
Fd	25.4 *(33.4)*	+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 4), as shown in Table 8 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 and 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 L/min) and the kitchen and hand basin taps (6 L/min), and a smaller WC cistern (4.5 L/usage), in addition to a more efficient washing machine and dishwasher. For case Db (equivalent to CSH 3 and 4, 94 L/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 L/min) and kitchen and hand basin taps (all uses in Table 5 except urinal). For case Da (equivalent to CSH 5 and 6, 67 L/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 L/p/day, 79% > typical UK practice) was achieved by using the most inefficient technologies (all uses in Table 5 except urinal).

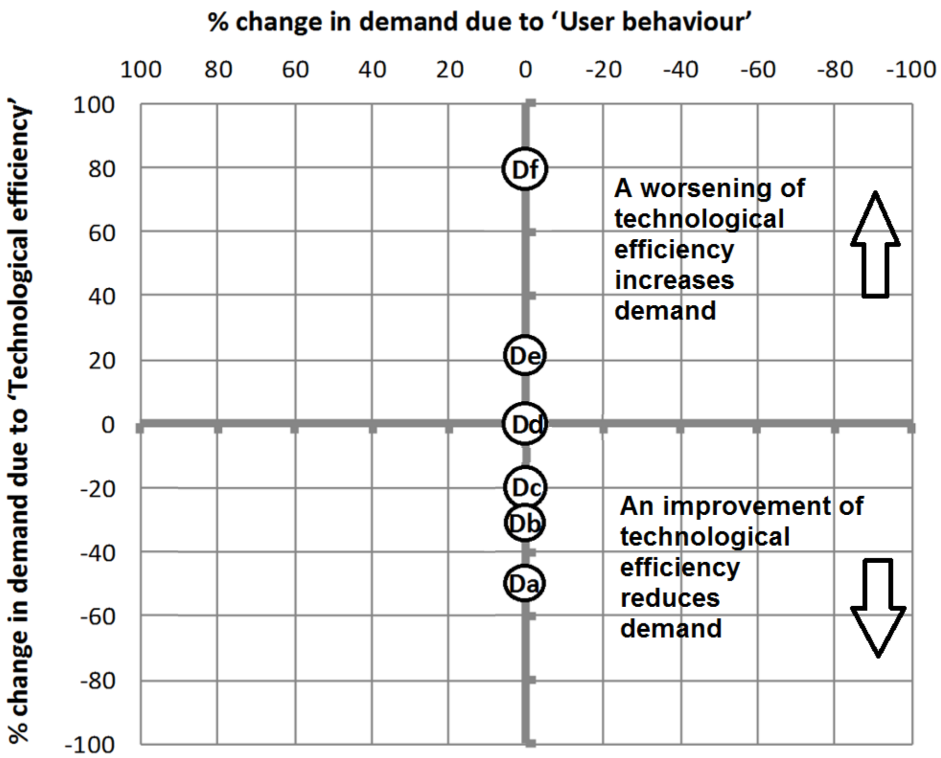
Table 8. Domestic demands achieved through changes in technology alone: "User behaviour" unchanged.

Technology/User Behaviour Mix	Demand (L/person/day)	Equivalent UK Water Benchmark (L/person/day)	% Change Compared to Dd
Da	67	CSH level 5 & 6 = 80	−55
Db	94	CSH level 3 & 4 = 105	−37
Dc	120	CSH level 1 & 2 = 125	−20
Dd	148	UK average = 150	0
De	179	None	+21
Df	265	None	+79

Table 9. Office demands achieved through changes in technology alone: "User behaviour" unchanged (*Italics* show where water use by females differs from that of males).

Technology/User Behaviour Mix	Demand (L/person/day)	% Change Compared to Dd
Da	5.6 *(9)*	−64 *(−56)*
Db	8.3 *(12.3)*	−47 *(−40)*
Dc	11.2 *(16)*	−28 *(−22)*
Dd	15.6 *(20.4)*	0
De	19.8 *(23)*	+27 *(+13)*
Df	25.7 *(31)*	+65 *(+52)*

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



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 9: In case Dc (11.2 L/employee/day) a smaller WC cistern, urinal and lower flow rate taps, as compared to the UK average, are adopted. In Db (8.3 L/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 L/employee/day) and this is 56% lower than typical UK practice. In case De (19.8 L/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 L/employee/day) adopted the most inefficient technologies resulting in the highest water demand, some 65% higher than case Dd.

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). What it does very neatly is show a possibility space for future domestic water demand scenarios. The four quadrants are typical of a scenario approach that uses two axes-of-uncertainty (as previously defined in Figure 3 and Figure 2). Quadrant 4 is what we would aspire to happen for water conservation strategies—a sustainability paradigm where a step-change in both user behaviour and technological efficiency is achieved. Quadrant 1 is what we would wish to avoid—a market forces driven world where high water consumption exists driven by excessive user behaviour and very inefficient water using technologies. Figure 4 is useful in conveying that there are an infinite number of ways to achieve the same level of water reduction performance explicitly achieved through mixes in changes to user behaviour and technological efficiency. This is why demand contours have been used at 20% spacing—the thick black contour (0%) represents "no change" in total water demand. Anywhere above the contour shows an increase in water demand and below shows a decrease in water demand. This offers a very different representation of the data as compared to Figure 5 which shows very well that there is positive correlation between reducing water use and water-efficient technology/water conservation behaviour(s).

Although it would be very simplistic to think that user behaviour is not intimately linked with the technology of water fixture. The interesting and perhaps more complicated aspect is to define (or even measure) what pushes, pulls or nudges [17] a step-change in user behaviour from Quadrant 1 to Quadrant 4 (or *vice versa*). For example, there may be an assumption from those who have adopted water efficient technologies that they would reside below the black line and well within Quadrant 4. Yet research shows they often underestimate the actual amount of water they use in their home and can be higher than average use for similar family types [14].

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

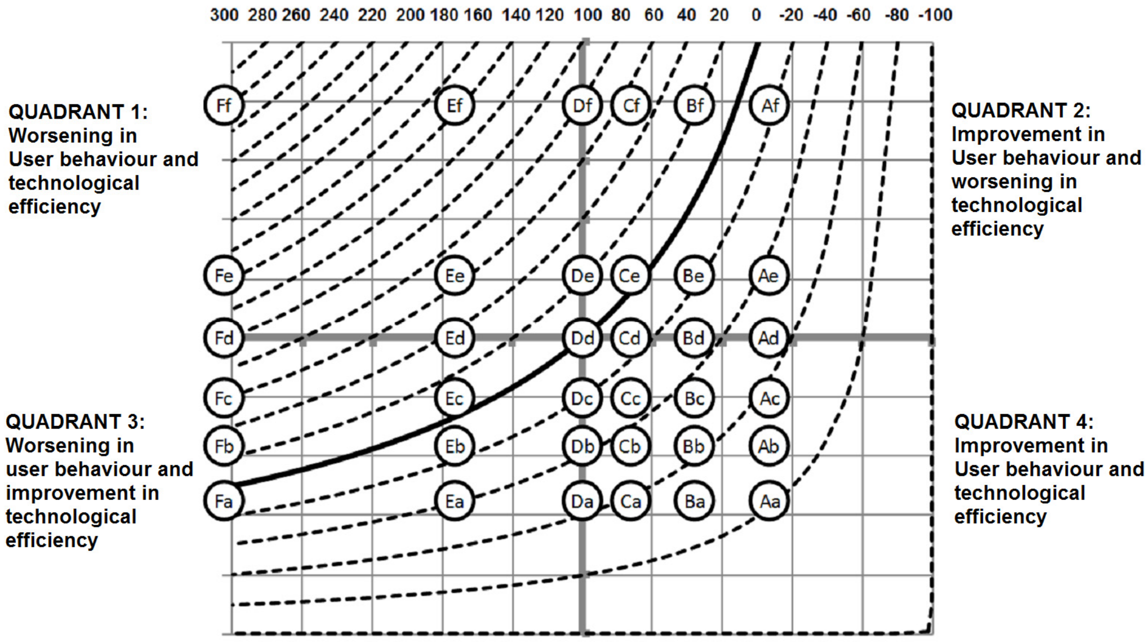
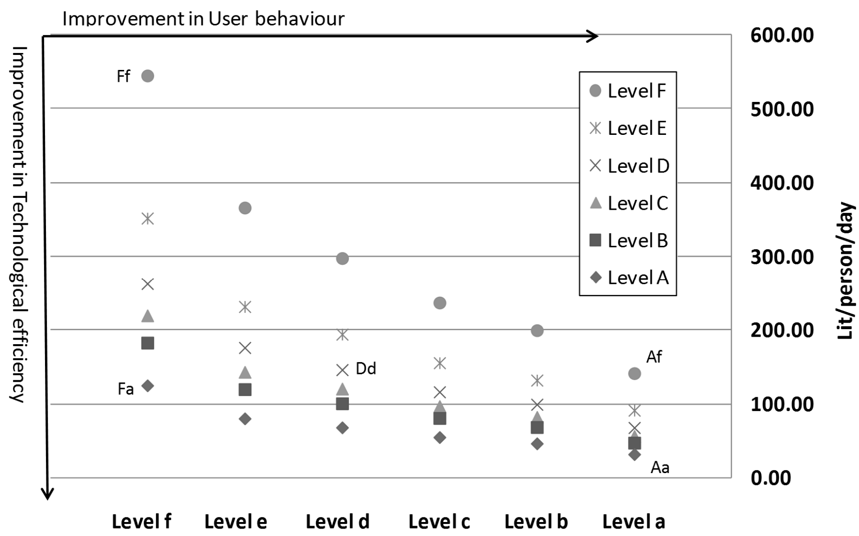


Figure 5. Domestic demands through behavioural and technological change (conventional representation).



Therefore there is a risk that water use might be located some way above the black line in Quadrant 3, or even Quadrant 1. This is something you would wish to avoid as would be the case for an individual who has adopted a power shower inadvertently increasing the time spent therein. The futures framework presented here is particularly good at making this type of message explicit.

Through combining the most efficient technology options with behaviour options (point Aa), the lowest level of water demand of 31.9 L/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).

The daily breakdown of demands in litres per person 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 10), but still twice the minimum basic human need (Level 0).

Table 10. Domestic water demand scenarios showing breakdown by water needs.

Water Needs		Demand Scenarios							
		0	1	2	3	4	5	6	7
Survival	Drinking/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 (L/day)		15	24	25	32	50	82	143	235
[References]		[52,53]	[52]	[52,54]	[52]	[55,56]	[52]	[52]	[52]

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 L/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 (through timing devices) with 6 L/min showers in order to achieve such dramatic reductions. This is eminently possible and has already been achieved in Australia [12,14,21]. 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 (East Bay, Seattle, Tampa [57]) indicated that the duration of showers was similar with and without a low-flow showerhead [58] 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 L/person/day; point Ff in Figure 4 and 5) is achieved in the case where the most inefficient user behaviour (Level F in Table 4) 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 show the total water consumption (per male employee) in a typical office building when combining the various levels of user behaviour and user technology.

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

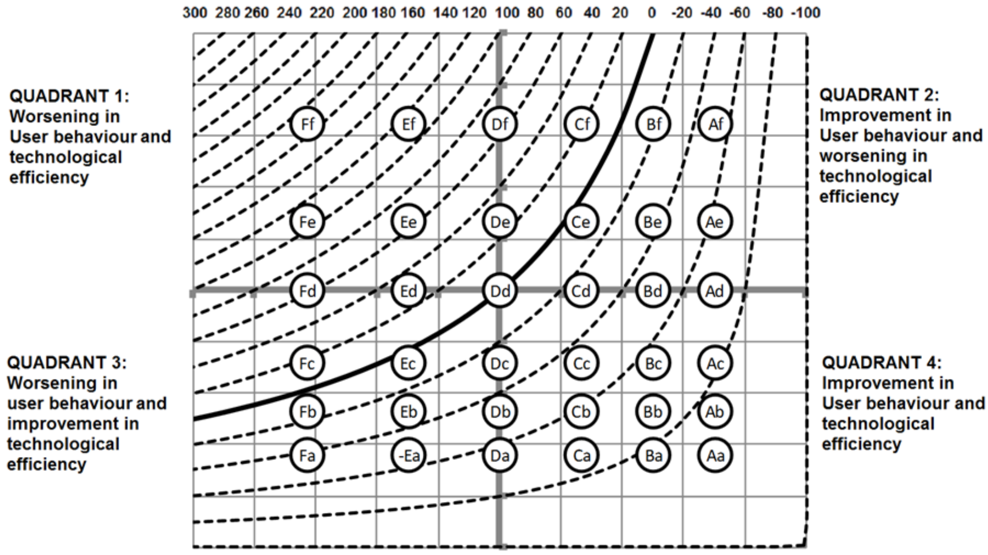
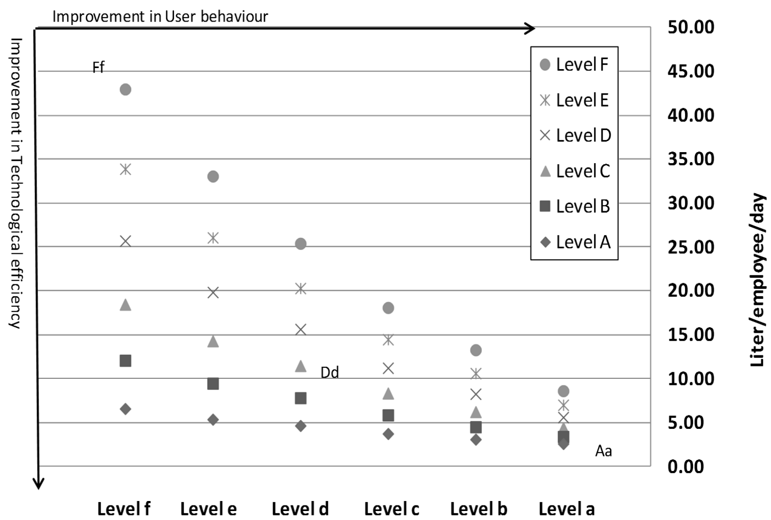


Figure 7. Office demands through behavioural and technological change (conventional representation).



Adopting the most efficient user behaviour (Level A in Table 4) 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). As can be seen in Figure 6 this represents >80% reduction in 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 in water consumption compared to Dd.

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. Philosophical Arguments

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. Behaviour Changes

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 (which is influenced by technology and the extent to which the user opens up the tap–user behaviour) and the amount of time the shower is kept running (user behaviour). The later is most definitely influenced by a sufficient time for washing and relaxation/contemplation and these will differ with each individual. Whilst a reliable quantitative evidence-base does not exist for this (and would be hard to substantiate) it is self-evident that unsustainable water using behaviour would waste enormous amounts of clean water.

It is a critical obligation to encourage people and society to behave more efficiently in their use of water, and one means of doing this would be via media such as Facebook. 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 only, 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 [59]. 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 [60]. 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 L/person/day over a ten-year period [39]. Germany likewise introduced economic incentives, leading to a 17% decline in daily water consumption over 20 years to reach 122 L/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 water 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 powered washing of hard surfaces or car washing and outdoor garden irrigation, all of which consume very large quantities. As these demands are the most elastic part of water consumption (typically) because of so many the external influencing parameters they were assumed beyond the scope of this paper, although they are considered in a recent paper by Hunt and Rogers [61]. 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 trialed 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. It is suggested that best practice benchmark for domestic users might be fixed at a 50 L/person/day benchmark [61] this is based on the UN minimum requirement to live and requires a 67% reduction in demand which relates to Cc and Bd in our analysis. (It should be noted here that the absolute minimum basic survival water need is reported to be 15 L/person/day [52,53] or a 90% reduction in demand is achieved in Aa). 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 [62], as well as delivering greatly improved resilience to this essential service provision [63]. 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 individual "liveability" lens (which includes costing) to each water option. This is important as research shows that consumer feedback (e.g., pie charts of specific household use from near-real time smart metering) has substantial impact on water reduction—even in times of low existing water use.

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. 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.

4.5. Allied Issues

Energy and carbon savings constitute 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—which is good. However any associated carbon emissions within the home would require additional consideration of the energy using efficiency of the water using technologies mentioned within this paper; for example, the adoption of an electric water heater (e.g., a 9 kW electric shower) *versus* a gas powered combi-boiler. Moreover user behaviour, once again, will influence the water-energy equation (e.g., the influence of water temperature—41 degrees or hotter—is important).

5. Conclusions

This paper 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 vary considerably reduce the domestic water demand in urban areas and readily meet sustainability code levels, such as levels 1 and 2 and levels 3 and 4 of the Code for Sustainable Homes, without adopting any recycling or reuse systems. However, in order to achieve levels 5 and 6, there is a need to implement the most efficient water devices that the public will accept. The question remains as to what new water supplying, new water using or improved water saving devices might be invented in the future and to what degree will user acceptance be considered—ultimately this depends on how much water is available to go round.

Water is an undeniable essential requirement for life, health and human dignity. 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 these arguments 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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Authors Contributions

Sara Zadeh conducted the outline research for this project during her PhD studies. Chris Rogers subsequently strengthened the discussion sections of the paper. Dexter Hunt strengthened the paper throughout its derivation and introduced the futures framework approach. In addition he carried out all of the additions/changes during the review and publication process.

Conflicts of Interest

The authors declare no conflict of interest.

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