



# Reframing intervention: What does a collective approach to behaviour change look like?

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# **WATER EFFICIENCY CONFERENCE**

**9-11 September 2014**

**University of Brighton, UK**

**[WWW.WATEFNETWORK.CO.UK](http://WWW.WATEFNETWORK.CO.UK)**



**University of Brighton**



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## **Proceedings of the Water Efficiency Conference 2014**

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## Preface

This volume contains the proceedings of WatefCon 2014: The Water Efficiency Conference 2014 which was held from 9-11 September, 2014 at the University of Brighton, Brighton, UK. The paper and program were all administered and managed through the EasyChair Conference System. In all, the committee received over 40 submissions. Each submission was blindly reviewed by at least 2 program committee members. After the review process, the committee decided to accept 24 papers representing work undertaken by academics and industry practitioners. The program also includes 2 Keynote Lectures by **Ian Barker**, Managing Director of Water Policy International Ltd and **Jacob Tompkins**, Waterwise.

This is the Second Annual Water Efficiency Conference organised by The WATEF Network. The network is a global group of academics, industry, NGOs, interest groups and members of the public who share an interest in promoting water resource efficiency, progressive water policy, useful and usable codes and standards and general best practice. The WATEF Network is funded by the Water Efficiency policy team at Department of Environment, Water and Rural Affairs (DEFRA) UK, led by Alison Maydom. DEFRA has funded the network since its inception in 2011 and we graciously acknowledge the support of all the team and their continuing our funding for a further 3 years.

I would personally like to thank the conference chairs: **Dr Beatrice Smyth**, Queens University Belfast and **Dr James Jenkins**, University of Hertfordshire for their immense efforts to make the conference a success. Thank you to all network members and strategic partners too, the network would not be a success without you all. I encourage those who are not yet members to do so; membership is free.

Thank you to all the paper authors and presenters for making the conference interesting and enlightening. Thank you to the network's Water Reuse Technical Committee for giving their time and for the special session. Thank you all our sponsors, exhibitors, tour hosts for helping to make the program interesting and worthwhile. Special thank you to our special guest, the **Baroness Parminter**, for giving her time to attend the conference and dinner. And last but not least, thank you to Suzy Armsden, our network Administrator for doing an excellent job of making sure that the conference takes place and runs efficiently.

Welcome from the Water Efficiency Lab and WATEF network at the University of Brighton. I wish you all a pleasant time and hope to see you at one or all of our network events in the forthcoming year.

August 5, 2014  
Brighton, UK

Kemi Adeyeye

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## Program Committee

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## EDITORIAL

The United Nations has estimated that, by 2050, at least a quarter of people are likely to live in a country with chronic or recurring shortages of freshwater. With its focus on water efficiency, Water Efficiency Conference 2014 is both timely and topical.

The conference presentations include those on technical interventions and water efficiency devices, consumer attitudes and preferences, retrofits and real-life case studies, the impacts of drought restrictions, urbanisation, and water conservation measures, tariffs, and water company perspectives.

The conference draws together the views of academia and industry, as well as those of policy makers and national organisations. The wide-reaching nature of the challenges associated with water is reflected in evaluations from countries from throughout Europe and beyond, including the UK, Ireland, Germany, Portugal and Nigeria.

The interaction of the water and wastewater sector with energy and agriculture: the Nexus will also be addressed at the conference, with presentations on the use of wastewater in agriculture, irrigation with greywater, rainwater harvesting, and water and energy recycling. A joint panel discussion session on 'The Nexus – Water, Energy and Agricultural Fuel' will stimulate debate and sharing of ideas on the topic. Putting theory into practice, the conference will conclude with tours to Propelair® installations at the Royal Pavilion, and the Peacehaven Treatment Works.

We would like to extend our many thanks for your contribution to the conference, and we look forward to meeting you for fruitful discussion at the University of Brighton in September!

Conference Chairs:

Dr Beatrice Smyth, Queen's University Belfast

Dr James Jenkins, University of Hertfordshire

## Keynote lecture: "Why water efficiency matters"

*Abstract: Water availability: it cannot be taken for granted, yet frequently is. However, increasing pressures, scarcity and uncertainty must be reconciled with rising expectations for quality of life and of the environment, and affordable supplies. In the UK the 'twin track' approach forms the basis of supply-demand planning and investment; managing demand and then implementing timely interventions to increase supplies. For the first time water companies are now forecasting reductions in customer demand and the twin track appears to be delivering more sustainable water management. But the big challenges are the risks involved if the planned savings are not delivered, and how the trust and confidence of water users are essential to maintaining the reductions.*

### IAN BARKER



**Ian Barker** is Managing Director of Water Policy International Ltd, a consultancy and commentator on water and environmental issues.

He has over 35 years' experience in the water sector, including having had overall responsibility at the Environment Agency for water planning, regulation and management across England

and Wales.

He is an expert advisor to the OECD and is a non-executive director of the Water Industry Forum, and of Waterwise.

## Keynote lecture: "Fun and Games in the Water Industry"

*Abstract: Gamification has been used successfully in a range of sectors to enhance engagement. This talk assesses whether these approaches can be used in the UK water sector. It gives an overview of gamification in other utilities worldwide, looks at the elements that could be transferred to UK water and highlights the potential difficulties. It highlights the opportunity for smart IT to deliver bespoke gamification at the household level. The talk will reference a couple of examples of gamification in water ranging from catchment management games to neighbourhood competitions.*

### JACOB TOMPKINS



**Jacob** has 25 years' experience in environmental technology. He has degrees in civil and environmental engineering from UCL and in Hydrology and Environmental Systems from Imperial College. After carrying out research in the fields of hydrogeology, pollution control and climate

change at Imperial, he worked as an environment and land-use specialist at the National Farmers' Union of England and Wales, then as the environment policy lead for Water UK.

He is the managing director of the water efficiency body Waterwise which he established in 2005 and he also runs a consultancy specialising in environmental policy and he has worked on carbon trading and carbon reduction strategies. He was the water champion on Defra's Food Industry Sustainability Strategy and leads the domestic work strand for the Government Chief Scientist's UK Water Research and Innovation Partnership.

He has served as the secretary of the European Drinking Water Association and as the UK environment

representative on the European farming association Copa-Cogeca. He has managed and partnered on a number of international research programmes on water and energy.

Jacob is a regular commentator and columnist on environmental issues in both print and broadcast media and at international conferences and is on the editorial Board of Sustain Magazine. He has developed a number of disruptive environmental technologies in the water, waste and energy sectors, in areas ranging from product manufacture to influencing consumer behaviour and he is a technical adviser to a number of Greentech companies. He was a founding member of the Blueprintforwater grouping of NGOs and was a board member of the environmental and social justice NGO People and Planet.

## SPECIAL GUEST: BARONESS PARMINTER



Kate Parminter was created a life peer in July 2010. She sits in the House of Lords on the Liberal Democrat benches and she is the party spokesperson in the Lords on DEFRA matters (Department of the environment, food & rural affairs). She is a member of the House of Lords' Select Committee on the European Union and its Sub-Committee on agriculture, fisheries, environment and energy.

Kate was born in 1964 and grew up in West Sussex. Educated at state schools in Horsham she went on to study Theology at Lady Margaret Hall, Oxford from 1983-1986.

Subsequently she worked for Nestle, Simon Hughes MP and a PR Consultancy. From 1990-1998 she headed the Public Affairs for the RSPCA, during which time she chaired the Campaign for the Protection of Hunted Animals which helped to ban hunting. In 1998 she became Chief Executive of CPRE, the Campaign to Protect Rural England.

From 2004-2010 she has been a freelance consultant advising corporations and charities on charity, CSR and campaigning issues. Clients included Lloyd's, the City of London Corporation, Mencap & Age Concern.

She was a Liberal Democrat Councillor on Horsham District Council in West Sussex for eight years (1987-1995) and is a Trustee of the Liberal Democrats.

Kate is a trustee of the think tank, IPPR and is also a Patron of the Meath Epilepsy Trust.

She lives in Godalming, Surrey with her husband and two school age daughters.





# CONFERENCE PROCEEDINGS

# EFFECTS OF MEASURES OF WATER EFFICIENCY IN BUILDINGS IN THE CONSUMPTION DIAGRAMS

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## ABSTRACT

Water efficiency is a matter of growing importance due to unsustainable water use worldwide. Climate change has exacerbated this scenario and it is expected that in some countries, such as Portugal, the predicted reduction in rainfall or alterations in its system may create or aggravate situations of scarcity or water stress.

Grounds for sustainability impose, therefore, measures of efficient water use in all sectors. However, measures of water efficiency applicable to buildings, in addition to reducing the consumption of drinking water, alter the diagrams of consumption, particularly in regard to consumption peaks and the coefficients of simultaneity usually considered in the design of internal networks. Thus, with the trend towards an increasing use of water efficiency measures in buildings, it becomes necessary to revise and validate new bases for the design of the installations.

In this paper the results of three studies conducted by ANQIP (Portuguese Association for Quality and Efficiency in Building Installations) in buildings where different water efficiency measures were implemented are presented. Overall, these results confirm that the policies for water efficiency in buildings require rethinking of the usual design criteria for building networks.

**Keywords:** coefficients of simultaneity, consumption diagrams, peak factors, water efficiency.

## INTRODUCTION

Water efficiency is an issue of growing importance due to unsustainable water use in the world, as a result of the exponential population growth on the planet and the current highly resource-intensive and pollution generator global economic growth model. Climate change can exacerbate this scenario and it is expected that in many countries the predicted reduction in rainfall or change in the regimen can create or aggravate situations of scarcity or water stress in the short / medium term.

Water efficiency is also reflected in a significant contribution to energy efficiency, through the nexus water – energy. A study carried out in Portugal revealed that the adoption of simple water efficiency measures in houses could lead to an average of 30% savings in water consumption, meaning a reduction in energy consumption in public networks and in heating and pumping water in the buildings corresponding to

1,140 kWh per household per year, which would lead to a reduction in GHG emissions of 105 kg of CO<sub>2</sub> per person and per year. (Silva-Afonso *et al.*, 2011).

Grounds for sustainability require the introduction of measures for efficient water use in all sectors, including obviously the buildings, embodied in the so-called principle of "5R". The first R, reduction of consumption, is a priority measure and passes through the adoption of efficient products or devices and other non-technical measures (economic ones as well as general awareness). The second R, reduction of losses and waste, can involve interventions such as the control of losses or installation of circulation circuits of hot water. The reuse and recycling of water constitute the third and fourth R, whose difference is to consider a "serial" use or the reintroduction of water early in the circuit (after treatment). Finally, the fifth R, the use of alternate sources, may involve the use of rainwater, groundwater or even saltwater (Silva-Afonso & Pimentel-Rodrigues, 2011).

These various water efficiency measures naturally reduce the average consumption of drinking water from the public network, but can also cause changes in the diagrams of consumption, particularly in regard to consumption peaks and coefficients of simultaneity used for the design of water supply networks in buildings. In the case of rainwater harvesting systems, for example, with the use of non-potable water for watering gardens and flushing cisterns, the coefficients of simultaneity commonly used in the sizing of the inner water networks are significantly changed with the grouping of devices with similar characteristics. Therefore, with the trend towards increasing the use of water efficiency measures in buildings, it becomes necessary to revise and validate new bases for the design of the installations, in regard to drinking and non-potable water supply networks.

This paper presents the results of some studies conducted by ANQIP (Portuguese Association for Quality and Efficiency in Building Services) in buildings where different water efficiency measures were implemented within the principle of 5R, with continuous recording of consumption through telemetry systems and the study of the diagrams of water consumption, particularly as regards the coefficients of simultaneity. Although the studies performed relate to a short period of time and a relatively small number of households, which can possibly affect the quality of the findings, the results clearly indicate that the policies for water efficiency in buildings may imply a change in the usual design criteria for the water supply in buildings. The paper includes a comparative analysis with the sizing criteria of the European Standard EN 806-3 (CEN, 2006), which is being continued in other residential buildings of different typologies in order to improve the conclusions.

The extension of the records, which will also be done in some cases under study may also help cushion any possible change of behavior of residents during the monitoring period, at least during the initial phase as a reaction to the fact of knowing that their habits are being studied.

## **CASE STUDY 1: DWELLING WITH RAINWATER HARVESTING**

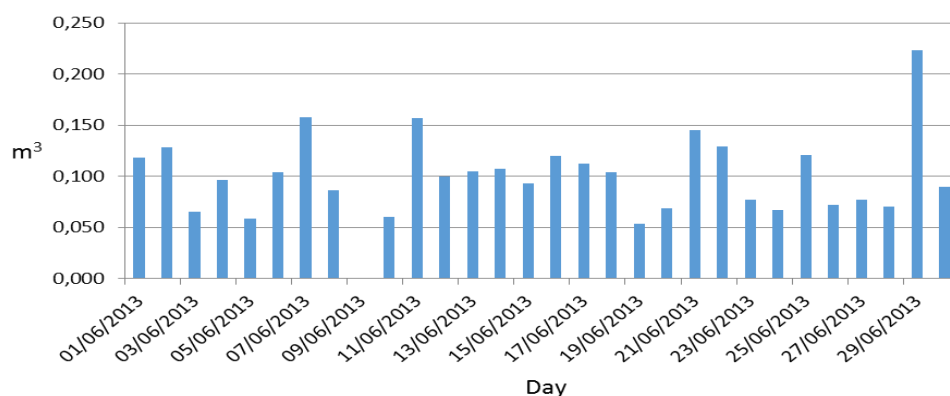
### **Methodology**

The house is inhabited by a family of four, it consists of three floors and has a system for harvesting rainwater, designed to feed three flushing cisterns and the watering taps situated in the garden and yard. The supply of this building network with rainwater is made using a pump from a cistern of about 12 m<sup>3</sup>, providing an estimated reserve of 45 days in a normal year. The garden area is approximately 200 m<sup>2</sup>.

Data processing was done between April 2, 2013 and September 12, 2013, with hourly consumption data collection by a telemetry system. In this period there was an interruption in data collection between July 23 and August 27, due to a malfunction of the counter, which is why the data for the month of August were not considered. In addition to differential treatment of data for the drinking water network (supplied by the public network), the network of rainwater and the total consumption of the two networks, the consumption on weekdays, weekends and holidays were also analyzed separately.

## Results

As an example of the records obtained, the daily consumption, from the public network and from the rainwater network, registered during the month of June 2013 are shown in the following diagrams (Figures 1 and 2). The highest consumption observed in the two networks occurred on the 29th, Saturday, but it was due to the presence of guests outside of the family cluster and some demonstrations of the functioning of the system during that day. On the 9th, Sunday, when the residents were absent all day, no consumption from the public network was observed, although there was a scant consumption from the rainwater system, probably resulting from the operation of automatic watering in the garden.



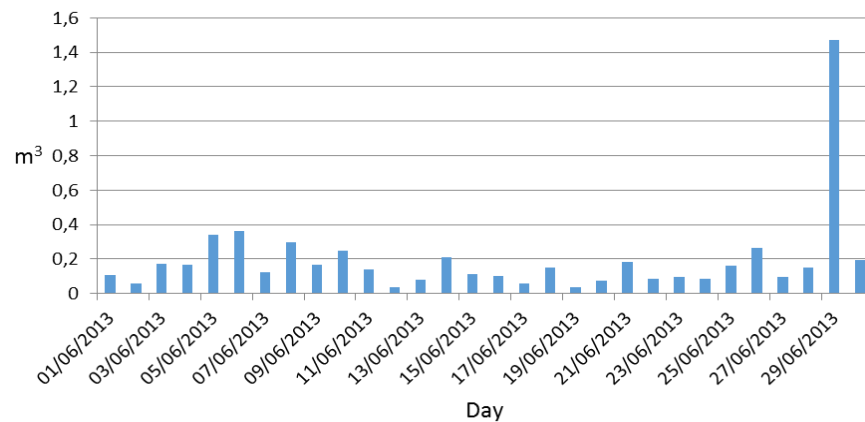
**Figure 1. Public network – Daily consumption during the month of June**

The analysis of consumption for this month showed that only 34% of the total consumption of the household was met from the public network, which revealed a significant savings potential of drinking water in this house by harnessing rainwater, in the order of 2/3 of the total consumption of the month. In the previous months the savings were even higher (4/5 of the total in May and  $\frac{3}{4}$  in April).

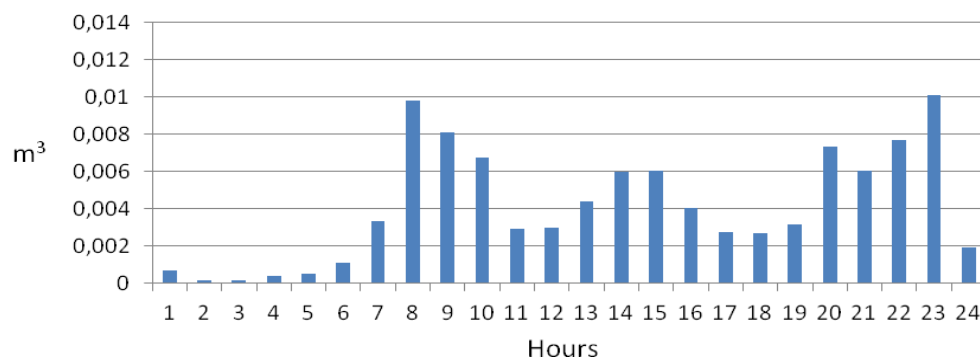
The average capitacion determined during the study period were 81.8 l/inhab./day, where 60.5 l/inhab./day corresponded to the rain water system and only 21.3 l/inhab./day to the potable water supply. It should be noted, however, that the occupants have professional or school activities outside the home during weekdays, so these values of daily consumption are partial.

In the following diagrams (Figures 3-4) one can see, for the month of June, the average hourly consumption from the public drinking water network and the use of the rainwater network. In general, the consumption diagram in Figure 3 follows the usual behavior in homes where most occupants have professional or school activities outside the home during the day, with a peak demand between 7:00 and 10:00 and another between 20:00 and 23:00, with a less significant peak during lunchtime.

Regarding the rainwater system, watering the garden/yard at the end of the day, which becomes habitual in Portugal from June onwards, seems to be the most significant note in the diagrams obtained. The graphs seem to indicate the existence of small leaks in the automatic irrigation network.

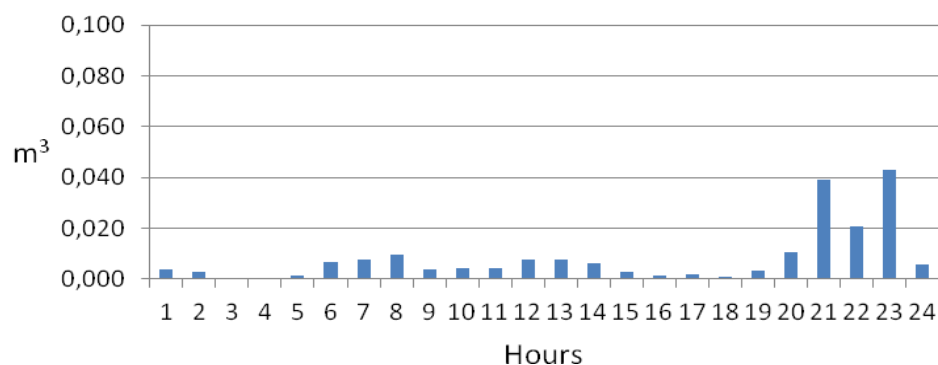


**Figure 2. Rainwater network - Daily consumption during the month of June**



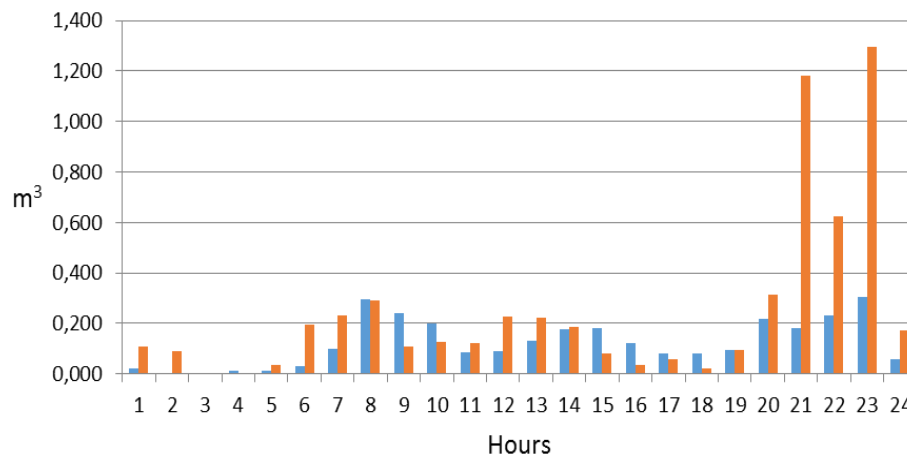
**Figure 3. Public network - Hourly average consumption during the month of June**

In Figure 5 the average hourly consumption in both networks during the month of June are compared and it may be seen that the consumption of rainwater is highest at the end of the day, as a result of its use in watering the garden/yard, as aforementioned.



**Figure 4. Rainwater network - Hourly average consumption during the month of June**



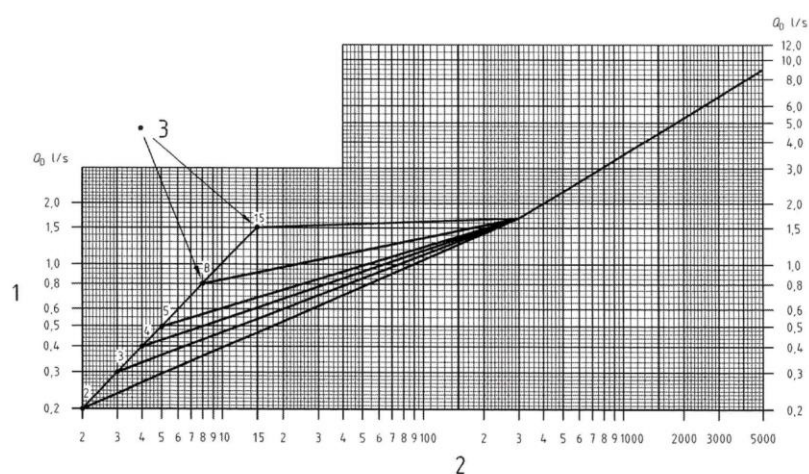


**Figure 5. Comparison of hourly average consumption during the month of June (the public network is in blue and the rainwater network is in red)**

According to the European Norm EN 806-3:2006, the design flow can be obtained from Figure 6, where **1** is the design flow rate and **2** is the total flow rate, in loading units (*LU*). According to the Norm 1 loading unit is equivalent to a draw-off flow rate of 0.1 l/s. From the relationship between these flows it is possible to determine the coefficient of simultaneity underlying the sizing in every situation.

In general, it is considered that a building system is sized appropriately for a medium level of comfort shape when the design flow is not exceeded more than 99% of the time (Silva-Afonso, 2001). Based on this criterion and the records obtained throughout the observation period, the hourly “design flows” in the two networks are determined.

A direct comparison with the corresponding values determined by the European standard is not feasible because the records do not allow instantaneous flow rates to be determined, but one can obtain some indications that are considered important, and that justify the need for more studies in this area with further development. The flow rates obtained and the corresponding coefficients of simultaneity are summarized in Table 1.



**Figure 6. Flow calculation based on the total flow rate (in LU) for current installations (EN 806-3, 2006)**

Although the results presented in the above table are just reporting a period of half a year, and thus cannot be fully representative, they seem to indicate that the calculation method commonly used in the design of internal networks is not appropriate when there is separation of networks. In fact, while analyzing the coefficients of simultaneity (those obtained and the normative), corresponding to each supply network, it can be seen that the normative coefficients, being always higher than those determined, based on hourly consumption (as expected), do not seem to follow the large variations effectively observed in the two networks in this field.

**Table 1. Case study 1 – Comparison between the coefficient of instantaneous simultaneity and the coefficient obtained from the hourly records**

	Total flow rate (l/s) (m <sup>3</sup> /h)	Design flow estimated with basis on the hourly consumption (m <sup>3</sup> /h)	Coefficient of simultaneity	Design flow obtained with basis on EN 806-3 (l/s)	Coefficient of simultaneity according to EN
Drinking water network	2.10 7.56	0,04	0,005	0.70	0,33
Rainwater network	3.80 13.68	0.75	0.054	0.90	0.24
Total consumption	5.90 21.24	0.75	0.035	1.05	0.18

## CASE STUDIES 2 AND 3: HOUSES IN SMALL RURAL TOWNS

### Methodology

The dwellings that were studied in small rural towns in the south of Portugal, correspond to different types, including a 3-bedroom apartment in local government housing (T3) (Residence A), endowed with only a toilet, and a 3 bedroom villa (V3), with two toilets and yard (Residence B). Within its typologies, they correspond to current and relatively representative residential buildings in Portuguese rural towns.

In the local government housing none of the occupants has an activity (professional or otherwise) outside the house, because they are retired. The household inhabiting the dwelling V3 (a married couple with a child) have professional (or school) activities outside the house. Residence A has only one bathroom with a fitted washbasin, bidet, bath and toilet, a kitchen with a sink and a washing machine. Residence B has a kitchen with a sink and dishwasher and two bathrooms: a full bathroom (washbasin, bidet, bath and toilet) and another just with washbasin and toilet (and a washing machine). This residence is also equipped with a faucet for watering the garden.

The study (which is being continued with other interventions) included monitoring hourly consumption during the period of approximately one month in the two selected households (18 October to 20 November 2013), followed by an audit of water efficiency and the implementation of various measures proposed in the audit, followed by a new monitoring schedule of hourly consumption over one-month period (October 20 to December 20, 2013). Interventions following the audit have included the regulation of the flushing cisterns, where possible, or replacement of complete discharge mechanisms for dual flush mechanisms, so as to transform the existing toilet

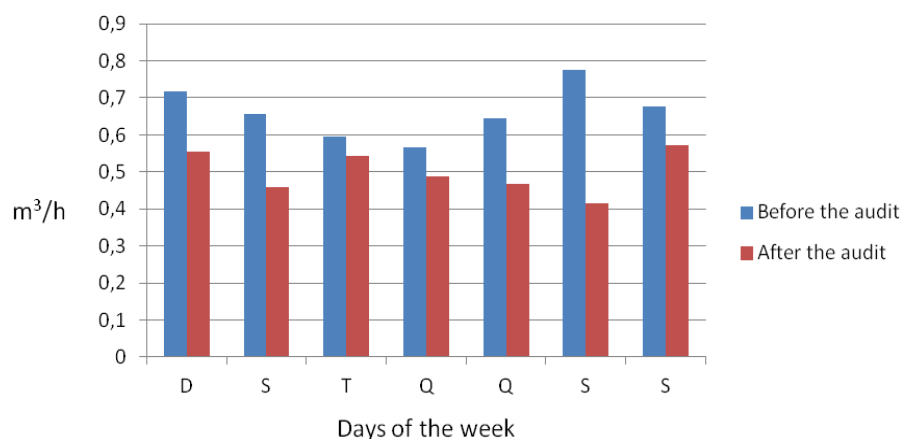
flushing cisterns equivalent to class "A" water efficiency of ANQIP (or upper class), according to Technical Specification ETA 0804 (ANQIP, 2012a).

In relation to kitchen sink taps and showers, either flow economizers have been installed or a replacement of the devices by more efficient ones was carried out, with certification and labeling of ANQIP water efficiency class "A" or higher, according to Technical Specification ETA 0806 e 0808 (ANQIP, 2012b e ANQIP, 2012c). The economizers installed also aimed at reducing flow rates to values compatible with the class "A" (or higher) water efficiency, although in some cases, the reduction of flow has been constrained by the minimum values required to start up the boiler. All economizers installed were previously certified by ANQIP with development of flow/pressure curves, which were the basis for selecting the most suitable model for the site and pressure available.

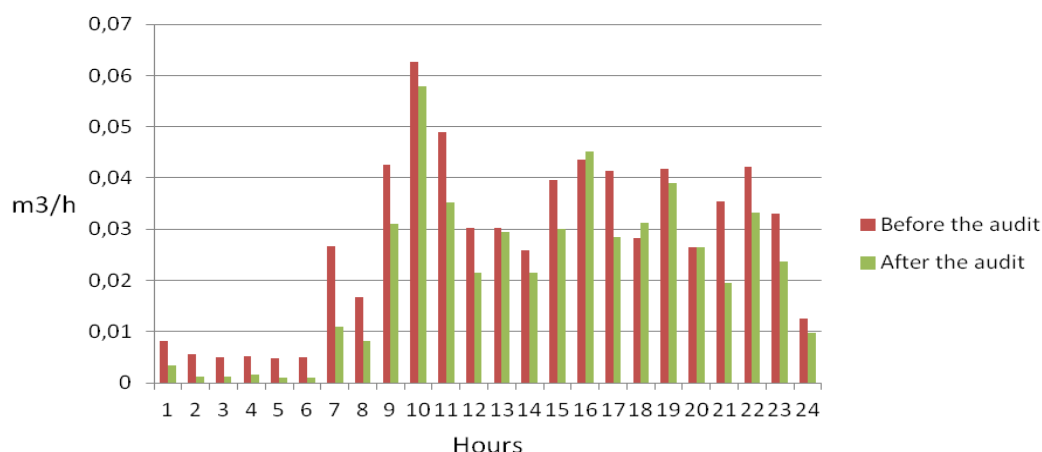
## Results

The most significant result obtained from the interventions carried out in the residences, which must be emphasized, is reflected in the reduction of consumption achieved with the water efficiency measures that were implemented. Although the study was conducted in a limited time period, a lowering in monthly consumption from 20.97 m<sup>3</sup> to 15.38 m<sup>3</sup> (less 27%) was found in Residence A and in Residence B from 11.64m<sup>3</sup> to 8.67m<sup>3</sup> (less 26%), which, regardless of the representativeness of the sample, it shows that there are significant potential savings in the residential sector in Portugal.

Figures 7 to 8 show the diagrams of average consumption over the days of the week and time schedules in Residence A, before and after implementation of water efficiency measures. The analysis of the figures shows that the implementation of water efficiency measures introduced some changes in the consumptions diagram of this residence, with a greater leveling of values. No explanation was found for the difference observed on Saturday.



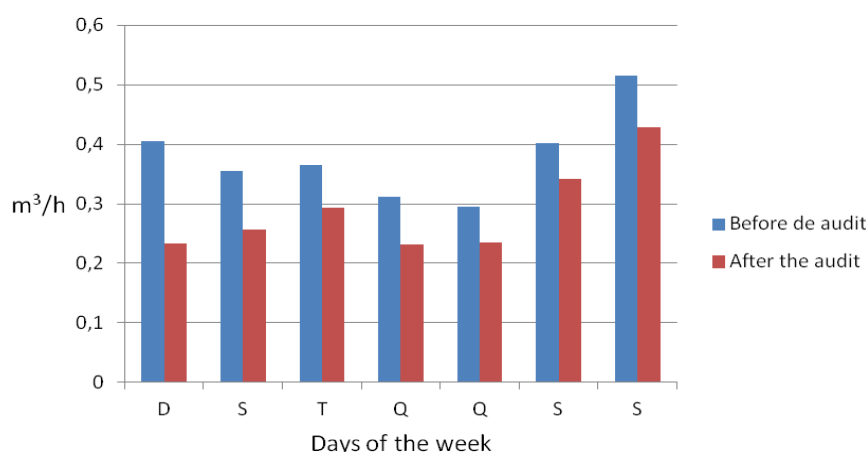
**Figure 7. Residence A – Average consumption on weekdays, before and after the audit**



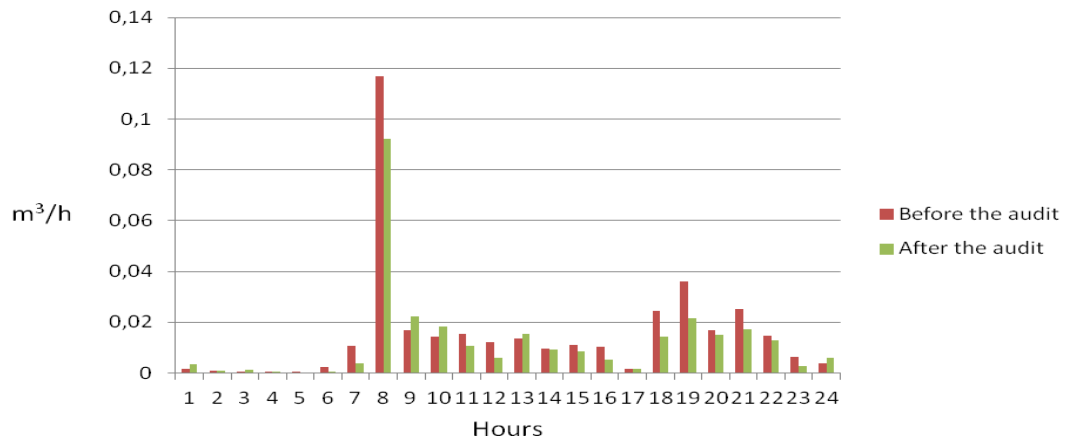
**Figure 8. Residence A – Average hourly consumption, before and after the audit**

Regarding Residence B, Figures 9 to 10 show diagrams corresponding to the same situations. In this case, no significant changes in the diagrams are observed due to the implementation of water efficiency measures, as was expected, since the reductions were introduced in almost all devices and analogously. The diagrams of hourly average consumption are typical of families in which most members of the household are out of the residence during the day. As regards the coefficients of simultaneity the values obtained are summarized in Table 2 on the basis of the hourly flow rates and values from the European Standard (applied to instantaneous flow rates).

As in the case of study 1, the direct comparison with the values determined by the European standard is not feasible, because the records registered in the residences are unable to determine instantaneous flow. However, it is observed that the “hourly” coefficient of simultaneity decreases with increasing water efficiency of the building, a situation which may also exist with respect to the coefficients applicable to instantaneous flow rates, but which are not considered in the European Standard.



**Figure 9. Residence B - Average consumption on weekdays, before and after the audit**



**Figure 10. Residence B – Average hourly consumption, before and after the audit**

**Table 2. Case studies 2 and 3 - Comparison between the coefficient of instantaneous simultaneity and the coefficient obtained from the hourly records**

	Total flow rate (l/s) (m³/h)	Design flow estimated with basis on the hourly consumption (m³/h)	Coefficient of simultaneity	Design flow obtained with basis on EN 806-3 (l/s)	Coefficient of simultaneity according to EN
Residence A (before the implementation of water efficiency measures)	1.10 3.96	0.16	0.040	0.55	0.50
Residence A (after the implementation of water efficiency measures)	1.10 3.96	0.14	0.035	0.55	0.50
Residence B (before the implementation of water efficiency measures)	1.50 5.40	0.22	0.041	0.60	0.40
Residence B (after the implementation of water efficiency measures)	1.50 5.40	0.17	0.031	0.60	0.40

## CONCLUSIONS

Although the time periods for records that were used in preparing this study are not very extensive, can be emphasized some conclusions. Studies continue to be conducted and it is expected, in later research, to install instantaneous meters and thus strengthen the conclusions presented now and also draw some conclusions regarding the effects on the public network diagrams of the water efficiency measures in the buildings.

Firstly, the importance of conducting audits of water efficiency in existing buildings and the implementation of the measures recommended therein should be emphasized, enabling apparently very significant reductions (that were close to 30% in case studies 2 and 3, with low-cost interventions and rapid payoff). The appeal for non-potable purposes to alternative sources such as rainwater further reduces the need for drinking water, according to the findings in case study 1, and suggests an average reduction of around 66% in needs of water from the public network.

As regards the coefficients of simultaneity used in the sizing of building networks, these seem to vary with the implementation of water efficiency measures and, in situations where there is separation of networks, the values appear to vary significantly, which may be explained by the fact that under these conditions, each network feeds devices with relatively similar characteristics.

Although the findings are not yet consolidated, this study showed the apparent existence of variations in the coefficients of simultaneity considered in the design of installations when implementing water efficiency measures, with probable consequences for the peak factors in the public networks, which justifies the development of the study and further analysis.

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# BEYOND THE WATER EFFICIENCY CALCULATORS

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## ABSTRACT

Evidence suggests that since water shortages are partly rooted in human behaviour, the environmental impact can consequently be managed through behaviour change. Before behaviour change can occur the existing behaviour must first be observed, and the influences understood. Even though research in environmental behaviour is abundant, past studies attempting to link psychological variables to conservation behaviour are thought to have produced mixed, inconclusive findings. Moreover, most of this research has concentrated on recycling and energy conservation, and there are still few studies investigating the combined physical, sociological and psychological aspects of household water usage to a sufficient level of detail and granularity.

This paper presents findings of an initial review of behavioural theories and models in existing literature learning from the broad evidence in resource efficiency studies for specific applications to water efficiency. The paper concludes with an integrated framework for the design and delivery of water efficiency interventions. This framework will provide the theoretical basis to a study which aims to propose a simplified intervention approach that integrates the physical, sociological and psychological influences in water efficiency interventions.

The resulting framework is also beneficial in the wider context to align detailed and accurate water end use data with a range of socio-demographic, stock inventory, residential attitude and behavioural factors. This will aid the development of tools and techniques that are capable of revealing the determinants of water end use. This will contribute to even more robust understanding of water demand and inform the design of effective water use interventions.

**Keywords:** Behaviour, Demand management, Domestic, Framework, Water Efficiency.

## INTRODUCTION

The inefficient use of water combined with environmental factors such as climate change contributes to the increasing stress of water resources in parts of the UK in the future (EA 2011). The need for improved and efficient water resource management within the UK is therefore apparent. The long term uncertainty of supply and the continuous need to

manage demand and efficient water use supports the need for water efficiency practises across the supply and demand spectrum. The strategies for promoting water resource efficiency require a multi-faceted approach, that is; water efficient policy and regulations, water efficient planning, water efficient buildings, water efficient products, and water efficient people. The role of the user is widely accepted to be crucial for achieving any resource efficiency goal (Korfiatis *et al* 2004). Understanding the propensity, tendency and motivations of the water user is also important for the design and implementation of water efficiency interventions. This knowledge is particularly useful for policy makers to define groups who are both active and less enthusiastic with regard to saving water (Gilg 2004).

In addition to policy aimed at understanding users and promoting behaviour change, policy and legislative instruments also target building design and systems particularly in buildings to ensure that buildings deliver the baseline targets for water efficiency. Section 7 and Part G of the current Building regulations in England and Wales (HMGovernment, 2010) specifies this baseline requirement. The water efficiency requirement in this instrument is further supported with the water calculator (BRE 2009) and other assessment methodologies to aid designers, specifies and building providers in their efforts to comply. These tools also provide good estimations of the potential water savings that can be derived through first design or retrofitting water saving fixtures and fittings in a house. The main criticisms of these tools and assessment methods are that the evidence used in the algorithms often rely on average use factors, whereas water conservation technologies are susceptible to the bias of human judgement and rely on human interaction to conform to the desired behaviour (Corner, 2012; John, 2011). Also, they often disregard the unpredictable use of water or the variability in household in location, community attitudes and behaviours (Corral-Verdugo *et al.*, 2003; Turner *et al.*, 2005; Stewart *et al.*, 2011). Therefore, this bias towards water conservation technologies as the sole means of achieving water efficiency in buildings does not always guarantee actual water savings.

Research into environmental behaviour is abundant, however past studies attempting to link psychological variables to conservation behaviour are thought to have produced mixed or inconclusive findings (Cook & Berrenberg, 1981; Stern & Oskamp, 1987). Therefore, the understanding of what determines or informs water use behaviours by water users will contribute to a more robust evidence base for water demand forecasting and management which will be beneficial for informing government and water company instruments but more importantly, empower water users to make personalised appraisals towards the design and implementation of water efficiency interventions to suit their needs and preferences.

## **BEHAVIOURAL MODELS**

How behaviour is formed is a key step to understanding consumer behaviour (Sofoulis 2005). Previous research and the resulting models demonstrate the factors and associated

relationships that generate behaviour (Jackson, 2005). This review presents four of the primary environmental behaviour models; Rational choice model (Simon, 1955), Reasoned model (Ajzen and Fishbein 1980), Interpersonal model (Triandis 1977) and the Gregory model (Gregory 2003). It then explores the key characteristics and limitations of each of the models.

### **The rational choice model**

The rational choice model first outlined by Simon (1955) suggests that human beings behave in such a way to maximise the expected benefits from the actions (Jackson, 2005). The model suggests that the consumers' pro-environmental choices require that sufficient information must be provided to make informed decisions. However, Jackson (2005) noted that the private decisions of an individual does not always account for social influences or wider interests, which have been proven to have an effect on personal behaviour. One central criticism of this model is that it overlooks cognitive deliberation, and disregards mental short cuts such as habits, routines and cues, which are proven to reduce the effect of cognitive deliberation. Another is the assumption that self-interest provides the foundations for human behaviour, where in fact social, moral and altruistic behaviours also form human behaviour.

### **The reasoned model**

One of the best known attitude behaviour models is Ajzen and Fishbein's (1980) theory of reasoned action. The reasoned model assumes that all behaviour is formed from intentions to perform specific behaviours, and that these intentions are formed from the relative importance of attitudes, subjective norms, suggesting that factors external to cognition have a role on behaviour formation (Jackson, 2005). Some criticisms of the reasoned model are the distinction between subjective, moral and personal norms. However, Fishbein and Ajzen (1980) suggest that personal norms are essentially subjective behavioural beliefs whilst others argue that moral and personal norms need to be considered as separate components of the model (Jackson, 2005). Furthermore, this model fails to acknowledge the diversity of cognitive deliberation. It also ignores the role of habits, routines and cues and their influence on behaviour. Nonetheless, the reasoned model has been applied to many areas of research with feasible research outcomes (Leonard, 2004).

### **Interpersonal model**

First outlined by Triandis (1977), the interpersonal model is a multidimensional model incorporating both internal and external influences on determining behaviour. As with the reasoned model, intentions are the primary antecedents of behaviour (Jackson, 2005). The interpersonal model also seeks to verify that the conditions exist to facilitate the intended behaviour. According to this theory, behaviours are neither fully deliberative nor automatic, nor they are influenced by moral beliefs but the impact of these is moderated by emotional drives and cognitive limitations. The limitations of this model is that as with the reasoned and rational choice models it follows a linear formation process, assuming that intentions and habits are not influenced by one another. The interpersonal model also

assumes that the facilitating conditions only enable the desired behaviour and does not influence any factors contributing to the behaviour.

### The Gregory model

As every student of psychology knows, explaining human behaviour in all its complexity is a difficult task (Ajzen, 1991). The Gregory model begins to address some of the limitations of the previous models. The model considers relationships to be non-linear with defined feedback loops between behaviour and influencing factors. It also suggests that influences can change as the effect of behaviour changes. The initial research framework conducted into environmental behaviours as developed by Gregory (2003) presents the impact of stimuli and influences on behaviour (Ronis, 1989). It utilises factors such as awareness, unreasoned influences (cognitive processes), reasoned influences, and situational influences (e.g., income, family size) to explain behaviour. This framework is supported by previous research which suggests that behaviours may be a function of both reasoned influences (e.g., attitudes, intentions) and unreasoned influences (e.g., habits; Aarts, 1998; Thøgersen & Møller, 2008).

### Discussion of the models

The four models explored in this review demonstrate similar yet unique methods of understanding behaviour. Table 1 illustrates the four models and the behavioural influences of each model.

**Table 1 - Review of behaviour and influence models**

	Rational choice	Reasoned	Interpersonal	Gregory
Attitude		✓	✓	✓
Intention	✓	✓	✓	✓
Subjective norm		✓	✓	✓
Social factors		✓	✓	✓
Affect			✓	✓
Habits		✓	✓	✓
Facilitating conditions	✓		✓	✓
Reflexes				✓
Awareness	✓			✓
Involvement				✓

The rational choice model has the fewest considered influences, yet it is widely used by western policy makers (Hassell, 2007). Triandis (1977) developed the interpersonal model, in response to the limitations in the rational choice model. The interpersonal model thereby incorporates habits, routines and cues as well as facilitating conditions. However it does not consider the role of awareness or individual role of each component. The Gregory model combines several models to create a generalisation of the role of stimuli (awareness in pro-environmental fields), unreasoned influences, reasoned influences and situational influences in forming behaviour. Environmental decisions can be considered on a scale ranging from purely habitual to purely cognitive.

## FUNDAMENTAL INFLUENCES IN DOMESTIC WATER USE

Water consuming behaviour is a mixture of self-interest and pro-social motives (Bamberg, 2007). This suggests that cognitive evaluations can be supplemented by habits and even override the attitudinal and subjective norms influencing behaviour (Thøgersen & Møller, 2008). Therefore, the proposed research framework includes an additional relationship between cognitive evaluation and subjective norms. However, an understanding of the determinants affecting water consumption in domestic properties is required to develop a new domestic water behaviour framework. These can be broadly described under two categories; behavioural influences and environmental influences.

### **Behavioural influences**

Behavioural influences consist of awareness, attitudes, habits, belief amongst other factors. According to Gregory (2003), an important first step towards understanding the impact of human behaviour on the environment is awareness. This enables an individual to consciously accept and process informational cues. The awareness of an individual can inform and alter the attitudes and habits of the individual. Whereas, Cottrell (2003) suggests that attitudes provide a better understanding of why people do what they do. Korfiatis *et al* (2004) determined that attitudes towards environmental issues were in fact reliable predictors of environmental behaviour. However, the knowledge itself does not automatically lead to environmentally conscious behaviour (Pelletier *et al*, 1998). It is also probable that habits, recurrent practice or patterns of behaviour (Aitken, 1992), impact on the knowledge to behaviour gap. Habits are developed by extensive repetition, and are so well-learned that they require limited cognitive processes conscious effort (Ronis, 1989).

Whilst awareness attitudes and habits form elements of individual influences, socio-demographics have been shown to play a critical role as a situational factor for water consumption in domestic properties (Renwick and Archibald, 1998; Willis *et al.*, 2009). Thus should be considered as indicators of residential water consumption (Inman and Jeffrey, 2006). Likewise beliefs, firmly held opinions or convictions, have been shown to form a precursor to environmental behaviour (Niemeyer, 2010). It has also been previously established that the attitudes and beliefs of consumers directly impact on water use behaviours which are closely linked to water demand (Hassell and Cary, 2007).

The engagement of an individual within a process, or the individual's involvement with water issues has also been shown to result in a higher level of awareness in local concerns and lower water consumption in washing machines (Gregory and Leo 2003). It is clear that increased stakeholder involvement in environmental decision making does increase the effectiveness and implementation of environmental decisions (Newig, 2007).

Behavioural influences demonstrate how individual's differences in behaviour can be created through internal factors, such as awareness, habits and engagement. However behaviour can also be effected by external factors that enable particular behaviours, these are commonly referred to as environmental influences.

### **Environmental influences**

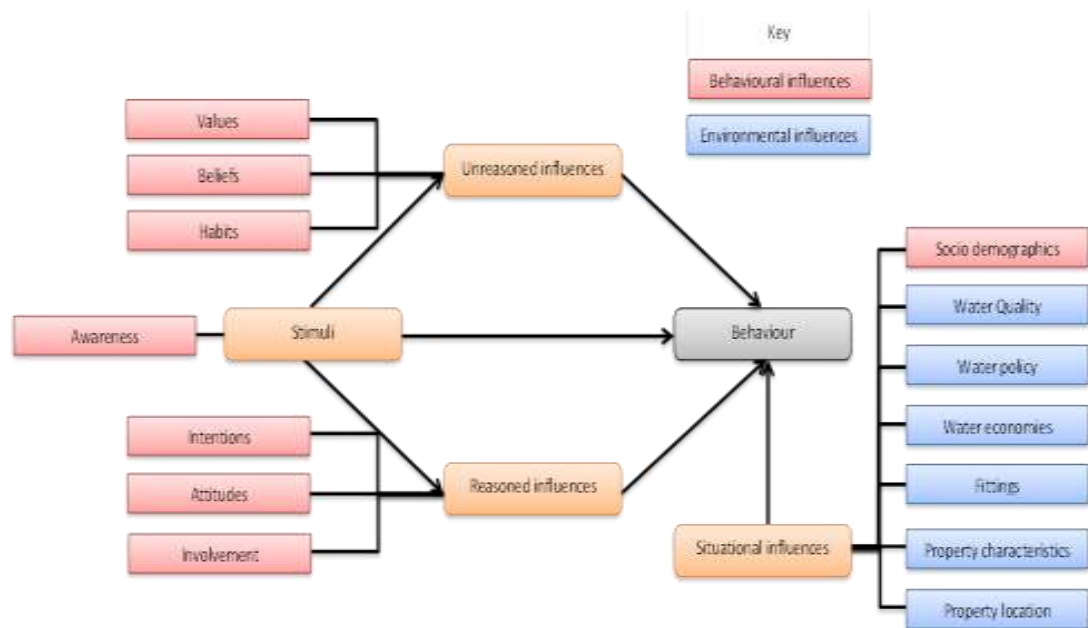
Environmental influences are widely considered to be situational or enabling influences on water consumption. For example, the quality of water supplied to the dwelling can significantly influence domestic water consumption as this will influence multiple other factors such as; attitudes, habits and preferences (Tebbutt, 1998). Regulations, policies and ordinances (e.g., water restrictions, local government planning regulations) can change the water consumption (Klein et al., 2006). For instance a hosepipe ban can be enacted to reduce external water consumption in the south east of the UK but not in the North West. Restrictions have also been found to be closely linked to the price of water, with consumers less responsive to restrictions when the cost of water is low or the cost of fines is low (Kenney et al, 2008). Although it is noteworthy that Worthington (2008) found that there appears to be very little correlation between the pricing of water and the consumption of water. Essential water use is often considered the reason for price inelasticity (Arbu'és et al, 2003).

Situational influences such as property characteristics affect the overall water consumption as the kind of homes people live in and whether they own or rent, influence how they perceive their water use (Randolph and Troy 2008). For example, a colder bathroom may result in a longer shower, as the hot water flows it warms the room thus making the shower more comfortable (Scott et al, 2009). Water metering provides enables consumers to reconsider their habits by providing information of how much water they are consuming enabling them (Randolph and Troy, 2008). Fittings are the source of water within domestic properties; therefore they have a significant impact on domestic water consumption. For example the use of efficient water appliances has been found to influence residential water consumption (Inman and Jeffrey, 2006). Likewise the ability to upgrade existing fittings influences the penetration of water efficiency technologies.

Environmental and behavioural influences clearly have a role on water consumption behaviour. A framework would provide a better understanding of the relationships between factors is useful.

## **BEHAVIOUR FORMATION FRAMEWORK**

The proposed framework, illustrated in Figure 1, utilises the previously explored models and influences on domestic water consumption. It demonstrates the relationship between the individual influences and the overall formation of water consuming behaviour. This framework builds in the Gregory model of behaviour (2003) altering the model into a framework suitable for water efficiency studies. The intention of the framework is for the framework to be adapted into a methodology, using case based evidence that can appraise and optimise the deployment of water efficiency interventions.



**Figure 1- Proposed domestic water efficiency framework**

The framework separates behavioural influences into two primary categories; behavioural and environmental, showing that situational influences are primarily formed of environmental influences, with the exception of socio-demographics which are considered situational influences as they are out of conscious control of the individual. However one limitation of this framework is that it focuses on an individual and not the relationship or water use behaviour of a multiple occupancy household, reducing its applicability to whole house end demand management.

However, it is considered that with the correct expertise, the framework could be utilised to align detailed and accurate water end use data with behavioural factors. It can also aid the development of improved water efficiency tools that are capable of revealing the determinants of water end use.

## CONCLUSION

The proposed framework expands on existing assessment methodologies by providing an opportunity to integrate specific individual variances in anticipated water use patterns and characteristics. This framework provides a platform which should support behavioural and environmental considerations when appraising both water consumption and efficiency interventions. As evidence is collected, to support the framework a methodology can be developed such that a procedure can be followed to appraise water efficiency interventions.

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## RETROFITTING FOR WATER EFFICIENCY: A HOTEL CASE STUDY

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### ABSTRACT

Water efficiency in building makes good environmental, economic and social sense. There are improvements to water efficiency standards in new buildings – domestic and non-domestic which is influenced by recent changes to building regulations, increase in environmental awareness, corporate social responsibility, delivering better lifetime value to clients and customers etc. Retrofitting water efficiency in existing buildings however, can be more challenging due to uncertainties about the cost-benefits of certain technologies, existing building systems and products, existing and anticipated user response and engagement etc.

This paper will present a retrofitting case study of a small to medium sized hotel in Sussex, England. It will discuss the reason for the retrofit program from the hotel and water company perspective. It will then discuss the methodological approach to determining the potential and actual outcomes of the water efficiency retrofits, integrating the client and user perspective where necessary. The paper will conclude with lessons learned and recommendations to similar programmes on hotel sites.

This project is carried out collaboratively by the Lodge at Winchelsea, Chandlers Building Supplies, Southern Water and the Water Efficiency Lab, University of Brighton.

**Keywords:** Cost savings, small to medium sized hotel, water efficiency retrofits, water savings

### INTRODUCTION

Water efficiency in buildings is promoted through building services design, water efficient plumbing fixtures and fittings and the efficient use of water by water users.

Previously, there has been significant interest and research application on the efficiency of plumbing fittings and behaviour change of water users particularly in domestic buildings. However, there is a changing trend to non-domestic buildings and strategies for water efficient retrofits in buildings; domestic and non-domestic.

Water efficiency for domestic uses goes beyond the use of water in individual houses and apartments. Collective water use in other 'residential' settings such as halls of residences and hotels is an important aspect of understanding and promoting water efficient practises when the water user is not directly responsible or accountable for their water use.

This paper presents a case study of water efficiency retrofit in a small to medium sized hotel in the South East of England. It discusses the purpose and approach taken to the retrofit program. It then presents the potential and actual outcomes of the water efficiency retrofits, integrating the client and user perspective where necessary. The paper concludes with lessons learned and recommendations to similar programs on hotel sites.

## **CASE STUDY AND METHODOLOGY**

The case study hotel consists of 28 guest rooms of various sizes and capacity, a reception, bar and restaurant area, kitchen, 1 function room, guest and staff toilet facilities, laundry facilities, staff accommodation and predominantly hard standing landscaping with some planted hedges, planters and potted plants.

The analysis is derived from measured flow-rates in sampled rooms, use factors in the water efficiency calculator (DCLG 2009) and occupancy data factoring in seasonal differences and projected savings from retrofits to water using fittings in guest rooms. The efficacy of the water calculator has been reviewed by researchers (e.g. Churchill, Booth and Charlesworth 2014). This benchmark was nonetheless considered credible for use in the absence of actual use figures from guests during the study period.

The rationale for the pilot scheme from both the hotel and water company perspective are enumerated below.

### **The Hotel**

As with most businesses in a competitive market, the case study hotel is always looking at ways to reduce wastage and, more importantly, cost. In doing so, the hotel is able to price its services attractively and maintain profit margins. The challenges to this are that some operational elements of consumption by the guests staying the hotel are hard to monitor and control such as electricity usage and water consumption in the guest rooms.

The Lodge's involvement in this project was aimed at reducing environmental impact and deriving further value for customers by achieving water savings in the guest rooms whilst making sure their experience remains positive and their comfort is not compromised or diminished.

The hotel manager was aware of some of the water saving retrofit options but by engaging with others to explore retrofit options, was delighted to see the large range of options that are now available. Also, the importance of engaging with guests in the process was crucial

*"We are aware that changing bathroom facilities is not the whole solution to water usage and have introduced more information and guidance for guests in the rooms"*

The project particularly demonstrates how organisations can work together to achieve business and environmental objectives.

## **Water Company**

Southern Water undertook this pilot project to further its understanding of how it can effectively assist small and medium sized businesses (SMEs) with new products and services. This particular project is being carried out in conjunction with other key studies including a university, guest house, hairdresser and school to increase the understanding of the needs and challenges of delivering new products and services in its Business Plan over the next five years.

Following the roll out of its Universal Metering Programme and the forthcoming introduction of commercial competition in the water sector, Southern Water is adapting its services to reflect the changing needs of customers. This pilot study is modelling key elements including: 1) speed of service 2) financial impact 3) robustness of products and 4) customer service.

This particular hotel was chosen because it was a good example of a robust medium sized business, similar to many spread across the Southern Water region. It also has an engaged hotel manager that is actively looking at ways of cutting costs and had already demonstrated an understanding of water saving through the requesting of save-a-flush bags to cut usage in hotel toilets. An effective water efficiency programme relies on several important factors, one of the most important is the passion of individuals and businesses to actively engage and put in place the dedication and planning to make a real difference.

## **OVERVIEW OF INTERVENTIONS IN GUEST ROOMS**

The billing data from May 2012-13 and the water use and fittings audit in October 2013 found that the water use in guest bedrooms including housekeeping accounted for a little over 80% of the Lodge's total water consumption. Pre-retrofit analysis show a 25% potential savings from the current retrofit programme and a further 10-15% savings if the WC cisterns and hot/cold basin taps are replaced and guests reduce shower times to an average of 5 minutes.

The breakdown of water consumption in guest rooms is shown in Figure 1 below, calculated using occupancy factors and the use factors specified in DCLG (2009). The

current figures do not account for behavioural variations and they are based on aggregated annual occupancy percentages alone.

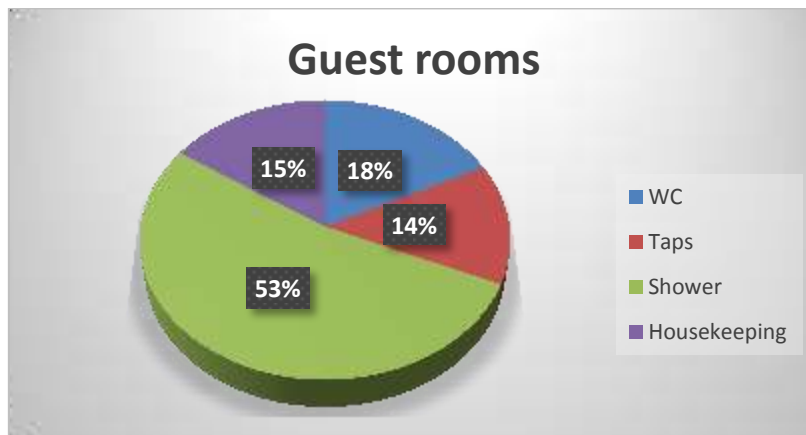


Figure 1: Percentage breakdown of water use in guest rooms

## Taps

Figure 1 show that there is potential for further water savings in the proposed tap retrofits. Majority of the guest rooms have single hot and cold water taps as shown in Figure 2 below. The average flow rate of cold water taps was 20 litres per minute (l/m) and 8l/m for hot water taps. By comparison, the average flow rate from the mixer taps with flow regulators was 5l/m.



Figure 2: Separate hot and cold water in majority of guest rooms

It is understood that there are plans to upgrade the existing single hot/cold basin taps in the near future and the previous figures highlight the savings possible from efficient taps. Considering the wide variance in flow rates in the existing hot and cold taps, retrofitting to 4-5 litre mixer taps can potentially provide a further 20-40% savings on current tap use figures.

## Toilet cisterns

Majority of the guest rooms currently have a 13 litre per flush cistern which were retrofitted to provide dual flush capability i.e. 13/6.5 litre flushes, or an average of 9.5litres per flush. This retrofit has the potential to reduce water used for flushing by

between 20-25% on current consumption levels, with a further savings of up to 25% if the old systems are replaced with 6/4litre dual flush cisterns.



Figure 3: Ecobeta® cistern retrofit

## Showers

The performance of a shower is affected by a number of variables; existing water supply pressure, the type of shower supply and control mechanisms, shower head design etc. The range of the existing shower types and supply/operation systems, as well as low water pressure in parts of the hotel meant that the most significant savings occurred in the rooms with pressurised shower systems – potential saving of up to 9litres per minute if retrofitted with the Methven's® range of Eco-showers.



Figure 3: Typical shower cubicle in the upper floor guest rooms

Based on the data generated from sampled rooms and assuming 8-minute average shower duration, the current retrofit program potentially offers 35-40% savings on current water consumption in showers. A further 20% is possible with successful behaviour change interventions that result in shorter 4-5 minute showers per guest.



## Housekeeping

Water use in housekeeping is a significant percentage of water use in guest rooms and can be equivalent to an extra 0.5-1 person in the room in some instances. Assuming 1 x toilet flush, 1min x tap and shower use, housekeeping accounts for up to 19% of water use in the guest rooms. Retrofitting water saving fittings offers potential savings of 25-35% on existing water use for housekeeping.

## Other areas

Due to insufficient data, it was not possible to offer projections on water use in other areas of the hotel. These areas include; public/staff guest 3 x washrooms, kitchen, bar, staff accommodation and laundry facilities.

The newly installed 3 x 200litres water butts on site should sufficiently offset outdoor water use at the hotel.

## PRE- AND POST-RETROFIT ANALYSIS

Using billing data from May 2012-13, the per capita consumption per guest per annum at the hotel was approximately 270-310m<sup>3</sup> per occupied bed, with total occupancy of approximately 6160 guests per annum. The best consumption figure for hotels is 227 m<sup>3</sup> per bed and worse 435 m<sup>3</sup> per bed (City West Water 2012).

In the first quarter since the retrofit, per capita consumption per guest reduced to on average 242 litres, ranging from 210-267 litres per guest for the months between November 2013 and February 2014. Therefore, the aggregate annual per capita consumption (per guest) is projected to be in the range of 210-250 litres after retrofits. If this trend continues, this equates to approximately 20-24% savings in the overall water use on the site including guestrooms, communal facilities and outdoor functions compared to original figures will be achieved.

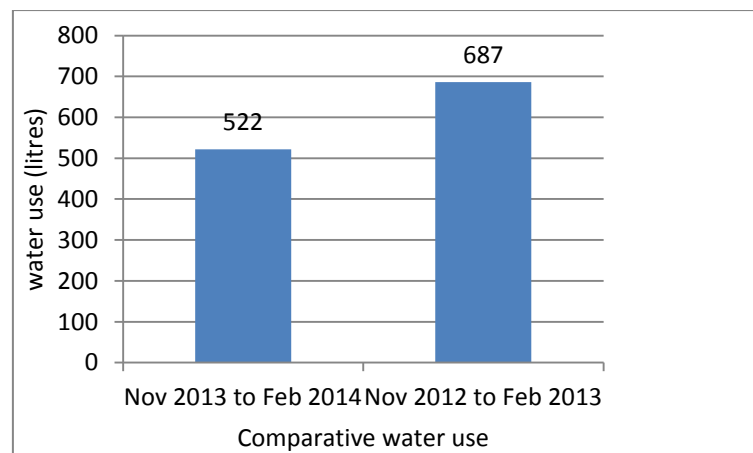


Figure 4: Current normalised savings show 24% water savings since the retrofit program was implemented.

The granularity of the audit data conducted prior to the retrofit program allows for further analysis of water use in the guest rooms. This was carried out using water consumption and occupancy data for the quarter as well as projected use factors.

It was found that retrofits to the taps and showers led to water use savings in these fittings. Comparatively, a measured increase to water use in WCs and a slight increase to the water used for housekeeping were observed. The increase in water use in WCs can be due to a number of factors including; increase in use by guests or misuse repetitive use linked to the performance of the retrofit systems on the old cisterns, inappropriate use of the dual flush cisterns where installed. This however needs further exploration.

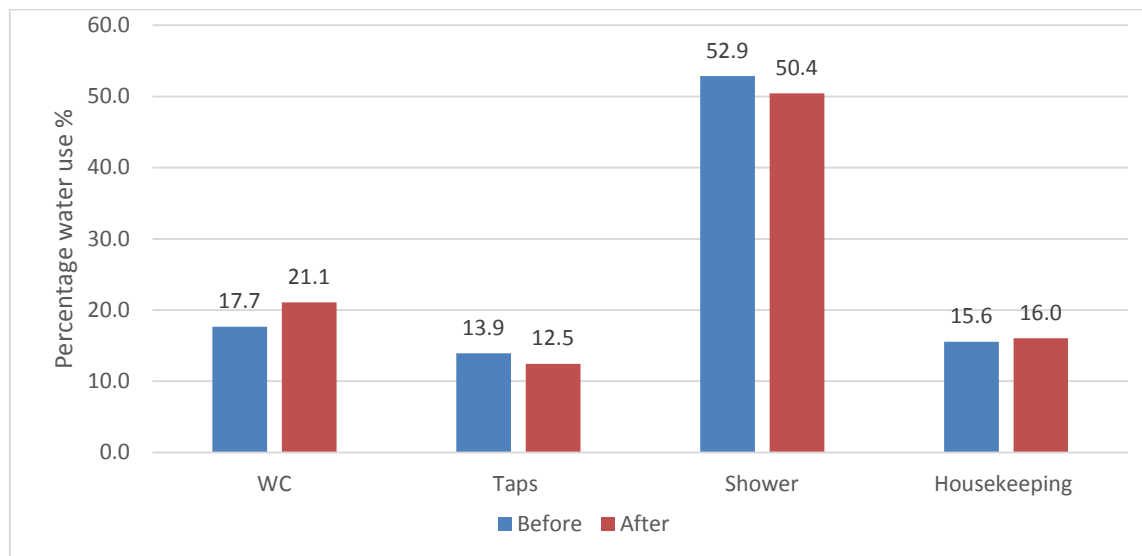


Figure 5: Percentage breakdown of water use in guestrooms, showing before and after the retrofits

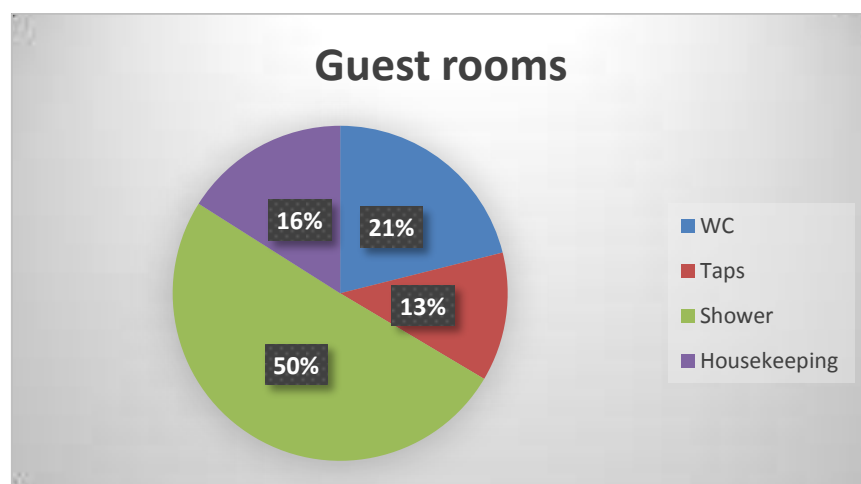


Figure 6: Percentage breakdown of water use in guest rooms post-retrofit (first quarter)

The retrofit program covered fittings and fixtures that were quick and easy to change and excluded changes that would lead to disruption in the operation of the hotel, or require large capital investment. There is therefore further scope to reduce water consumption to below 200 litres per guest per day. That is if the flow rate of all basin taps are reduced to 5litres per minute (4 x average daily use factor), all showers use on average 7litres

/minute (1.5 x 8minute shower duration), all toilets use 9.5 or 6 litres maximum accounting for the Ecobeta retrofits (4 x average daily use factor).

## COST PROJECTIONS AND CURRENT SAVINGS

The capital cost of the retrofit program was around £2500.00; Labour £800 (Incl travel cost), Materials £1700 (Shower Heads & Regulators, Retrofit Dual Flush Cistern Devices, Mixer Regulators, Water Butts and Hose Triggers).

Table 1: Projected cost savings from retrofit interventions

	Breakdown of charges														Annual projected savings
	Number of days in billing period	Total Usage	% of water returned to sewer	Wastewater volume in cubic metres	Clean Volume/variable charge	Clean standing charge	Wastewater Drainage	Waste standing charge	Surface Water Drainage charge	Highway Drainage charge	Total excl VAT	VAT	VAT rate	Total incl VAT	
Bill data from May 2012-2013	377	1909.00	95.00	1813.55	2173.26	18.74	3799.27	13.29	0.00	7.25	6011.81	603.37	0.20	6615.18	
<i>Resolved to 1 calendar year of 365 days</i>	365	1848.24	95.00	1755.82	2104.08	18.14	3799.27	12.87	0.00	7.02	6011.81	584.17	0.20	6404.61	
Annual at 20% less water	365	1478.59	95.00	1404.66	1728.47	18.14	3087.44	12.87	0.00	7.02	4853.94	970.79	0.20	5824.73	579.88
Annual at 40% less water	365	1108.94	95.00	1053.49	1296.35	18.14	2315.58	12.87	0.00	7.02	3649.96	729.99	0.20	4379.96	2024.66

The analysis prior to the retrofit program showed projected savings of 35% on current retrofits, so a conservative range of 20-40% was anticipated. Based on billing figures and an annual consumption from May 2012-13 of 1909.00m<sup>3</sup>, at the time of the retrofit program, a projection of best and worst case savings was calculated as shown in Table 1.

Table 2: Actual cost savings from retrofit interventions

Actual	Breakdown of charges														
	Number of days in billing period	Total Usage	% of water returned to sewer	Wastewater volume in cubic metres	Clean Volume/variable charge	Clean standing charge	Wastewater Drainage	Waste standing charge	Surface Water Drainage charge	Highway Drainage charge	Total excl VAT	VAT	VAT rate	Total incl VAT	
Bill data from Nov 2013-Feb 2014	122	521.54	95.00	495.46	609.68	4.20	1089.03	3.29	0.00	1.91	1708.11	341.62	0.20	2049.73	
<i>Resolved to 1 calendar year of 365 days</i>	365	1560.35	95.00	1482.33	1824.04	12.57	1089.03	9.84	0.00	5.71	1708.11	1022.06	0.20	6132.39	
Bill data from Nov 2013-Feb 2014 (without tariff change)	122	521.54	95.00	495.46	591.43	2.75	1030.56	1.89	0.00	1.04	1627.67	325.53	0.20	1953.20	
<i>Resolved to 1 calendar year of 365 days</i>	365	1560.35	95.00	1482.33	1769.43	8.23	1030.56	5.65	0.00	3.11	1627.67	973.93	0.20	5843.60	
Bill data from Nov 2012-Feb 2012 (without tariff change)	190	1069.20	95.00	1015.74	1212.47	2.75	2112.74	1.89	0.00	1.04	3330.89	666.18	0.20	3997.07	
Normalised Bill data from Nov 2012-Feb 2012 (without tariff change)	122	686.54	95.00	652.21	778.54	2.75	1356.60	1.89	0.00	1.04	2140.82	428.16	0.20	2568.98	

The figures above takes into account the tariff changes during the period. Based on a good and better scenario, the figures suggest a 9-30% cost savings on water and sewerage bills for the hotel.

Table 2 shows a breakdown of savings based on the actual billing figures in the first quarter (November 2013 to February 2014) since the retrofit.

The billing analysis shows £519.25 savings per quarter if compared directly with the previous year; achieving the forecast minimum of 20% savings. Since February 2013, there has been a tariff increase of about 3% and 5% for clean and waste water respectively. When the tariff changes are considered, then cost savings of 24% was achieved compared to the same winter quarterly period in the previous year.

Therefore at current levels of water savings, the payback for the retrofit scheme is 1.25 years, and about one year, if the tariff increase is factored in.

## DISCUSSION

The previous sections have introduced and discussed the rationale, method and findings for retrofitting water efficiency in an hotel in South East England. An interim water consumption and billing data analysis for the first quarter of the year since the retrofit show a 24% reduction in water use across the hotel and a 20% cost savings on the water bill.

Reduction in water use was also found in the use of taps and showers in the water fittings. However, a slight increase was found in water use in WCs and this will be further explored in the following months.

It is however worth noting that these data are from water use during the first quarter since the retrofit scheme was implemented. Further data collection and analysis is required to determine whether these savings will be sustained, or whether they increase or decrease over time. Continued data collection will also confirm if there are seasonal changes to water use in the hotel and the extent to which this affects the effectiveness of the scheme to deliver water and cost savings year on year. The study team will also explore the potential to further improve the granularity of the datasets to improve the capacity to determine the extent to which the water and resulting cost savings are due to the water fittings retrofit, guest behaviour or a combination of both.

Further steps in the study include:

- Continued metering and occupancy data: Regular metering data combined with periodic occupancy data will help to deconstruct the water use in the guest rooms and provide further insights into percentage water use in other areas of the hotel.
- Further audits and user data is required for water use analysis in the remaining areas of the hotel.

## CONCLUSION

The retrofit program discussed in this paper was embarked on to deliver some water and associated cost savings to the hotel, and to provide some evidence to further demonstrate the viability of such schemes on a wider scale. This to a large extent has been achieved, and the monitoring of the potential for continued savings from the scheme is ongoing. However, to achieve sustained cost benefits and water savings from the scheme, targeted information is recommended for staff and guests to include advice on how to use the new fittings as well as an encouragement to 'adjust' their behaviour to suit. This baseline information is necessary for the effective design and implementation of information and behaviour change strategies.

### Further steps

Since this preliminary review, the hotel has implemented further work in some of the guest rooms to upgrade some single flush toilets to dual flush.

The introduction of more information and guidance for guests in the room folders has had some impact but on a very small scale in comparison to the bathroom refitting. Guests behave differently in hotels and are generally more wasteful than they would be at home. As a result highly visual awareness notices are likely to be more effective and the hotel hopes that the water company will again produce tasteful stickers as they have done before in collaboration with the Tourism Board.

In terms of the effect this retrofit has had on the case study hotel, the feedback from the manager is that:

*"We are delighted to be saving not only costs but water too. Our customers have been impressed with the facilities and even though we are a budget hotel we are providing facilities above expectation. I wholeheartedly recommend other hoteliers seriously consider the improvements they could be making to their profits and the environment with some simple changes to their bathroom facilities and a bit of educational material for their clients."*

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## **An exploration of customer attitudes toward water conservation measures in East Hertfordshire**

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### **Abstract**

Understanding how customers engage with and view their water usage is crucial to the design of more effective water demand management policies and programmes. This paper presents the findings of a small-scale research project that sought to explore customer attitudes to the use of water and its conservation, particularly in the context of seasonal tariffs used during the summer peak usage months (May to August). A series of 20 face-to-face semi-structured interviews were carried out with domestic water users in Bishops Stortford, United Kingdom. As a consequence, it is argued that the study highlights study participants as being disengaged from their water usage and the associated efforts to reduce their usage, so simply increasing water prices at seasonal peak usage times was not, on this occasion, an effective method to adopt to reduce domestic water usage. However, by subsequently exploring customer attitudes towards a selected range of alternative water conservation measures, such as the subsidisation of water efficient appliances, and rebates for reduced water usage, it is established that alternative water conservation measures may have the potential to more effectively encourage a reduction in water usage. However, as the findings of this study also serve to highlight, the issue of ‘institutional trust’ emerges as a key issue to consider when seeking reductions in water usage by increasing its unit cost, with accusation of profiteering looming large. Therefore, in conclusion, it is suggested that a richer mix of policy responses demand management will be needed to convince domestic water users of the need to reduce their water usage.

**Key words:** *Domestic water consumption, seasonal tariff, water conservation, customer attitudes*

### **INTRODUCTION**

As world demand for water increases and shows no sign of decline (UNDP, 2006; UNESCO, 2009), understanding how customers engage with and view their water usage is crucial to more effective water demand management policies and programmes (Doron, *et al.*, 2011; Defra, 2011; Prosser, 2011; Randolph and Troy, 2008). Metering is envisaged as playing a central role in better managing water resources and reducing demand (Chambouleyron, 2004; EC, 2002; Defra, 2011; 2012). In the context of the United Kingdom (UK), whilst it has been found that the metering of domestic users can reduce initial [short-term] water consumption by about 10 per cent (NMTG, 1993), little is known about how seasonal tariffs affect customer demand for and attitudes to water usage [over the medium to long term]. From a theoretical standpoint, seasonal tariffs are envisaged as being able to affect a reduction

in water demand during the traditional summer peak demand period, yet research studies currently underway in the United Kingdom, in particular work being carried out by Affinity Water (UK), and from which this work stems, appear to cast doubt on this assumption. In fact, when research studies into human behaviour are explored, it is notable that simple cost signals, in the form of seasonal price differentials, may not be enough to affect a change in behavior. Indeed, it is important to state that human behaviour itself is shaped by a wide variety of ‘other’ and ‘external’ factors alongside concerns over cost. In particular, it has been found that age, gender, income, education, infrastructure/available services, and political affiliation can all affect behaviour, particularly with regard to water usage (see Hamilton, 1983; Baldassare and Katz, 1992; Sadalla and Krull, 1995; De Young, 1996; De Oliver, 1999; Lam, 1999; Stern, 1999; Gilg and Barr, 2006; Barr, 2007; Randolph and Troy, 2008). It is also worth noting that wider dimensions of attitudinal and behavioural variability, including notions of emotional involvement, participation, institutional trust, and an attitude-behaviour gap, also serve to shape human perceptions, attitudes, and behaviour in relation to environmental services and conservation measures (see De Young, 1996; Gregory and Di Leo, 2003; Fujii, 2006; Steg and Vlek, 2009).

### **Background to this study**

In an attempt to reduce demand for water during the seasonal peak demand period of the summer months (May to August), Affinity Water (UK) implemented a seasonal tariff metering trial in the area of Bishops Stortford, Hertfordshire, United Kingdom. The main purpose of the study was to assess the potential relationship between a change in water price/cost and relative demand for water during the peak demand period of the summer months. However, contrary to the expected impact of seasonal tariffs, the usage data collected by Affinity Water for the period (2009-2011) appeared to demonstrate average summer monthly consumption as increasing by approximately 3% in comparison to other metered customers in the local area, who were not subject to a seasonal tariff. However, it is important to note a key constraint of the seasonal tariff trial conducted by Affinity Water. In particular, when Affinity Water designed and subsequently implemented their seasonal tariff trial that they had to do so in the context of a ‘cost-neutral’ framework so as to comply with the regulatory conditions placed upon them by the water industry’s economic regulator Ofwat. Therefore, adopting a cost neutral framework for the application of a seasonal tariff trial meant that whilst prices increased during the peak summer months, prices were then decreased during the lower demand months to achieve a level of cost neutrality so long as consumption remained the same. The implications of this regulatory constraint on both the Affinity water trial, and in turn this study, it subsequently explored in the conclusions sections of this paper.

As a consequence of the above findings, Affinity Water commissioned the authors of this paper to undertake research targeted at exploring customer attitudes to seasonal tariffs, in an attempt to identify possible influencing factors that may underlie the observed increase in water consumption. Therefore, this paper discusses the findings of this research, which itself sought to explore customer attitudes to the seasonal tariff trial in an attempt to reveal why there had been an observed increase in water consumption. However, the study also sought to explore customer awareness of and attitudes toward water use and its monitoring. The justification for this focus was that if water users are unaware of the amount of water they are using and how they can monitor it, pricing controls such as the seasonal tariff may well be meaningless in

reality. Attitudes toward current and alternative pricing approaches, as well as alternative conservation approaches, were also the focus of a number of questions. This part of the study was undertaken to identify how much support existed for differential pricing and other conservation methods, including subsidies and rebates, with the overall aim being to identify alternative policy mechanisms and practical approaches to water conservation that may encourage a reduction in water consumption.

## **METHODOLOGY**

From a broad perspective, the research undertaken for this study adopted a qualitative approach, implemented through a series of face-to-face semi-structured interviews with a pre-defined sample population located within the area of Bishops Stortford (UK). Due to the exploratory nature of the research, a semi-structured interview approach was preferred in order to provide both a basic structure/format as well as a degree of flexibility to facilitate the acquisition of underlying attitudes and detailed expansion with regard to certain topics (Robson, 2002). A total of twenty customer households were selected for participation in the study. The selected customers were split into two equal sized groups depending on their relative water usage, with two groups of ten participants being formed to reflect either an increase or a decrease in water usage [as a consequence of Affinity Water's seasonal tariff trial]. It should be noted that customers who were selected to form these two user groups were randomly selected from the wider groupings of customer participants in the seasonal tariff trial that demonstrated either an increase or decrease in water usage. Although customers were selected randomly, care was taken to ensure participants were located throughout the entire study area. In turn, this helped to ensure that the sample of customers selected for interview were as representative as feasibly possible within the confines of the available data set and given geographical area.

## **CUSTOMER ATTITUDES TOWARD WATER USE**

To aid discussion of the results, the study findings have been split into four sub-sections. The first section focuses on exploring respondent engagement with the seasonal tariff trial and its impact on behaviour. The second section focuses on discussing respondent awareness of water use, charges, billing frequency, and the impact of metering on behaviour. The third section focuses on exploring respondent attitudes to water charges and conservation measures. Meanwhile, the final section focuses on discussing respondent attitudes to alternative approaches to water conservation.

### **Customer engagement**

When participants were asked whether or not water usage inside their home had changed as a result of the seasonal tariff trial, 85% of respondents stated that it had not changed since the introduction of the seasonal tariff, with no one usage group appearing more aware of a change in usage. This finding is in contrast to the usage data for two groups created for this study, where 50% of respondents were known to



have exhibited a decrease and 50% an increase in water usage. Subsequent interviewee comments revealed a range of issues which potentially explain this low level of awareness. In particular, respondents felt their household usage had not changed because not all members of the household were aware of the trial; they felt they were already careful with water and so had not instigated any changes as a result of the trial; water was not viewed as a seasonal issue; and a change in behaviour was not felt to be necessary because the costs involved were not a concern. Indeed, 20% of all respondents claimed they had either forgotten about the trial or were not aware that they were participating in a seasonal tariff trial.

The responses of those interviewed serve to highlight that respondents had a low level of awareness of how their usage may or may not have changed as a result of the seasonal tariff trial. Indeed, it is notable that 70% of those in the decrease usage group said they did not know if their water use had changed. This data, in combination with the finding that 85% of participants felt that their usage had not changed, raises the possibility that any observed decrease in water usage when the seasonal tariff trial was in operation was mainly attributable to chance [or other factors]. Indeed, the following interview comment, from respondents demonstrating a decrease in water usage, is illustrative and in turn supportive of this view:

*“It’s probably stayed the same [...] because we’re generally water conscious and we’ve made no lifestyle changes since being in the seasonal tariff. We all shower in the morning, people then like to have a bath as well in the evening. We’ve had a water butt since before the seasonal tariff started. I don’t see that the seasonal tariff has had any impact on our habits”.* (Decrease)

With regard to the increase usage group, it is notable that while some displayed awareness that their usage had increased, others had little to no understanding of whether their usage had increase or decreased as result of the seasonal tariff trial, as exemplified by the following comment:

*“It’s funny, if I had to guess I’d say decreased but I know from looking back over my recent bills that actually we’ve increased our use. I’m not really sure why that is. I do water the garden and wash my cars every week but other than that I feel we’ve cut down on water use more generally”.* (Increase)

When respondents were asked if the seasonal tariff trial had prompted them to fit any water saving devices, 90% of respondents said no. In this respect, it is notable that both usage groups reported in equal measure the non-fitting of water saving devices as a result of the trial. Furthermore, when respondents were asked what actions they had taken to reduce water usage during the last year, particularly when the seasonal tariff was in place, 60% of respondents reported that they had done nothing. However, it is notable that 40% of respondents did claim that they had taken action to reduce their water usage, with the most frequent action being the ‘reuse of water for garden activities’ (30%). It is striking that the usage group claiming to have taken the most actions is the increase group (50%), with the decrease group demonstrating the greatest inaction (70%). However, this result could in part be due to the fact that many in the decrease group were potentially already active in taking action to reduce their water usage prior to the introduction of the seasonal tariff.

When the issue of how much further respondents could go in saving water was explored, only a limited number of respondents suggested that they could do much more to save water and change their behaviour. In particular, just 5% thought they could do a lot more, 20% thought they could do some more, with 55% claiming they

could only do a little more and 20% saying they could do nothing more. However, with respect to the usage groups, it is notable that respondents in the increase group offered a more positive response to being able to conserve water. This finding is similar to the research findings of Randolph and Troy (2008), who found that water customers in Sydney, Australia, also viewed themselves as being unable to save much more water.

When interviewees were asked if more regular billing and information on the seasonal tariff trial would have encouraged them to think more about how much water they were using, respondents agreed that it would serve to engage them more and that they may then respond in a more positive manner. In this respect, research on the impact of communication on customer engagement with environmental initiatives has found that a lack of communication can serve to affect a decline in emotional involvement, awareness, perceived control, and personal responsibility (Gregory and Di Leo, 2006; Kollmuss and Agyeman, 2002). Indeed some interviewees did comment that being able to submit readings online for their gas and electricity usage, and being able to compare usage between month and years, did serve to engage them more and in turn encourage them to reflect on how they could alter their behaviour.

### **Customer awareness**

Approximately 65% of respondents said they knew how much they paid for their domestic water services, with the remainder not knowing. However, it is notable that while those individuals participating in the seasonal tariff trial were billed every six months, 40% of respondents said they either did not know how often they received a bill or that they thought they received a bill quarterly, which is not the case. Indeed, if one was to assume that those individuals demonstrating a decrease in consumption are more aware of what they pay and how often they are billed, the results of this study demonstrate the opposite. Therefore, in combination with the finding that those in the decrease group were not aware of whether or not their usage had changed as a result of the trial, it is questionable whether the decrease in water usage demonstrated by the decrease was the result of deliberate actions, as noted previously. So, in reality what has been observed with regard to water usage may have been more due to chance than a series of deliberate actions, as those in the decrease group appear to be no more aware than those in the increase group.

When respondents were asked how much water they use, only 5% of respondents said they knew. The following interviewee comments serve to typify and further exemplify responses received:

*“Absolutely no idea [...] a cubic metre of water means nothing to me [...] it really is hard to understand how much water you are using and what that actually means, entails etc...”.* (Increase)

*“No, not a clue”.* (Decrease)

This low level of awareness is not unusual, and is supported Randolph and Troy (2008) who found that only 19% of water customers in Sydney, Australia, were aware of how much water they used. Despite the aforementioned low level of awareness, 85% of respondents thought they were average or below average users of water compared with similar users in their area. In particular, 50% of respondents thought they used average amounts of water, while 35% thought they were below average

users. However, it is unlikely that such a large percentage would be low water users in reality (see Randolph and Troy, 2008). Again, when the results obtained for this study are broken down, with regard to the usage groups created for this study, the results obtained do not show any one usage group as being more aware of their water use, which again appears to suggest that the decrease in water usage exhibited by those in the decrease group is down to chance and does not appear to appear to be the result of any deliberate change in behaviour driven by the introduction of the seasonal tariff.

When respondents were asked how often they check their water meter, as a way of gauging how much water they use, 95% of respondents claimed they had never checked their water meter, with there being no significant difference between usage groups in this respect. When respondents were subsequently asked if receiving a metered bill made them reflect on how much water they used and whether they then took action to reduce their usage, 60% of respondents suggested that receiving a metered water bill did not make them reflect and take action. When it was explored with respondents why they 'never' checked their meter a series of reasons emerged. In particular, issues revolving around the location and accessibility of the meter; not knowing where the meter was; not having access to the meter; and the cost of water supplied not being a major source of household expenditure to warrant further checking.

Although 40% of respondents did feel that receiving a metered bill did, if albeit temporarily, make them reflect on their water usage, the majority of respondents felt that receiving a metered bill did not affect their behaviour. The reasons for this were that their water usage habits were necessary, water usage costs were considered to be relatively low and, they were already being economical so being metered did not affect them. Some felt they lacked knowledge as to how much water certain appliances used which made considering taking action a pointless exercise. Again no particular differences in the reasons offered were detected between the two usage groups.

### **Water charges and conservation**

When the perceived fairness of current water charges and their ability to encourage water conservation was explored, 60% of respondents thought that current water prices were fair, with 10% feeling that they were not fair. Both usage groups were equal in their responses to this question. However, it is notable that when asked if current overall water charges encouraged the conservation of water, 60% of total respondents thought that current prices did not encourage conservation, with 30% thinking that current prices did encourage conservation. However, it is notable that twice as many in the decrease group did feel that current water prices did encourage water conservation, with 70% of those in increase group, as compared to 50% in the decrease group, feeling that they did not encourage conservation. When it was subsequently explored with respondents whether or not extra charges should be made for higher than average water use, 60% of respondents thought that extra charges should apply for higher than average water use, with 20% more respondents in the increase group feeling this to be a reasonable course of action.

Despite widespread support for differential pricing to encourage water conservation, and a majority of respondents feeling that current water prices did not encourage conservation, it is notable, and somewhat paradoxical, that 80% of respondents stated

that water prices should not be increased in order to encourage people to use less water / water conservation, with 75% of respondents not agreeing with the idea of general price increases to fund improvements in conservation policies and practices with regard to water use. Thus the aforementioned responses appear to indicate that people feel they should not have to pay more for their everyday use of water but are tolerant and accepting of the idea that higher than average users should pay more, which they may or may not consider themselves to be. As to why respondents were against water prices being increased to encourage people to use less water, it seems that respondents view water as an essential resource people cannot do without and subsequent usage is therefore seen as somehow fixed and unalterable:

*“No, because it would penalise everyday usage and that would not be fair [...] I can't do anything about my usage [...] (water) is not something that you think about when you use it”.* (Decrease)

With regard to being against increased prices to pay for improved conservation policies and practices aimed at conserving water, issues of trust and concerns over the use of the resultant funds were expressed by many of those interviewed:

*“Absolutely not, particularly when water companies are making such high profits”.* (Decrease)

*“If that is where the money goes, and I doubt it would [...] I think it is something to consider so long as you could clearly demonstrate that is where the money went and not on reducing leakage for instance”.*  
(Increase)

The above discussion and associated respondent comments highlight issues relating to trust and respondent understanding. Therefore, future policies and practices, particularly with customer cost implications, do need to take into account how water provider can more effectively cognitively align itself with its customers. Such cognitive alignment is crucial to increasing the effectiveness of attempts to alter customer behaviour. It is notable that research by Blake (1999) and Jorgensen *et al.* (2009) serves to highlight that an apparent lack of trust between customer and company can have a detrimental effect on conservation initiatives with mutual understanding of each other's concerns being key to effective conservation initiatives.

### **Alternative approaches to water conservation**

During the course of the study, consideration was given to identifying and subsequently exploring respondent attitudes toward alternative approaches aimed at encouraging a reduction in water use. When respondents were asked if they would allow someone to fit a 'free' water saving device for them in their home, 70% of respondents were found to be in favour of such a service, with both usage groups being equally positive in this respect. Therefore, this finding suggests that a reduction in water use is possible if water providers were to engage in a programme of fitting water savings which may help to overcome customer cost concerns and apathy in fitting such devices themselves.

When customers were asked if they took into account the water consumption of household appliances when making a related purchasing decision, 60% of those interviewed said that they did consider this issue, with 75% of interviewees saying that the subsidisation of more water efficient household appliances would encourage them to subsequently purchase such appliances.

When customers were asked if a rebate on their water bill would incentivise them to try to reduce their water usage, 70% of respondents claimed that they would be ‘more likely’ to try and reduce their water consumption if they were offered a monetary rebate on their water bill. Such a move, rather than simply charging customers more at a certain time of year, might help to more effectively encourage customers to reduce their water usage via the fitting of water saving devices and/or the adopting of water saving behaviours around the home. It is of note that this finding mirrors wider research suggesting that rebates can act as a ‘facilitating factor’ that encourages the fitting of water saving devices and/or the adoption of water saving behaviour because it helps to overcome barriers to change attributable to the relatively inexpensive cost of water not encouraging the adoption of efficiency devices and/or a change in behaviour (see Barr, 2007; Steg and Vlek, 2009).

## CONCLUSIONS

The findings of this research study also appear to suggest that simply increasing water prices at seasonal peak usage times is unlikely to be an effective method of managing domestic water demand in the short to medium term, particularly when a ‘cost-neutral’ framework is adopted (i.e. as well as prices increasing in the peak summer months, prices are then decreased during the lower demand months to achieve a level of cost neutrality so long as consumption remains the same). As previously highlighted, few respondents demonstrated any significant engagement with their water usage. Indeed, many respondents commented that water was not a major source of household expenditure and that they viewed it as relatively insignificant. If this finding is reflective of the wider customer base involved in the seasonal tariff trial, the issue of ‘price sensitivity’ raises questions about the price signal and practical mindset being sent to customers. Indeed, it is notable that the majority of respondents interviewed thought it fair that higher than average users should pay more for water. Therefore, this finding, in combination with an observed increase in consumption during the peak demand period, serves to call into the question the effectiveness and in turn the validity of adopting a cost-neutral framework. Indeed, as discussed in the results section, the actions of customers, in the context of the seasonal tariff trial, appear to demonstrate them as viewing water more as commodity [and literally a customer item] to be used without constraint, and not as a scarce natural resource to be conserved, because water usage has increased despite the prospect of increased water bills.

However, as this study has found, customers are unwilling to pay more for their water to improve its conservation. In fact, this study is suggestive that customers in general think that their water consumption is not a problem and that they should not have to pay for a solution. This is not to say, as Randolph and Troy (2008: 453) have observed, that customers ‘who use substantial amounts of water should not be charged more’, it is more that customers feel they should not have to because they are not the problem. This finding, in combination with customers being found to be distrusting of what water companies would do with any increased revenues associated with conservation efforts, does raise the need for more effective knowledge transfer partnerships to be developed between not only the company and the customer, but also the regulator.

The findings of this study, in conjunction with previous research, are illustrative of the need for respondents to be targeted with a diverse range of policies and programmes at

any one time, particularly if a sustained and more effective decrease in water usage is to be achieved. Therefore, it is notable that this study has revealed substantial potential demand for a number of different water usage reduction schemes. For example, the study has shown potential wider customer support for the free fitting of water saving devices and the subsidisation of water efficient household appliances. If embraced, such measures have the potential not only to deliver immediate reductions in water usage but provide long term solutions to reducing water usage, as they have in other countries. Also, it is notable that the study has revealed customer support for the usage of a 'bill rebate' to encourage a reduction in water usage. Therefore, in combination with the finding that customers may be somewhat distrusting of the company rationale for embracing certain water conservation techniques, it is apparent that greater attention needs to be paid, by both government and water provider alike, to developing sustained and targeted education campaigns focused on building trust between all stakeholders involved in the delivery of water. A simple one-policy-fits-all approach, such as seasonal tariffs, is unlikely to achieve permanent long-term reductions in water usage, particularly if poor customer knowledge and issues of trust are allowed to fester or worsen. Such reflection and appropriate action is argued as being crucial to facilitating a reduction in water usage, particularly when approaches connected with metering have to adopt a 'cost-neutral' framework, as is the case for England and Wales.

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# MONITORING DRAINAGE WATER QUALITY DURING GREEN ROOF IRRIGATION TRIALS USING SYNTHETIC GREYWATER

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## ABSTRACT

The potential was evaluated for substituting the irrigation of green roofs using greywater, instead of irrigating with mains drinking water. The use of greywater for green roof irrigation is attracting increasing interest in the UK, for its potential for watering during drought conditions. At these times, rainwater and mains water resources become increasingly constrained and the sustainability of green roof planting can be adversely affected.

A trial was conducted using two sets of plant boxes having either 10cm or 20cm substrate, and applying three planting schemes with *Sedum*, or *Stachys byzantina* or no planting (bare soil). The research procedure applied either mains water or BSi-standard synthetic greywater (BS: 8525-2, 2011 without final effluent) for irrigation. Evidence was noted of the filtering capacity of the substrates and the chemical composition of the drainage water after filtration.

Pervious research by Gross et al, (2005), has suggested the probability of Sodium (Na) accumulation in soils and plants. Observations were made regarding the conservation of the total mass of Na retained in soil, soil moisture and in plant material. Statistical evaluation of Na concentrations in plant material showed that *Sedum* and *Stachys* both accumulated similar amounts of Na, whilst the soils showed only marginal evidence of accumulation.

Conclusions are drawn concerning the future for using greywater for watering green roofs. No improvement was observed in the quality of the greywater after filtration through the soil matrix. For longer term watering using greywater, the choice of Na resistant species should be considered, although the *Sedum* species used in this study showed no recorded adverse growth effects from Na accumulation.

Key words: Rainwater harvesting (RWH); *Sedum* and *Stachys* green roofs; irrigation of green roofs with greywater; Sodium accumulation in green roof species; BSi-standard greywater.

## INTRODUCTION

Climate change and increasing urban populations are contributing to the increasing frequencies of water scarce events. The United Nations (2011) estimates that the global urban population will increase from the current 51% to 67% by 2050. This increase in urban populations exacerbates environmental problems already experienced in urban areas, including: air and water pollution, the urban heat island effect and the availability of clean water resources. Accessibility to clean water in urban areas is an increasing global issue. The World Water Organisation predicts that by 2025, two thirds of the global population will face water shortages (Grey and



Connors 2009). Furthermore, the application of rainwater & mains water for uses including green roof irrigation becomes constrained under drought conditions.

Green roof technology can assist with the mitigation of climate change effects felt in urban areas. An EPA (2006) study suggested that within urban areas, roof cover occupies around 20% to 25% of the total land area. To gain the optimum benefits from green roofs, vegetation must be kept healthy and sufficiently irrigated.

To decrease the potential demand for irrigating green roofs with potable water, it has been suggested that for specific applications, greywater may provide a significant alternative water source (Hyde et al, 2013). The average person in the United Kingdom uses around 150 litres of water per day (Environment Agency 2012), and a significant percentage of this water may potentially be suitable for reuse.

In the UK, greywater is defined as water originating from sources including baths, showers, washbasins and laundry waters (British Standard (BS): 8525-1, 2010). Noticeable differences in greywater quality are suggested by Hyde et al, (2013) due to the organic and physical pollutants arising from various sources. Other factors affecting greywaters chemical composition include; the variety of cleaning products available and the chemical composition of mains water (Al-Jayyousi, 2003). Christova-boal et al, (1996) tested the chemical composition of kitchen and bathroom greywater indicating that kitchen greywater contains more pollutants. This suggests that even in a single household, the greywater is likely to be of variable quality. Consequently, irrigation using greywater from any particular source could potentially produce variable effects on plants and substrates, leading to questions over its suitability and sustainability for this purpose (Saphira 2011).

The agreed objectives, included experimental data collection, analysis & evaluation; 1) assessing the quality of irrigation water following application; 2) assessing the effects that greywater irrigation has on plants and soils within the green roof system; 3) evaluation regarding whether or not the application of greywater is a viable alternative to the use of mains water for irrigation of green roofs, both in terms of water quality and in terms of the potential effects on plants from Na in greywater.

## **MATERIAL & METHODS**

### **Materials**

#### **Substrates, plants and treatments**

The experimental period of 28 days was chosen as a short term study, with the potential for expansion at a later date. Experiments started on the 28<sup>th</sup> of May 2012. Thirty-two 0.4m by 0.6m planting boxes were drilled with eight holes in each, for effluent water drainage and effluent sample collection. The substrate used was John Innis Compost No.2, and no additional fertiliser or nutrients were added during the experiment. Sixteen boxes were filled with 10cm of substrate, and the other sixteen with 20cm of substrate. The purpose was to establish how substrate depths affect the chemical and inorganic holding capacity of the substrate. Two species of plant were tested: *Stachys byzantina* and *Sedum*. Twelve boxes were planted with *Stachys byzantina* another twelve with *Sedum*, with the remaining eight containing bare soil as a baseline parameter. The groups of boxes were further subdivided into watering

groups and irrigated with either synthetic greywater or mains water. Boxes were placed in greenhouses in order to control irrigation volumes.

### **Sodium; accumulation and toxicity to plants**

Sodium can be a toxic to plants, hindering growth and development (Luan et al., 2009). A low K, high Na soil characterises stressful conditions and impacts plant growth (Luan et al., 2009). The conservative nature of Na leads to accumulation in plants causing health issues and death.

### **Synthetic greywater recipe and production**

The British standard synthetic greywater recipe was chosen for application to the planted boxes, whilst making one modification which was the exclusion of any tertiary effluent. This was primarily due to Health and Safety restrictions. The adapted recipe can be seen in Table 1.

Components	Amounts
Mains Water	9.913 litres
Shower gel (Johnson's baby Soft wash)	0.0086 litres
Oil (Sunflower)	0.0001 litres

Table 1: Adapted British Standards (8525) basic bathroom synthetic greywater recipe.

The tertiary effluent was replaced by an equivalent volume of mains water expressed in the table above. Batches of synthetic greywater were produced, 10 litres at a time, in which the consistency could be assured by preparation to the BSi method and extra greywater was stored at 4°C for up to 24hours (BS: 8525-2, 2011)

## **SAMPLING**

### **Moisture content and plant irrigation**

A soil moisture probe was used to estimate the moisture concentration in each box. The moisture concentration results determined the subsequent irrigation regime. Soil moisture was measured daily between 12.00 and 13.00 hrs. The volume of water delivered was just sufficient to meet the plants' varying moisture requirements as determined by the moisture probe. Whilst the bare soil and *Stachys* boxes were irrigated when the moisture content fell below  $0.25\text{m}^3/\text{m}^3$  due to higher moisture needs, *Sedum* was irrigated when moisture fell below  $0.20\text{m}^3/\text{m}^3$  as it has a high drought tolerance (Van Woert et al 2005).

### **Plant and soil sampling**

Samples were taken on day 0 and day 28 of the experiment. Five,  $1\text{cm}^3$  samples of soil were taken from the entire depth of the substrate. The five samples were combined to form a representative sample from each box and dried at 40°C. At the same time, plant tissue sampling was undertaken by removing 5 leaves from each plant near the top of the stem. These leaves were added to an aggregated sample, dried and crushed to form a box representative sample.

### **Influent and effluent sampling**

Influent and effluent, tap and greywater samples were collected on experimental days 0, 14 and 28. Influent mains water samples were collected from the greenhouse water mains. Greywater samples were collected 1 hour after production (BS: 8525-2, 2011). Effluent samples were collected by irrigating boxes manually, at a slow pace, with 500ml every 5 minutes until dripping occurred. The boxes water retention times and holding capacity differed due to soil depths and plant types.

## MEASUREMENTS AND METHODS

### Water quality measurements and visual assessment of plants

To assess the influent and effluent water quality, the pH, Total Dissolved Solids and Electrical Conductivity (EC) (ion selective electrodes) were tested on day 0 and day 28 of the experiment. Boxes were photographed every seven days for the purpose of a visual assessment of plant colour and growth.

### Sodium extraction preparation (Soil)

Ammonium nitrate was used to extract Na from the soils. Ten grams of soil was sieved through 2mm gauze and placed in a centrifuge tube. 25ml of 1 mol/litre ammonium nitrate was added. Samples were shaken for two hours. After, the samples were centrifuged at 3600rpm for 10 minutes. The remaining solution was filtered through No.540, Whatman filter paper. The first 5ml of filtered solution was discarded. The solution was analysed for the Na concentration using a Corning 410 flame photometer.

### Sodium extraction preparation (Influent and effluent water)

Samples were filtered with paper filters Whatman no. 540 before the filtrates were analysed using a Corning 410 flame photometer.

### Sodium extraction preparation (Leaf tissue)

Sodium was extracted from plant material by nitric acid digestion; 0.25g of dried, and ground plant material was placed in Kjeldahl tubes. 5ml of concentrated AnalaR nitric acid was added to all tubes and capped with glass bubbles. The tubes were left to stand for 24h and then placed in a digestion block and heated at 60°C for 3 hours. The temperature was gradually increased to 110°C, and samples digested for another 6 hours. The glass bubbles were washed using ultrapure water, helping to dilute the nitric acid before the digest was filtered using Whatman 540 filter paper. Digest liquid was placed in 100ml volumetric flasks which were made up to 100ml with ultra-pure water. The Na concentrations were measured using flame photometer analysis.

### Soil moisture content of the samples analysed for Na concentration

Soil moisture content was measured to get an accurate Na concentration per gram of dried soil. 10g of soil was placed in a foil boat of known weight; this was then placed in an oven at 105°C overnight. The samples were then reweighed and the difference weight from before and after drying is the soil moisture content.

## RESULTS & DISCUSSION

### Influent composition

Conductivity and pH measurements of the mains water and greywater taken over the 28 days showed little change. The pH of the greywater is not dissimilar to that measured in other studies with a range between 6-9pH (Ernst et al 2006, Asano 2007). Measurements also fell within the recommended ranges set by the British Standards of between 7-8pH. The electrical conductivity (EC) of the greywater is low in comparison to some other studies (Li et al 2008) who suggests EC results of 1000 $\mu$ S cm<sup>-1</sup> and above. However, there is a high variability of conductivity results from many different literary sources. The composition of the greywater having limited contaminants could suggest why only small variation between tap water and synthetic greywater conductivity was observed.

Higher Na concentration of greywater when compared to mains water was expected, due to chemical constituents in the soap (Johnsons “Soft wash”). These include: “Sodium Laureth Sulfate, Sodium Lauroamphoacetate, Sodium Chloride, Sodium Hydroxide and Sodium Benzoate”. The increase in Na over time (table 2) in both tap and greywater is likely to be due to the fluctuations in mains water concentrations.

Day	pH		Conductivity ( $\mu\text{S cm}^{-1}$ )		Sodium (mg/l)	
	Mains water	Greywater	Mains water	Greywater	Mains water	Greywater
0	8	7.6	560	610	13.6	22.7
14	7.8	7.6	595	510	17.7	26.3
28	7.7	7.3	580	600	18	29.2

Table 2 Influent composition of mains water and greywater (Results are averages from triplicate samples)

### Total dissolved solids (TDS)

When comparing effluent samples from mains and greywater irrigated boxes, the TDS results presented little differences. The soil-water interactions led to a fairly homogenised TDS content of effluent waters. This demonstrates that the substrate has a greater influence on TDS concentration in effluent water, than initial differences between tap and greywater composition.

Parameters	Substrate depth	10cm			
	Irrigation type	Mains water		Greywater	
	Box type	Day 0	Day28	Day 0	Day28
TDS (mg/l)	Soil	4500	4200	5100	3000
	<i>Sedum</i>	6530	2200	2730	1200
	<i>Stachys byzantina</i>	3330	4200	4870	3500
pH	Soil	6.2	6.5	6.6	6.8
	<i>Sedum</i>	6.3	6.8	6.5	6.8
	<i>Stachys byzantina</i>	6.9	6.85	6.6	6.9
Conductivity ( $\mu\text{/cm}$ )	Soil	3420	4510	4950	4840
	<i>Sedum</i>	3540	2280	2080	1580
	<i>Stachys byzantina</i>	3360	2350	4720	3720
Sodium (mg/l)	Soil	75.7	125.7	100	114
	<i>Sedum</i>	91.6	95.56	68.8	87.7
	<i>Stachys byzantina</i>	116.2	125	150.3	160.3

Table 3 Results of effluent water collected from boxes containing 10cm of substrate (Results are averages from triplicate samples)

The boxes containing plants show a greater decrease in effluent TDS over the soil control. TDS in the effluent from boxes with 20cm of substrate was less than that of boxes with 10 cm substrate (tables 3&4). The effluent water TDS of bare soil boxes are stable in comparison. The results do conflict with others including Hardin and Wanielista (2007) who found that effluent TDS from vegetated roofs increase over time. The experiment however, was over a 5 months period and based on irrigation using mains water. Coleman et al, (2001), found that TDS of effluent increased over time, however, this was unexpected. Results suggest increases in TDS were likely due to the release of exudates from plant roots and/or microbial release of ions upon decomposition of dead plant roots. Coleman et al, (2001) concluded that plants directly or indirectly influenced effluent TDS concentrations.

High transpiration rates and water uptake by plants is a likely factor in the decrease of effluent TDS. Boxes containing *Stachys* show a decrease in the effluent TDS over the experiment, with *Stachys* planted in the 20cm of substrate showing the highest degree of difference (Table 4) when compared to the *Sedum*. The TDS concentrations in bare soil boxes seem relatively stable in comparison. Results indicate that TDS constituents (organic and inorganic) are being absorbed by the plants, causing a decrease in the drainage water.

### pH

The influent and effluent water results suggest that once the water has interacted with the soil matrix the pH decreases (Table 2, 3 and 4). This is further confirmed by decreased in pH in both tap and greywater effluent samples suggested by Anwar (2011) to be due to soil-water interaction. The soil showed little or no changes in pH, demonstrating that irrigation with mains water or synthetic greywater have affected soil pH to a similar degree.

	Substrate depth	20cm			
	Irrigation type	Mains water		Greywater	
Parameters	Box type	Day 0	Day28	Day 0	Day28
<b>TDS (mg/l)</b>	Soil	3300	5600	5000	5300
	<i>Sedum</i>	6300	5070	9730	5670
	<i>Stachys byzantina</i>	7800	4270	10730	5200
<b>pH</b>	Soil	6.7	6.1	6.4	6.6
	<i>Sedum</i>	6.6	6.2	5.6	6.2
	<i>Stachys byzantina</i>	6.2	6.6	6.7	6.7
<b>Conductivity (μ/cm)</b>	Soil	3310	5780	4740	5110
	<i>Sedum</i>	5770	4900	8190	5270
	<i>Stachys byzantina</i>	6950	4200	9780	4950
<b>Sodium (mg/l)</b>	Soil	70.4	134.5	105.1	129.1
	<i>Sedum</i>	115.9	136.1	187.3	197.3
	<i>Stachys byzantina</i>	173.8	177.6	242.8	221.9

Table 4 Result of effluent water collected from boxes containing 20cm of substrate (Results are averages from triplicate samples)

However, comparable work by Christova-boal et al (1996) demonstrates that more highly polluted greywater (laundry water), and an extended experimental period, soils are more severely affected. This leads to higher soil pH, soil micro-nutrient deficiencies, sodium and zinc accumulation and plant health deterioration. Anwar (2011) explains that if soil pH were to exceed 9, dissolution of organic material and induces dispersion in the soil can occur. Dissolved organic matter is likely to leach out of the soil, leading to degradation over time, affecting plant health and survival. Both Christova-boal et al (1996) and Anwar (2011) suggest greywater affects the soils once used for irrigation. Product variability, activity in which greywater is generated and the quality of water supply will all contribute to the composition of the greywater, therefore effecting its pH (Eriksson et al 2002). Substrate depths seem to have little effect on pH of soil and effluent water. The results have shown that a deep substrate leads to higher variability of pH values when compared to the shallower substrate boxes. This is likely due to the higher irrigation levels generally applied to 20cm substrate boxes. Results indicate that in the short

term, soil and effluent pH values were not adversely affected by irrigation with synthetic greywater. The presence of plants seems to have little impact on pH; of the soil and effluent however, this may be due to the short experimental period.

Parameters	Substrate depth	10cm			
	Irrigation type	Mains water		Greywater	
	Box type	Day 0	Day28	Day 0	Day28
<b>pH</b>	Soil	5.6	5.7	5.8	6.1
	<i>Sedum</i>	6.1	6.2	6	5.9
	<i>Stachys byzantina</i>	6	5.9	5.8	5.7
<b>Conductivity (<math>\mu</math>/cm)</b>	Soil	420	420	510	450
	<i>Sedum</i>	430	240	220	260
	<i>Stachys byzantina</i>	470	450	380	320
<b>Sodium (mg/l)</b>	Soil	45.3	39.8	35.4	44.4
	<i>Sedum</i>	29.2	34.1	25.2	28.8
	<i>Stachys byzantina</i>	31.9	56.9	31.1	48.4

Table 5 Results of soils analysis from boxes containing 10cm of substrate (Results are averages from triplicate samples)

### Electrical Conductivity

Irrigation water increased in conductivity once water had passed through the soil matrix (tables 3 and 4) which was also seen in results presented by Travis, et al (2010). The 20cm substrate boxes produce a higher conductivity effluent, this likely due to the larger soil volume and higher water retention time. The results suggest that the soil influences the effluent conductivity to a higher degree than the constituents in the synthetic greywater. However, these results may vary dependant on type of greywater used for irrigation and substrate composition.

The soil and effluent samples collected from planted boxes (both 10cm and 20cm) suggested a decrease in conductivity over the experiment period. This was expected as it was assumed that plants would absorb some charged ions. Due to increased Na concentrations in plant tissue, it is assumed that other unmeasured, charged ions were absorbed by the plants, contributing to an overall decrease in effluent water conductivity.

Parameters	Substrate depth	20cm			
	Irrigation type	Mains water		Greywater	
	Box type	Day 0	Day 28	Day 0	Day 28
<b>pH</b>	Soil	5.5	6.1	5.7	6.6
	<i>Sedum</i>	5.6	6.1	5.5	6.2
	<i>Stachys byzantina</i>	6	6.6	5.8	6.7
<b>Conductivity (<math>\mu</math>/cm)</b>	Soil	440	360	510	350
	<i>Sedum</i>	490	340	390	330
	<i>Stachys byzantina</i>	470	330	540	440
<b>Sodium (mg/l)</b>	Soil	36	40.1	39.4	38.7
	<i>Sedum</i>	31.1	43.1	33.3	42.6
	<i>Stachys byzantina</i>	32.1	39	34.8	37.8

Table 6 Results of soil analysis of boxes containing 20cm of substrate (Results are averages from triplicate samples)

Stevens et al (2010), produced tables of conductivity values associated with risk to plant health. Comparing our results to these it suggests that irrigation with synthetic greywater poses insignificant impact on 95% of the garden plants. This is likely due to similarities in the conductivity between the influent tap and greywater samples. The plants health has been affected dependant on the type of irrigation they received. By visual inspection, *Stachys* irrigated with greywater seemed to deteriorate over the course of the experiment seen during visual inspection. This could be linked to greywater irrigation, but other factors including, over watering and green house temperatures could cause poor health. *Sedum* showed no signs of being adversely affected by the greywater irrigation instead greywater may have enhanced the plants growth.

## SODIUM ANALYSIS

### Sodium concentration of water samples and soils

Na concentrations in the effluent (tables 3&4) increased as it passed through the soil matrix due to ionic exchange between the soil and the irrigation water. It may therefore be suggested that a longer retention time of irrigation water equated to a larger quantity of Na becoming entrained. The results seem to support this suggestion, as the 20cm substrate boxes, due to its larger drainage area, had higher Na concentration in the effluent samples compared with boxes containing 10cm. When irrigating, all boxes displayed signs of ponding water in the lower parts of the substrate. A higher presence of water or moisture lower in the substrate may have led to increased Na concentration due to its highly soluble nature and leaching potential. The presence of moisture weakens the bond between Na and the soil allowing to be transported in the box. An experiment was conducted on a 20cm bare soil box, to establish the moisture differences between the top and bottom layers of substrate. This helped confirm that after irrigation, more moisture is present in lower layers substrate compared with the top. A soil moisture probe was used to test the top 5cm and the bottom 5cm of the substrate and compared how the moisture varied after 1, 3 and 7 days. The results showed that the moisture content of the bottom 5cm of the soil was consistently higher with 44%, 27% and 34% more moisture present after 1 day, 3 days and 7 days respectively. Due to a constant presence of moisture in lower parts of the substrates, it is likely that Na, due its high solubility, was kept in an aqueous state during the experiment, once extracted from the soil. Using the standard soil moisture method to determine when boxes should be irrigated, may have led to inconsistent degrees of soil moisture saturation. The moisture content was measured in the top five cm of soil. It is now known that the moisture concentrations of the lower parts of the boxes were significantly higher than those of the top. This meant that the moisture content, obtained from the top part of the soil profile did not represent the total moisture concentration in each box. This problem would have caused higher than necessary irrigation rates, meaning that moisture was likely present at the bottom of the boxes in relatively high quantities, for the entire experiment. The presences of moisture at the bottom of the boxes and the higher than necessary irrigation rate could enable large quantities of Na to leach from upper to lower parts of the soil profile. Soil Na, in most boxes increased over the experiment period. This is likely to be due to the method of irrigation whereby the boxes were not irrigated to saturation.

Analysis of plant tissues indicated Na accumulation of between 0.55 to 0.72 (mg/g.I) (Table 7). The evidence indicates that irrigation with greywater tends to lead to

higher Na absorption in leaf tissue than in the case of irrigation using mains water, due to the higher concentrations of Na in greywater. The tissue of plants within the 20cm substrate demonstrated a greater increase in Na concentrations than plants grown in 10cm substrate. Both a greater volume of soil and a greater volume of water were available to the plants in the 20cm substrate boxes, thereby meaning that a greater mass of Na was available in those boxes. Furthermore, in the case of the 10cm boxes, the depth of soil mass was available to most of the plants, whereas in the 20cm boxes, many of the roots did not penetrate to the lowest soil.

Parameters	Substrate depth	10cm			
	Irrigation type	Mains water		Greywater	
	Box type	Day 0	Day 28	Day 0	Day 28
Sodium per g. leaf tissue (mg/g)	<i>Sedum</i>	7.5	8.3	7.5	8.1
	<i>Stachys byzantina</i>	11.4	12.3	11.4	16.3
Sodium per gram of leaf tissue per litre of irrigated water (mg/g.l)	<i>Sedum</i>	-	0.67	-	0.72
	<i>Stachys byzantina</i>	-	0.55	-	0.77
Parameters	Substrate depth	20cm			
	Box type	Day 0	Day 28	Day 0	Day 28
	Irrigation type	Mains water		Greywater	
Sodium per g. leaf tissue (mg/g)	<i>Sedum</i>	7.5	11.4	7.5	9.3
	<i>Stachys byzantina</i>	11.4	13.6	11.4	17.9
Sodium per gram of leaf tissue per litre of irrigated water (mg/g.l)	<i>Sedum</i>	-	0.57	-	0.58
	<i>Stachys byzantina</i>	-	0.52	-	0.67

Table 7 Sodium concentrations of leaf tissue for both 10cm and 20cm substrates (Results are averages from triplicate samples)

Visual inspection indicated that greywater irrigation affected *Stachys* more adversely than *Sedum*. Na accumulation in leaf tissue is likely to be a contributing factor into the poor health of *Stachys* seen during visual inspection. It could therefore be suggested that *Stachys* may experience further health problems if greywater irrigation continued for a prolonged period of time. However, as stated previously other factors may also have contributed to the health deterioration of *Stachys*.

A mass balance approach was taken to establish where Na from the influent water would be stored and lost. Different boxes were irrigated with different volumes of water, dependant on the soil moisture explained above. For each individual box, the total amount of Na applied, through irrigation, was calculated by multiplying the total volume of water irrigated by the average Na concentrations seen in either the tap or greywater samples. In all cases the mass balance equation showed an excess of Na that was not accounted for, either by storage in the plants or soils, or losses through effluent water.

There are a number of reasons why the Na concentrations may not be equal in the mass balance equation. Firstly it is suspected that there may have been unequal water distributing when the boxes were flushed. It is plausible to assume that water that was collected during the flushing event was not representative of the entire box. Due to the box design there were areas where water would have collected and not been able to leave the box through one of the eight holes made for collection. Due to these ponding areas it could then be assumed that Na could become trapped and be unable leave the



system, possibly leading to a slight under representation of Na concentrations in the effluent.

The soil sampling method may have led to an under-representation of Na concentrations. If leaching in the soil profile occurred, concentrations of Na would be greater in deeper parts of the substrate. The sampling method took five 1cm<sup>3</sup> soil samples for the entire depth of the box. The samples were combined and subsampled for further analysis. Higher concentrations of Na would therefore be under represented in the collective sample, as the averaged result would give a lower Na concentration, compared to that in the deeper parts of the substrate. Further analysis is needed at 1 to 2cm intervals in the soil substrate, to analyse Na concentrations throughout the soil profile.

The mass balance approach is also affected by leakage from the boxes following irrigation. While the watering method was conducted with attention to detail to prevent leakages, it is impossible to achieve 100% certainty, and thus, Na mass would be lost through undetected leakage. Plant roots may also account for some undetected Na.

## CONCLUSION

Green roofs can be an important addition to urban areas; however, management plans are needed to ensure their full potential is reached. If green roofs were to be widely implemented in urban areas, irrigation needs careful consideration. Green roof irrigation is likely to become a lower priority as drinking water resources become increasingly scarce globally. The aims of this experiment were to establish how different plants, substrate depths and types of water can affect the effluent quality, but also how the substrates and plants react to synthetic greywater irrigation. Green roof management plans need to be designed to encompass research on plant types, substrate types and depths, greywater type and purity, and the long term effects of all of these factors. However this study has helped demonstrate that greywater, if used sensibly, can be used for green roof irrigation. It is also recommended that a small self-assessed monitoring program of effluent water quality and plant health is undertaken. Assessments of long term uses of greywater irrigation on green roofs is needed to assess whether green roofs are capable of sustained greywater irrigation.

This study has shown that after tap water and greywater have passed through this type of substrate, the water quality decreases. One benefit of utilising a 'simple' synthetic greywater composition was that variance arising from experimental, operational and system variables were better controlled and less subject to random variation. It is therefore suggested that the choice of substrate is assessed for its ion holding and exchange capacity. Further research needed to understand how substrates can be designed and used in a green roof context, to improve water quality, for collection and use in other applications including toilet flushing.

With respect to: greywater types, an increased understanding of the chemical composition of different types of greywater and how the dynamics of green roof systems benefit green roof planning and implementation is needed. This experiment has shown that further research is needed to gain a better understanding to the long term effects of greywater or synthetic greywater irrigation on the green roof systems as there is limited knowledge in the literature. Over a longer time frame the chemicals

and dissolved solids' composition may change as a result of a chemical build up in the soils and plants (Gross et al., 2005). The results allow us to suggest that green roof designs should include hardy plants that have a high Na tolerance if irrigated with greywater. The evidence suggests greywater composition is affecting the amounts of Na accumulation in the soils and plant tissues.

Greywater is a precious resource which can be utilised to benefit climate change adaptation and mitigation measures, including green roofs. Greywater has been demonstrated as a viable alternative to potable water, for the application to green roofs as long as a strict monitoring process and management plan is in place.

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# DECENTRALISED WATER AND ENERGY RECYCLING IN BUILDINGS: A CORNERSTONE FOR WATER, ENERGY AND CO<sub>2</sub> EMISSIONS REDUCTION

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## ABSTRACT

Greywater is a sustainable resource for energy and water and greywater recycling is one effective tool to improve the efficiency of water use in buildings. This case study presents 2-year research results from a residential passive house in Berlin, Germany, where greywater recycling combined with energy recovery from greywater had been implemented. Energy from the warm greywater originating from showers and bathtubs is harvested by means of a heat exchanger. The cooled greywater undergoes a multi-stage, physical-biological treatment (MBBR) followed by UV disinfection without the use of chemicals. A total of 41 flats with 123 occupants are connected to the recycling system. Around 3,000 litres of the low load greywater (showers and bathtubs) are treated daily to produce high quality service water for toilet flushing. The heat energy recovered from greywater is used to preheat the cold water before it enters the building's combined heat and power plant (CHP). The total electrical demand for heat recovery, greywater treatment and service water distribution amounts to 1.4 kWh/m<sup>3</sup> (0.8 kWh/m<sup>3</sup> for water treatment, 0.25 kWh/m<sup>3</sup> for heat recovery, 0.35 kWh/m<sup>3</sup> for distribution). This decentralised approach yields much more thermal energy (10-15 kWh/m<sup>3</sup>) than that required for its operation. The highest degree of efficiency is achieved with this system during the winter months when the water temperatures are lowest. The space requirement for the combined system is 0.1 m<sup>2</sup> per person and the investment costs do not exceed 10 €/m<sup>2</sup> of floor space, including installation and 19% VAT. Ways to increase the system efficiency will be also discussed. About 4,485 kg of CO<sub>2</sub> emissions can be saved yearly with the above combined water and energy recycling system.

**Keywords:** CO<sub>2</sub> emissions reduction, Decentralised systems, Energy recycling, Greywater recycling, Utility costs savings.

## INTRODUCTION

Water and energy are closely connected and the water sector is considered one of the largest consumers of electricity. A city like Berlin with 3.5 million inhabitants and advanced water treatment technologies requires for its water sector as much electrical energy as the household electrical energy demand for a city with 280,000 inhabitants (BWB, 2012). Kluge (2010) gives an energy consumption of 1.4 to 5.3 kWh/m<sup>3</sup> for the drinking water supply only and assumes energy savings up to 6 kWh/m<sup>3</sup> from greywater recycling. Therefore, the integration of more decentralised technologies which recycle water and energy may contribute to an increase in both water and energy efficiency in new buildings.

While energy costs in the past 25 years using the example of premium gasoline rose 3-fold from 0.50 to 1.50 €/l, the water costs in Berlin rose 5-fold during the same time span, thus illustrating the necessity to save water at least from an economical perspective. In well insulated low-energy buildings water costs often largely exceed the costs for space heating, hot water generation or even household electricity. For a standard passive house defined as having an energy demand for space heating of 15 kWh/m<sup>2</sup>/a, more energy is needed for hot water generation than for space heating. In general, most of the heat released in a low-energy building is lost via the generated warm wastewater rather than through the building's facade, illustrating again the need for energy recovery schemes in new buildings.

Similar to solid wastes segregation at the household level, wastewater is also a valuable resource for water, energy and nutrients (fertilisers), whose potentials had not been widely exploited yet. Therefore, wastewater segregation (greywater/blackwater) at the household level should be also considered in future building schemes.

The concept of energy recovery from household wastewater and the reuse of the recovered energy are not new. Previous pilot projects largely failed due to high maintenance costs and low system efficiency (Hahn 1990; Nolde, 1995). To improve both was a major aim of this pilot project.

In an attempt to quantify the water and energy saving potentials as well as savings made in the utility costs, a residential passive house with an already existing dual-piping installation was retrofitted with a novel greywater recycling system coupled with heat recovery from greywater (Photos 1 & 2). The combined system was subjected to an intensive monitoring programme and diverse optimisation phases over a period of two years and the results are shown in this paper.

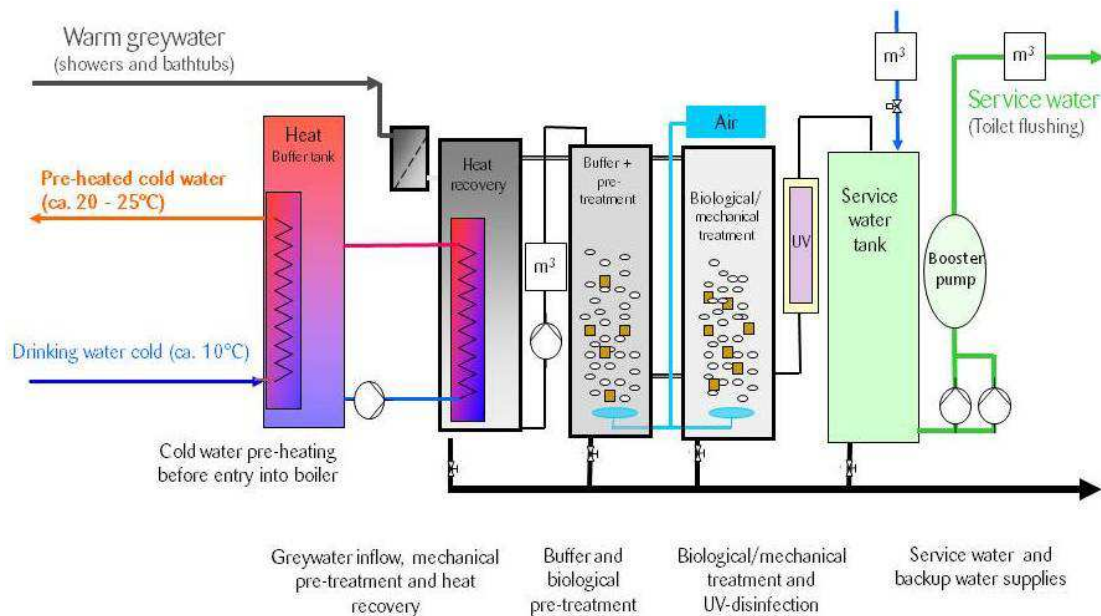


**Photos 1 and 2:** Multi-storey passive house at Arnimplatz incorporating greywater recycling combined with heat recovery. The combined system is placed in the basement adjacent to the building's heating system occupying an area of 9 m<sup>2</sup> (approx. 0.1 m<sup>2</sup>/person).

## PROJECT DESCRIPTION

The passive house in Berlin “Arnimplatz” completed in May 2012 is a new residential construction with 110 tenants occupying an area of 4,600 m<sup>2</sup>, in addition to 650 m<sup>2</sup> allocated to 4 commercial units with a total of 13 employees. The building's heating system is a gas-fired combined heat and power plant (CHP) with a capacity of 16 kW (electrical) and 35 kW (thermal). A set of 92 photovoltaic modules (20 kWp) which had been installed on the roof of the building provide 18,000 kWh of electricity a year. Water saving devices such as 6/3 litres toilet flushing systems, flow-regulated water taps and low-flow showerheads (9 litres/minute) had been also incorporated. The greywater recycling system with a treatment capacity of approx. 3 m<sup>3</sup>/d and an upstream heat recovery unit was installed in March 2012 in the well-insulated boiler room found in the basement of the building and occupying an area of 9 m<sup>2</sup>. Since the ambient temperatures in the boiler room do not drop below 24 °C, it was not necessary to additionally insulate the system components.

Warm greywater from showers and bathtubs passes a sieve to remove the suspended solids before it enters the heat exchanger, where the heat energy is withdrawn by means of a 20 Watt circulating pump (Fig. 1). This energy is used in turn for hot water generation (60 °C) following preheating to 20-25 °C, in this case in the building's combined heat and power plant (CHP).



**Figure 1:** Schematic diagram of the greywater recycling system coupled with heat recovery.

The use of a heat pump with higher end temperatures was dismissed due to reasons of energy efficiency. The slightly cooled greywater exiting the heat recovery tank enters the 3-stage aerobic moving bed biofilm reactor (MBBR), where the main organic fraction of the wastewater is oxidized. Cleaning of the sieve, heat exchanger and biological reactors takes place automatically. The final effluent exhibits constantly a  $BOD_7$  concentration of  $< 5$  mg/l and a turbidity of  $< 2$  NTU. The treated greywater undergoes UV disinfection before it enters the service water tank. From there it is pumped to the dwellings and the 4 commercial units by means of a booster station (4 bar) to be reused as service water for toilet flushing. At no stage of the treatment process are chemicals in form of disinfectants, acids or alkali being used.

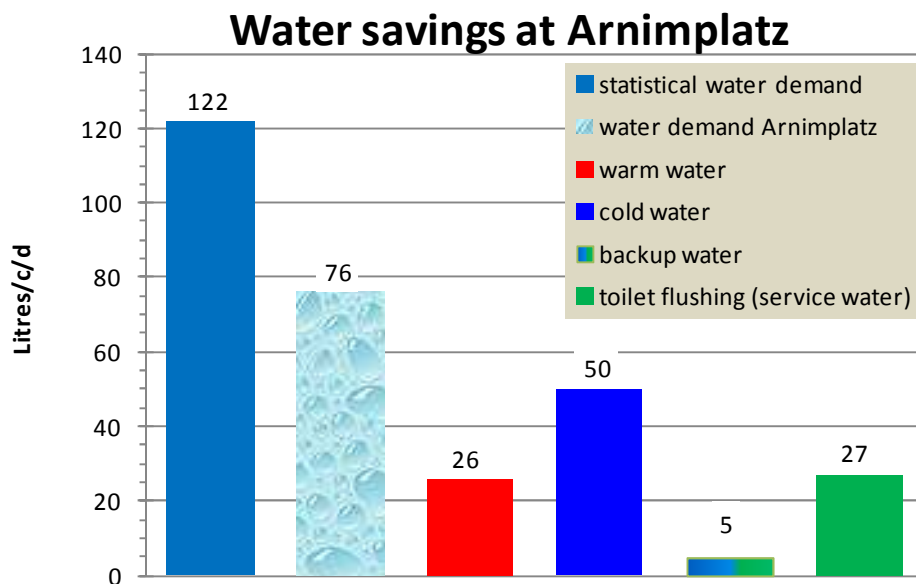
In order to possibly keep a continuous low-maintenance and low-cost operation of the combined greywater recycling and energy recovery system, diverse maintenance functions had been largely automated and energy requirements constantly minimised. The plant status as well as operation data of major system components could be retrieved at all times by means of a remote online monitoring system. This minimises the frequency of on-site inspections, furnishing at the same time a dense and useful network of data. In addition, quantitative data on the daily savings in water and energy can be made available to the client.

The investment costs for this prototype of greywater recycling system combined with energy recovery including remote online monitoring, installation and VAT amounted to 52,288 €. About 25% of the total investment costs (approx. 13,000 €) are allocated to the heat recovery system.



## RESULTS

From April 2012 till January 2014 no maintenance or repair works were required. Merely the monitoring software had to be repeatedly optimized. The satisfaction of the tenants with the water quality was very high and there were no complaints regarding hygienic safety or comfort loss. Since start-up and system operation in April 2012 the service water quality was constantly high even then, when greywater was cooled down to 15°C following the heat recovery process, the service water quality requirements according to the “Berlin List” ( $BOD_7 < 5 \text{ mg/l}$  and hygiene requirements according to the EU Directive for Bathing Water) had been fulfilled at all times (Berlin Senate for Urban Development, 2007; EU Directive for Bathing Water, 2006). Figure 2 shows the water saving data of the passive house during the first year of operation. Due to water saving measures and greywater recycling the potable water consumption was reduced by 38% from 122 to 76 l/c/d. Whereas 27 l/c/d are needed for toilet flushing only 22 l of service water are generated in the building originating from showers and bathtubs. Therefore, 5 litres of cold water per person and day are needed to backup the system. In this case, the total water demand at Arnimplatz excluding greywater recycling would amount to 98 l/c/d.

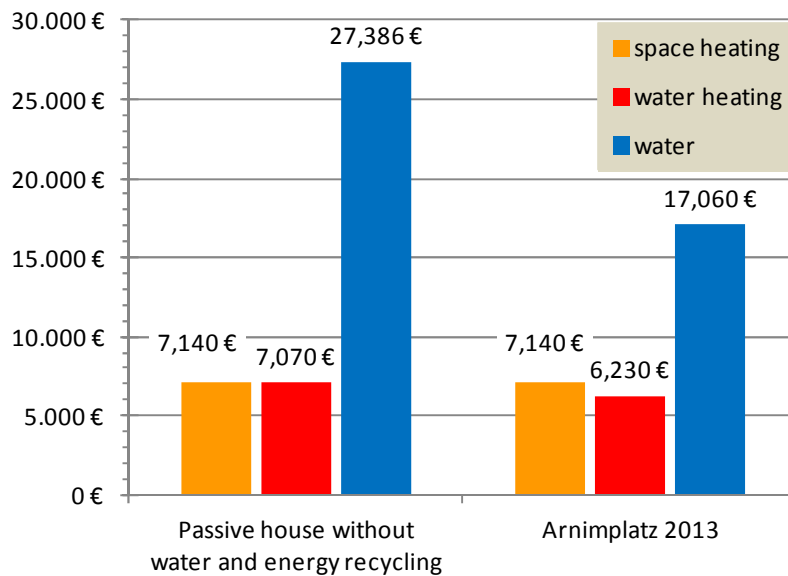


**Figure 2:** Water savings (from 122 to 76 l/c/d) due to water saving measures and greywater recycling from showers and bathtubs.

Figure 3 shows the total yearly energy costs for space heating and warm water production for the whole building which amounts to approx. 14,210 € (203,000 kWh x 0.07 €/kWh). Using water-saving devices combined with greywater recycling and heat recovery resulted in **net savings** in the utility costs in 2013 of 10,763 €. This in turn shows the economic significance of integrating water recycling schemes and water efficiency measures in buildings, not to mention the environmental and social benefits.



## Water and energy costs

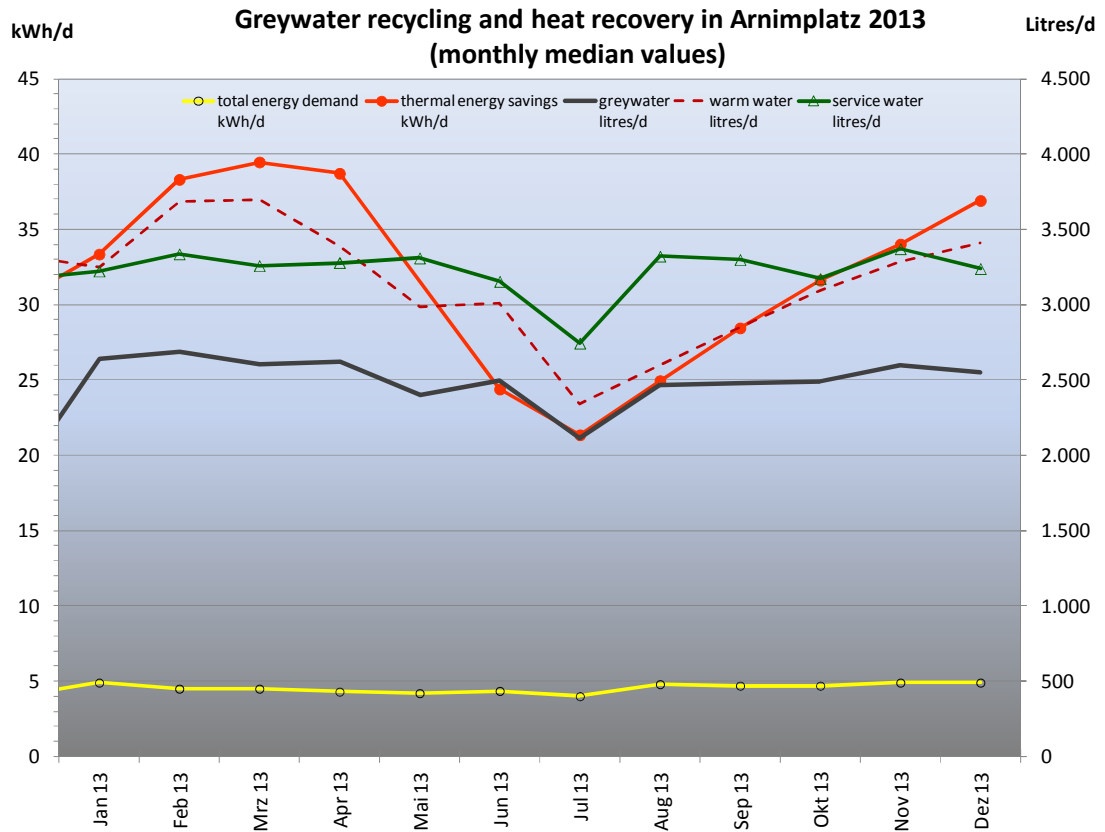


**Figure 3:** Running costs with and without water saving devices, greywater and energy recycling at Arnimplatz in 2013.

Compared to the energy demand for the conventional water system in Berlin (approx. 2 kWh/m<sup>3</sup> for water supply and wastewater treatment, etc.), about 2,455 kWh of electric energy were saved in 2013 with the above combined system resulting from the reduction in the drinking water consumption. This also results in CO<sub>2</sub> emissions reduction which is equivalent to 1,473 kg of CO<sub>2</sub>. The heat recovery process (12,000 kWh<sub>therm.</sub>) in the above system results in a yearly CO<sub>2</sub> emissions reduction of about 3,012 kg of CO<sub>2</sub>.

### Water and energy data

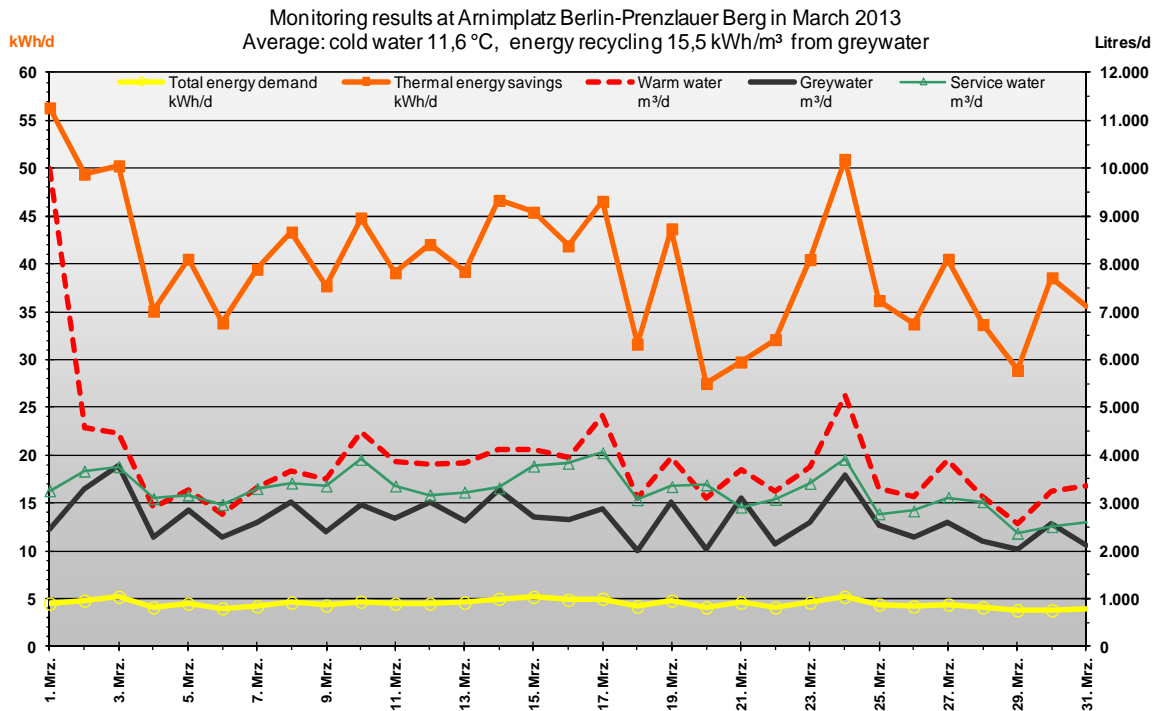
Figure 4 shows the major water and energy data of the combined recycling system in 2013 based on monthly median values. The total amount of greywater from showers and bathtubs was lower than what had been expected mainly due to the use of water saving devices in addition to the limited greywater resources (originating exclusively from showers and bathtubs). During the summer holiday (June-August) a minimum of hot water, greywater and service water had been registered, which in turn resulted in a minimum heat recovery from greywater. The daily maximum in heat recovery had been achieved when drinking water exhibited lowest temperatures (in the first and last months of the year). Figure 4 also shows the electrical energy demand for the whole plant which is always close to 5 kWh/d.



**Figure 4:** Monitoring results of water and energy input and output in the recycling system.

Figure 5 shows the monitoring results for energy and water for March 2013. Consuming less than 5 kWh<sub>elec.</sub> per day (yellow line), about 2 - 3.5 m<sup>3</sup> of greywater are treated daily to high quality service water for use in toilet flushing. Also included is the electrical energy demand for the heat recovery system of 0.25 kWh/m<sup>3</sup>. Slight fluctuations in the daily energy consumption are primarily due to the variable service water demand (pump flow) and less to the greywater treatment process.

These results also demonstrate that approx. 25% less greywater is generated than service water needed for toilet flushing. Hot water consumption (T= 60 °C) is significantly higher than the generated greywater, which demonstrates the unused potential of greywater originating from untapped greywater sources such as hand washbasins, laundry and kitchen. A mains backup system ensures that water for toilet flushing is continuously supplied at all times.



**Figure 5:** Monitoring results of water and energy input and output from the combined recycling plant during March 2013.

The energy yield from warm greywater (means 31 °C) is generally dependent on the amount of greywater generated as well as the current cold water temperatures and hot water demand. During March 2013, when the lowest drinking water temperatures were 9 °C, 45 kWh of thermal energy were recovered from 3.2 m<sup>3</sup> of greywater, whereas in August 2012, when the drinking water temperatures were significantly higher (16 °C) only 31.6 kWh were recovered in thermal energy. Due to the automated self-cleaning process, no scaling or coating of the heat exchanger was detected, which is also a result of the continuous high energy yield in the system. The decline in energy yield during the summer months is primarily due to the higher drinking water temperatures.

## DISCUSSION

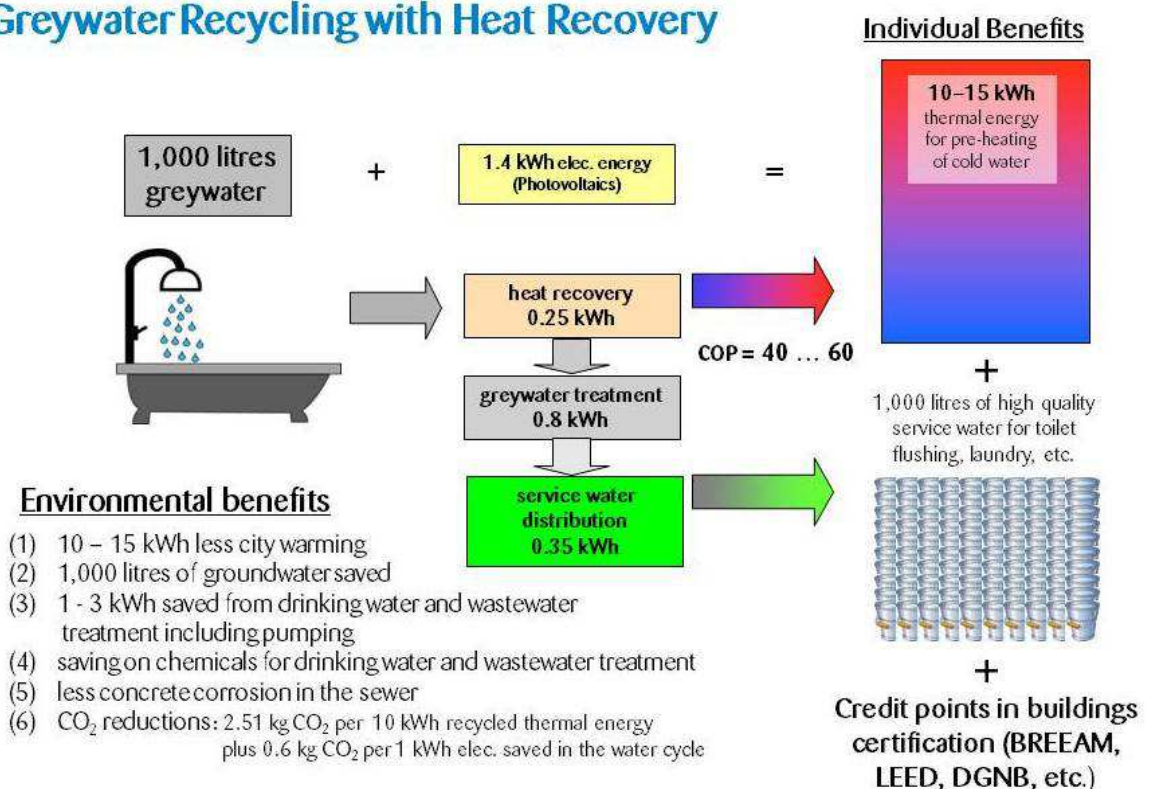
Biological wastewater treatment using the biofilm system, in this case the MBBR followed by UV disinfection has consistently proved to be a highly stable and efficient system. Even during a 4-week experimental period in January 2013, when the high load kitchen greywater from one commercial unit was fed into the greywater system, a high operational stability was maintained. Contrary to bio-membrane systems which are highly susceptible to bath additives, fats and other household chemicals and therefore require regular regeneration or replacement of the bio-membrane, the MBBR achieves a higher service life at considerably lower energy expenditure. In a previous project (Block 6) with a similar MBBR system treating greywater also originating from kitchen and laundry, the biofilm reactor had not been regenerated or replaced since the start-up of operation in 2006 (Berlin Senate for Urban

Development, 2008) and it is still operating up to date at high efficiency and minimum maintenance costs

The UV disinfection unit operates 3.5 h/d and the UV light bulb should be replaced after 7,000 h according to manufacturer's data, which means in this case after 5.5 years. Drinking water backup which amounts to approx. 25% is mainly due to the fact that greywater is collected solely from the apartments of the building (110 tenants) and only low load greywater sources are included (showers and bathtubs), whereas service water is distributed to a larger user community including the 4 commercial units of the building (architecture firm, organic food store, restoration shop, shoe store).

### Benefits of the combined recycling system

#### Greywater Recycling with Heat Recovery



**Figure 6:** Individual and environmental benefits of greywater recycling combined with heat recovery based on an inflow of 1,000 litres of raw greywater.

Figure 6 shows the benefits of the combined recycling system at the individual level (tenants and investors) as well as the environmental benefits based on 1 m<sup>3</sup> of greywater originating from showers and bathtubs. In addition to water and energy savings, investors place particular emphasis on the credit points which they could achieve within a building certification process. Environmental benefits include less energy consumption and less global warming as a whole, resulting in turn in less CO<sub>2</sub> emissions. Other benefits are also of significance as regarding the water supply and wastewater treatment sectors such as easing the burden on the groundwater resources, less use of chemicals and less concrete corrosion and depositions in sewer networks.

In addition to the high operational safety and low maintenance and energy requirements, architects and investors set a high value on the following aspects:

- A low space requirement ( $0.1 \text{ m}^2/\text{person}$ , equivalent to one A4 paper size/person)
- A low increase in the building costs (approx.  $15 - 20 \text{ €/m}^2$  of living space including dual piping and VAT)
- No specific user behaviour is required (e.g. ban of certain household chemicals).

Out of approx.  $3 \text{ m}^3$  of greywater generated daily, about 12,000 kWh of energy is recovered annually with the above system, which is equivalent to the energy gained from  $33 \text{ m}^2$  of solar panels. A special feature of this system is that it exhibits highest efficiency during winter, when the solar thermal system hardly achieves any yields. The investment costs for the energy recovery system (approx. 13,000 €) are also lower than those for the solar thermal unit. The required energy for overall system operation of maximally 1,800 kWh/a (including greywater recycling, energy recovery, etc.) can be delivered in practice by only 10 out of the 92 PV-modules installed on the roof of the building.

The benefit for the private user in thermal energy savings from  $1 \text{ m}^3$  of greywater is about 10 kWh/ $\text{m}^3$  in summer and 15 kWh/ $\text{m}^3$  in winter, when the potable water exhibits lowest temperatures. During the winter months heat recovery by means of the very low-maintenance heat exchangers achieved a coefficient of performance (COP) of up to 60. In addition to obtaining high quality service water which can be used for all non-potable applications (toilet flushing, laundry, irrigation, house cleaning, cooling, etc.), the environmental and financial benefits are also significant as shown in Figure 6.

The investment costs for the recycling system (prototype) including costs for the dual-piping network amount to  $< 20 \text{ €/m}^2$  of floor space. An early inclusion of water and energy recycling schemes in the building engineering systems design (site selection, pipeline design, pump installations, consideration of thermal yields) will have a cost-cutting impact on the investment project. Dependent on the local water prices, structural requirements and a good planning process, amortisation periods of less than 10 years can be easily achieved.

Since the plant operation in this case study is also taken over by the project's planning and design team (engineering firm/plant manufacturer/sanitary firm), this also meets well with the interest of the investor and property management to keep investment and operation costs low.

## CONCLUSION AND OUTLOOK

Decentralised wastewater technologies can achieve a higher resource efficiency in the water and energy sectors than centralised ones. Instead of spending much energy for treatment and pumping, energy, water and nutrients can be recovered instead from wastewater. Decentralised heat recovery can also become an integral component for new buildings delivering a substantial amount of the energy demand for hot water production throughout the year. A higher system efficiency can be also achieved in combination with greywater recycling. In both cases a dual-piping system is indispensable and should not be absent in any new building or refurbishment schemes.

Other investigations which had been worked out in the DWA-NASS Working Group KA 1.6 have shown that the separation of black/yellow water in buildings significantly reduces the load of nutrients entering the receiving waters as well as reducing the energy demand for wastewater treatment, in addition to generating fertilisers for agriculture (Oldenburg et al., 2012).

The extensive monitoring programme undertaken in this project offers the advantage of detecting optimisation needs and options. The collected data will be fed in a following project which will contribute to increasing the overall system efficiency.

Due to the inclusion of greywater from showers and bathtubs only, the water and energy recycling potential at Arnimplatz is by far not yet exhausted. Other greywater resources should be also fed into the recycling system to increase its efficiency and reduce the backup water consumption. Although greywater from hand washbasins, washing machines and kitchen sinks requires higher treatment expenditure, this would pay off economically and exert a positive impact on the environment, in addition to reducing the potable water demand down to 50 l/c/d.

From the 899 m<sup>3</sup> of greywater recycled by the above system in 2013, 12,000 kWh of thermal energy were harvested (13.35 kWh per m<sup>3</sup> of greywater) with a COP of 53.4. The use of a heat pump instead of heat exchanger will have a negative impact on the overall energy efficiency of the system bringing the COP down to 3.5, which is 15 times lower than the COP achieved with the above system using only a heat exchanger. On the other hand, using a heat pump to recover energy from wastewater would produce a higher yield (33,000 kWh/a) compared to the harvested 12,000 kWh using only a heat exchanger, as is the case here. The higher demand for electricity by the heat pump can be only justified if electricity is made available from renewable resources, which is not always the case in projects dealing with heat recovery from wastewater.

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# DECISION-MAKING AND SUSTAINABLE DRAINAGE: DESIGN AND SCALE

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## ABSTRACT

With the implementation of the SUDS provisions in the Flood and Water Management Act (2010), local authorities will become responsible for the approval, design, construction and future maintenance of sustainable drainage (SUDS) solutions serving more than one property. This paper reports on 2 related research projects designing SUDS at different scales, one of which develops a means of indicating suitable devices to be used at the city scale and the second models the storm attenuation benefits of such devices when designed as a Management Train. Geographical information was used to develop a series of maps indicating feasible locations for SUDS devices across a local government authority in Coventry, England. The maps provide initial guidance to local government on the type of SUDS devices likely to be suitable at individual sites in a planning area. The method of creating suitable maps is shown, and examples of some of the output maps are given. These outputs are intended to be more widely applicable in order to reduce barriers to implementation of alternative, more sustainable stormwater management techniques. Using the maps produced at the large scale, a regeneration site was selected and a management train designed using the software WinDes<sup>®</sup> to control runoff from the site at greenfield runoff rates. At all scales, the decision of what SUDS device to use was complex and influenced by a range of factors, with slightly different problems encountered at each scale.

Keywords: Design, GIS, Management train, Modelling, Sustainable Drainage (SUDS)

## INTRODUCTION

Designing sustainable drainage (SUDS) into the environment, whether urban new build, retrofit or in rural areas is a complex process; it needs to be fit for purpose. The approach is being encouraged through policy and legislation, for example the National Planning Policy Framework and its associated technical guidance (DCLG, 2012) prioritise the use of SUDS. Furthermore, the Flood and Water Management Act places responsibility on local government for their approval, design, construction and future maintenance where they serve more than one property. SUDS are said to be multiple benefit and flexible in application (Charlesworth, 2010), and thus local authorities will have to understand how this is achieved. They should conform to the oft-quoted SUDS triangle in which water quality, water quantity, amenity and biodiversity are equally balanced (Charlesworth et al., 2003). There are also other benefits beyond the SUDS triangle, as exemplified by Charlesworth 2010's "SUDS Rocket" whereby a suitable single SUDS device, or preferably an efficiently designed full SUDS management train, can mitigate and adapt to climate change. SUDS design therefore begins with a consideration of its overall role,



whether source control, infiltration, detention/ retention, filtration or conveyance, an overview of which is shown in Table 1.

Table 1 Overview of SUDS device groupings (Charlesworth et al. 2013; Woods Ballard et al. 2007).

<b>SUDS device grouping</b>	<b>Function</b>	<b>Examples SUDS Devices</b>
Source Control	Slow down, store and treat runoff at locations close to where rain has fallen. Water can be released gradually or utilised for non-potable purposes.	Green Roof Rainwater harvesting Permeable paving Sub-surface storage Trees Rain garden Disconnected downpipe
Infiltration	Runoff storage and infiltration into the ground to recharge groundwater	Soakaway Infiltration basin Infiltration trench
Detention and retention	Basins with temporary or permanent storage of runoff. Removal of pollutants to improve water quality	Detention basin Retention basin Pond Wetland
Filtration	Slow down flow and treat runoff to remove pollutants	Sand filter Filter strip Filter trench Bioretention device
Conveyance	Channels that convey runoff. Can also store and infiltrate water into the ground	Swale Rill

Underlying these factors are site-specific features of the drainage catchment which impact on the potential to infiltrate on site, detain water and also to be able to convey it to the next SUDS device, the receiving watercourse or groundwater reservoir. Soil type and ground conditions, for instance whether it is a brownfield site, also drive decision-making. Examples of other such factors are given in Table 2 which classifies them into those which are fixed over relatively long timescales, or variable, i.e. those that may alter over a shorter term. Physical (or environmental) factors included geology, soil, topography and the presence of water above and below ground level. Anthropogenic (human-induced) factors are related to definitions of groundwater protection near extraction boreholes, plus known and potential sites of groundwater contamination risk. All of these factors have scale-related importance in terms of efficient design, whereby knowledge of their extent and potential impacts is essential.

In common with conventional drainage, SUDS planning has to take account of the temporal and spatial characteristics of the design storm. Thus the draft SUDS National Standards (Defra, 2011) indicate that runoff from a 1 in 100-year rainfall event must not exceed greenfield runoff rates, which are set at  $2 \text{ l sec}^{-1} \text{ ha}^{-1}$ , with a critical storm duration of 6 hours. Using a UK drainage industry standard flood modelling product (Hubert et al. 2013), the software WinDes<sup>®</sup>, Charlesworth et al., 2013 modelled the storm attenuation potential of various SUDS management trains using a small part of the Canley Regeneration Zone (CRZ) in Coventry, West Midlands: Prior Deram Park. The resulting hydrographs showed that peak flow and time to peak were both reduced in comparison

with a pipe-based system, rainfall response increased and total volume of runoff decreased by 20%. Lashford et al., 2014, investigated how these reductions were achieved by deconstructing the management train hydrograph at different storm intensities. They found that a management train of green roofs, tanked porous paving, swales and dry detention ponds reduced peak flow by 88%.

The aims of this paper are:

1. To show how the decision-making process in terms of designing a SUDS management train is scale-related with reference to Coventry City Council, a local government authority in central England
2. To illustrate this with the application of a large scale site-specific model which identifies the individual SUDS devices suitable for the area using geographical information
3. To model at the smaller scale to achieve greenfield runoff.

Table 2 Site specific physical and anthropogenic factors driving SUDS design. Columns show the device groupings (see Table 1). Rows show characteristics. Cells marked as 'x' indicate the factors that influence implementation of the SUDS devices.

	Source Control	Infiltration	Detention	Filtration	Conveyance
Implementation guidelines	First priority	Infiltrate where detention is not possible, detain where infiltration is not possible		These should be used wherever possible	
Factors					
<b><i>Physical</i></b>					
Bedrock and surface geology		x	x		
Water bodies	x	x	x	x	x
Fluvial flood zones		x		x	
Soil drainage type		x	x		
Topography		x	x		
Water Table		x	x		
<b><i>Anthropogenic</i></b>					
Waste and landfill sites		x			
Current and former industrial sites		x			
Surface and ground water quality		x	x		
Land cover	x	x	x	x	x
Planning constraints	x				x
Land ownership, sewer and historical flood locations will also be involved later in the process and so are not discussed further; however, these do add a further layer of complication to the decision-making process.					

## METHODOLOGY

The case study presented here is based in Coventry, in the West Midlands, UK, specifically the Canley Regeneration Zone (CRZ), situated about 6 km southwest of Coventry city centre, and covering just over 123 ha, some of which is brownfield (for further site details, see Charlesworth et al., 2013; Lashford et al., 2014). Outline planning permission has been granted for 700 new dwellings in total, new community services and open space improvements (CCC 2008).

Based on the information contained in Table 2, the spatial distribution of each factor driving SUDS device choice across the CRZ was determined using data from a number of sources, including the British Geological Survey, Coventry City Council, Ordnance Survey, National Soil Resources Institute and the Environment Agency. A set of decision criteria, or rules, were created for each of the factors, for example, different rock types were assessed in relation to their capacity for infiltration or detention of runoff. These rules were agreed in collaboration with local government, environmental regulators and the responsible water utility, all of whom had local knowledge, and the rules coded so they could be applied spatially. The spatial relationships were then analysed using a GIS, in order to determine appropriate locations for the different types of SUDS for new developments and regeneration sites, the output for which was a set of maps. By using a GIS approach, the maps were scalable; they could be viewed at different resolutions from full city scale to that of individual development and regeneration sites.

Table 3 summarises the decision-making process in the design of SUDS across Coventry and signposts the outputs in this paper. Figure 1 illustrates the relationship between each set of data and factors in the production of the maps (Stage 8 in Table 3) based on detention of excess stormwater.

Table 3 Data collection and analysis overview (\* for further information, see Warwick et al., 2013)

Stage		Output
1	Define SUDS groupings	Table 1
2	Identify influencing factors	Table 2
3	Allocate influencing factors to SUDS groupings	Table 2
4	Determine site specific spatial distribution of influencing factors	Not shown in this paper*
5	Define rules for influencing factors	Fig. 1
6	Agree rules for influencing factors	Not shown in this paper*
7	Apply rules to each SUDS grouping	Not shown in this paper*
8	Present outputs in map form	Figs 2&3

Once the suitable SUDS devices had been mapped, both a SUDS management train and also a piped system for comparison were designed using WinDes® but at a reduced scale with the desktop modelling exercise located at a smaller parcel in CRZ, Prior Deram Park (PDP) where permission has been granted for the construction of 250 houses. A strategic flood risk assessment of CRZ (Halcrow Group Ltd 2008) identified SUDS generically as necessary to address flooding issues, without specifying suitable SUDS, advising only of the need to "take account of groundwater and geological conditions". The example SUDS

train was designed to comply with the draft SUDS National Standards (Defra, 2011) as defined above, i.e. runoff was limited to less than  $10 \text{ l sec}^{-1}$  for the whole 5 ha site. To ensure the site was developed as accurately as possible, a  $1\text{m}^2$  resolution DEM was used to determine the destination of runoff. Large-scale map information indicated that infiltration was not possible, therefore the design concentrated on provision of detention via detention ponds, which also provided a treatment stage. Runoff was directed into the nearby Canley Brook. The response of the site to the 1 in 100 year 30 minute winter critical storm ( $73.13 \text{ mm hr}^{-1}$ ) was then simulated.

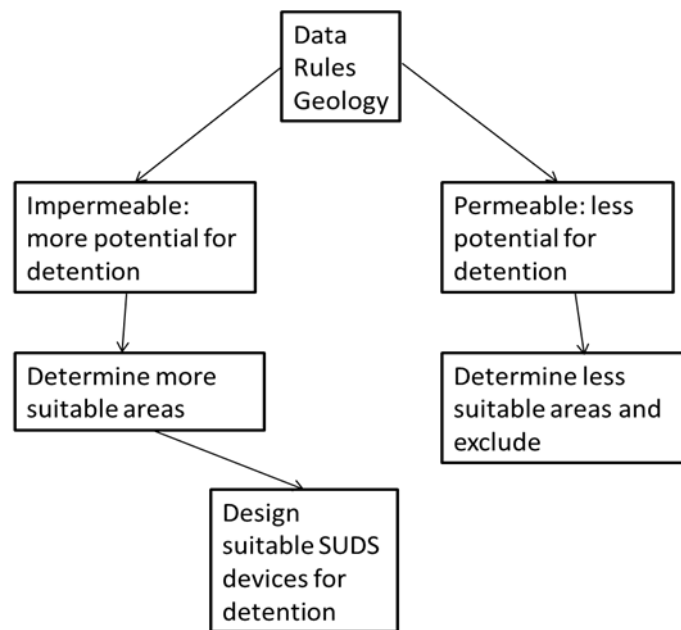


Fig 1 Map creation process for detention SUDS, based on the example of geology

## RESULTS

The hierarchy of recommended SUDS approaches for new build in Coventry developed from the mapping exercise described in the methodology is shown in Table 4. Placing source controls as the initial stage of SUDS agrees with SUDS management train principles in which excess rainfall should be dealt with as close as possible to the point at which it falls. Source controls can be designed to deal with runoff from the first 15 mm of rainfall, and will principally address water quality issues; they are feasible in over 99% of Coventry. However, source controls will not manage the large volumes of runoff which increase flood risk, for which one of the remaining approaches in the hierarchy should be selected. Infiltration SUDS, which reduce both the rate and volume of runoff, should be implemented as the second priority where potential land contamination is not a risk (14.5% of Coventry). Infiltration effectively removes runoff from a drainage system, rather than retaining it within the system (Swan 2002). Where infiltration is feasible, but land contamination is a concern, field investigations should be performed to ascertain suitability before proceeding, which applies to 2.5% of Coventry. In areas where infiltration is not feasible, above ground vegetated detention and retention SUDS should be prioritised (32% of Coventry). In the remaining 50% of Coventry, engineered (e.g. re-landscaping, lined basins or hard infrastructure) detention and retention SUDS will be needed. Here also, above ground SUDS should be prioritised, although these will require greater design, and possibly construction, effort than in other suggested applications. A

spatial representation of these is depicted in Fig. 2 and shows the complexity of the decision-making process at the large scale.

The different performance characteristics of individual SUDS techniques must be taken into account when considering their suitability for addressing particular requirements at the detailed design stage. It is important to note that Fig. 2 offers outline policy guidelines, whereas evidence-based investigations at each site, undertaken for detailed planning and SAB applications, may generate alternative SUDS solutions which should take precedence over these recommendations.

Table 4 Hierarchy of recommended SUDS approaches for new developments in Coventry

Priority	SUDS approach	Suitable area of city
1	Source controls	99%
2	Infiltration SUDS	14.5%
3	Infiltration SUDS in former industrial land, if tests show no potential for contamination	2.5%
4	Vegetated detention SUDS	32%
5	Engineered detention and retention SUDS	50%

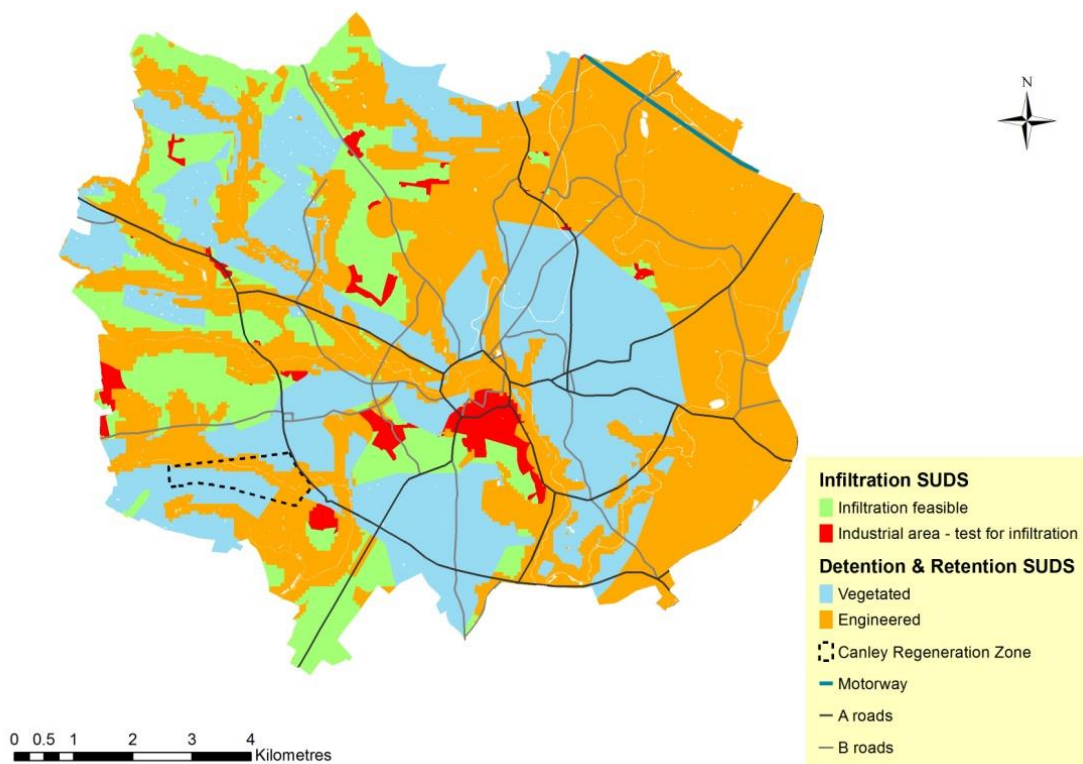


Fig 2 Locations of recommended SUDS approaches in new developments in Coventry.

Applying the methodology at the smaller scale, the recommendations given in Fig. 2 were applied to the CRZ. All groups of SUDS devices were possible in Canley apart from infiltration, where only small areas to the southeast and southwest of the zone were possible (Fig. 3a). Source control, filtration and conveyance were possible across the whole site, therefore no maps are presented for these. Fig. 3b shows the potential for detention and retention SUDS across the site, illustrating where “softer” vegetated SUDS

could be used, and also where the more engineered applications need to be installed due to ground conditions or proximity to the local watercourse, the Canley Brook.

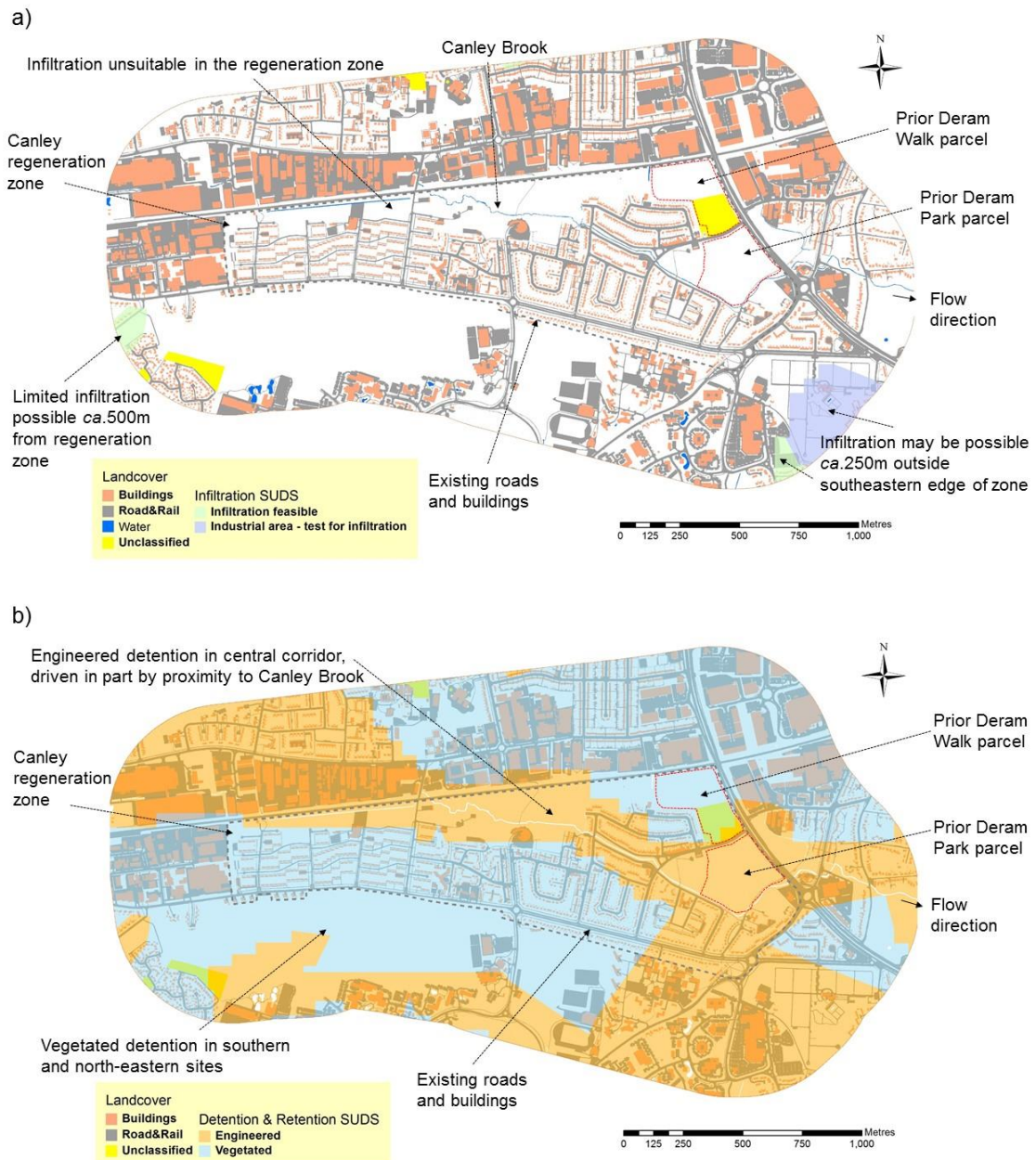


Fig 3 SUDS guidance for Canley Regeneration Zone: a.) Infiltration and b.) detention and retention

Lashford *et al.* 2014 undertook a more detailed desktop assessment, utilising detention ponds for storage, swales for conveyance, and permeable paving and green roofs as source controls while modelling combinations of techniques to judge the effectiveness of different SUDS management trains. Infiltration was not regarded as a suitable option at this site due to soil type and prior use of part of the site as a landfill as reflected in Fig. 2. The results of the desktop modelling exercise are shown in Fig. 4 and it should be emphasised here that this is just one possible suggestion; it has been designed primarily to address the runoff rates stipulated in the draft SUDS Guidelines (Defra, 2011).





Fig 4 SUDS management train designed for Prior Deram Park, CRZ, Coventry.

A combination of swales and pipes was used to convey water round the site, with tanked porous paving and a green roof to every house. Pipes were only used when either space was unavailable for a swale or water need to travel below either a road or the driveway of a house. Finally five ponds were installed across the site to retain water during a large event; all runoff was conveyed into one of the ponds prior to being released into the nearby Canley Brook at four separate outlet points. The open grassed park contained one of the ponds with a sand filter conveying runoff to the inlet. Its utility as both an amenity area and for water quality improvement and flood risk mitigation demonstrates SUDS' potential for multi-functional use. It would have been preferable to utilise a filter strip here, but it is not possible to model this device in WinDes<sup>®</sup>. A hydrobrake was added at the outlet of each pond to ensure compliance; this would be a weir plate of some kind to slow the water's exit from the pond. Comparing this design against a fully impermeable construction serviced by a piped drainage system, the SUDS management train would be able to successfully deal with a 1 in 100 year (+30% to account for climate change) storm easily, in fact it could cope with up to a 1 in 275 year storm, however, the piped system would result in the equivalent of 40 of the 250 houses being flooded, amounting to 858 m<sup>3</sup> of excess water.

The recommendations of the city-wide feasibility maps were compared with the more detailed assessment shown in Fig. 4, with the results presented in Table 5, which shows broad agreement between the two. The feasibility maps define a menu of possible SUDS choices, and not all feasibility map options can or should be used at an individual site. Detailed designs need to consider how individual SUDS features can best be combined into a management train. Fig. 4, adapted from Lashford et al. 2014, indicates how SUDS can be designed to manage flood risk at the scale of a redevelopment site. While the focus of Fig. 4 is to address flood risk, some of the designed SUDS features also address water quality issues, as well as providing amenity and biodiversity benefits. The feasibility

maps indicated additional options that could have been included in the site design, such as rain gardens and rainwater harvesting for runoff attenuation, but like filter strips, these were not available options in WinDes<sup>®</sup>. Bioretention devices were suggested by the feasibility maps, and could have been included in the more detailed design to manage runoff from the estate roads.

Table 5 Comparison of SUDS feasibility map proposals for CRZ with Fig.4 for PDP.

<b>Device grouping</b>	<b>Detailed assessment for Prior Deram Park (Fig.4)</b>	<b>Broad-scale feasibility map options for CRZ</b>
Options in <b>bold</b> show agreement between the two methods across different scales		Proposals that could be considered for this site.
Source Control	<b>Permeable paving; green roofs; sub-surface storage; trees</b>	Green roof; rainwater harvesting; permeable paving; sub-surface storage; trees; rain garden; disconnected downpipe; soakaway; infiltration trench; bioretention device
Infiltration	none	none
Detention & retention	<b>Detention ponds, Hydrobrake</b>	Engineered: detention basin; retention basin; pond; sub-surface storage; rainwater harvesting; bioretention device; swale
Conveyance	<b>Swales</b>	Swale, rill
Filtration	<b>Sand filter</b>	Sand filter; filter strip; filter trench; bioretention device; detention basin; retention basin; pond; swale; permeable paving

## CONCLUSIONS

This paper has considered the design of sustainable drainage systems at different scales and has illustrated the factors and decision-making required for this process to be successfully carried out. However the use of SUDS in England requires local government to understand these techniques. This study presents a method which can identify feasible locations for SUDS devices at the city scale early in the decision-making process. However, the process to build the maps requires a substantial amount of information and an understanding of its meaning. Whilst it is recognised that the larger-scale maps are suitable for the early stages of discussion, more technical tests and modelling results are required for a detailed planning application, and other design approaches will be more appropriate for these later stages. The maps provide information which is readily understandable and which will support the initial discussions which take place between planning officers and developers. Consequently, they may contribute to the reduction of potential barriers limiting the uptake of more sustainable forms of stormwater management.

A similar positive outcome was seen in the subsequent design of a site-specific SUDS management train for flood resilience, following the draft SUDS Guidelines (Defra 2011). The SUDS design produced a plan that would easily deal with a 1 in 100 year (+30%) storm, compared to a conventional piped-based system which would be unable to cope, producing flooding extending to one fifth of the planned new build housing. SUDS management trains can provide betterment over conventional drainage solutions, but need to be designed so that the component devices link effectively. Whereas



conventional drainage focuses on water quantity, SUDS management trains can be designed to include provision for water quality and amenity and therefore have multiple benefits; such a design at Prior Deram Park included temporary storage for excess surface water which also had a role as a community park. The maps provided guidance at the large scale, but could be subject to issues associated with coarseness of scale. In this study, closer examination at the smaller design scale supported findings from the larger scale maps.

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# **The Potential of Rain Water Harvesting for Increasing Building and Urban Resilience: A Case Study of Coventry University and Coventry City Centre**

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## **ABSTRACT**

The demand of portable water is constantly increasing due to factors such as growing population and changing user behaviour. Global and UK population is projected to increase further in the coming decades, which may lead to increased pressure on the scarce fresh water sources and the infrastructure for managing mains water supply and waste water management. Rain water is freely available resource which can be harvested to reduce the need mains water demand, as well as reduce the pressure on urban drainage infrastructure. Rain Water Harvesting in a wide scale within urban areas have the potential to increase both sustainability and resilience of building and urban environments, by reducing extraction of scarce surface and underground water resources. Higher education sector was responsible for significant carbon emissions and consumption of water resources with high cost and carbon emission. The paper is based on a case study of Coventry University building facilities. The impact of rain water harvesting has been investigated in Coventry University buildings and the potential impact within the surrounding urban environment of Coventry city centre has been discussed. Building inventory survey has been carried out to establish total building footprint for rain water harvesting, the data has been used to calculate total rain water yield from the case study buildings. Results show that Coventry University consumes about 97,000 m<sup>3</sup> of water per year while the calculated rain water that can potential be harvested from the buildings is about 24,000 m<sup>3</sup>, which amounts to about 25% of Coventry University's total annual water consumption.

**KEYWORDS:** Building and Urban Resilience, Higher Education, Rain Water Harvesting, Whole Life Costing

## INTRODUCTION

Global climate change and the rapid increase in atmospheric greenhouse gases are one of the biggest and most complex challenges of our time, with very significant consequence for the future of our planet. The United Kingdom set a legally binding target of at least 80% cut in greenhouse gas emissions by 2050 (Climate Change Act, 2008). The efforts towards carbon reduction and climate change mitigation have significantly focussed on energy consumption and the emissions resulting from it. Higher education sector in the UK is a very high carbon emitter, in 2008-09 the Higher and Further Education sector produces emissions of 2.6 million tonnes of carbon dioxide (CO<sub>2</sub>) equivalent. This high carbon emission from FHE institutions led HEFCE from 2011 to link capital allocations to FHE institutions to carbon reduction. FHE institutions in England are required to develop individual carbon reduction strategies and carbon management plans, these institutions consumed about 24 million m<sup>3</sup> of water per year between 1990 and 2006 which led to the emission of about 10,000 tCO<sub>2</sub> per year. Water consumption in higher education institutions in England and Wales contributed about 1% of emissions from these institutions (HEFCE, 2009). The UK government has motivated its Higher Education Institutions (HEIs) to reduce their carbon emissions in line with the national reduction targets.

HEFCE (2012) estimates that about 5 million metric tonnes of carbon dioxide equivalent (Mt CO<sub>2</sub>e) per year is emitted by water companies as a result of the energy and process emissions for water and wastewater pumping and treatment, and this is estimated to be around one per cent of UK GHG emissions just from 23 companies. As water demand and consumption increases, there will be commensurate increase in carbon emission associated with the processes of water and waste water treatment.

It is predicted that warming of the planet as a result of climate change will alter the hydrological cycle, which will create changes to the amount, timing, form, and intensity of rainfall. These changes are also likely to affect the programs designed to protect the quality of water resources and public health and safety. Some of the manifestations of climate change include the unpredictability of weather events such as rainfall which under certain circumstances can overwhelm the existing infrastructure such as the sewers within urban centres. Rain water harvesting can provide a targeted solution not only to mains water demand but also and most important help in increasing the resilience of urban infrastructure by providing a buffer for the amount of rain water that goes into the sewer during periods of intense rainfall, which can mitigate the risk of flooding by relieving the pressure on the local drainage systems.

## SUSTAINABLE URBAN WATER MANAGEMENT AND RESILIENCE

The United Nations (2011) estimates that the global urban population will increase from the current 51% to 67% by 2050, with this increase in population majority of which is concentrated in urban environments, the demand for scarce water resources is likely to increase with increase in waste water discharge to the urban drainage infrastructure. Novotny and Brown (2007) identified requirements for the urban water systems of cities of the future as new paradigm which should look at water supply issues in holistic manner by given due consideration to

*‘greenhouse gas emissions reduction, and treat storm water and reclaim used water as a resource to be reused rather than wasted, requiring costly disposal that can further damage the environments’.* Rain water harvesting is therefore an important component of Integrated Urban Water Management which is a resource that reduces the amount of main water consumed and all the associated energy consumption and carbon emission associated with it.

The predicted changes in weather conditions under different climate scenario has been developed by the UKCIP which shows that under current trend of emissions climate change scenario, rainfall levels are likely to see significant change by 2080s, with the South East projected to see 50% reductions in summer and 30% increase in winter. The North West England will be likely to experience about 30-40% reduction in summer and increase of about 20-25% in winter. Flooding can be an unpleasant and difficult situation for communities, ICF International (2007) estimates that water companies could potentially have to spend around £1 billion per year to stop sewer flooding getting worse, given increased intensity of rainfall events due to climate change. The resilience of urban drainage infrastructure can be increased either through costly infrastructure expansion or through a decentralised building level approaches geared towards both demand reduction and maximising the use of available natural water resources which in turn reduces the amount of water that the urban drainage infrastructure have to cope with.

Urban centres also have to be designed to consider the sustainable urban drainage system to mitigate flooding and other environmental damage. Rain water harvesting is very important in the approach to Sustainable Urban Drainage System (SUDS) which represents an integrated approach to the design of drainage system to avoid flooding and other environmental damage. Agudelo-Vera et al (2012) found that by harvesting rain water from roofs, potable tap water use can be reduced up to 32% in Amsterdam.

## RAINWATER HARVESTING

In non-domestic buildings a significant proportion of water consumption is for non-portable uses, WC and urinal flushing accounts for up to 63% of water use. Figure 1 shows the distribution of water consumption by uses, these components of water use should utilize non-portable sources such as reclaimed rainwater which provides adequate quality for such uses.

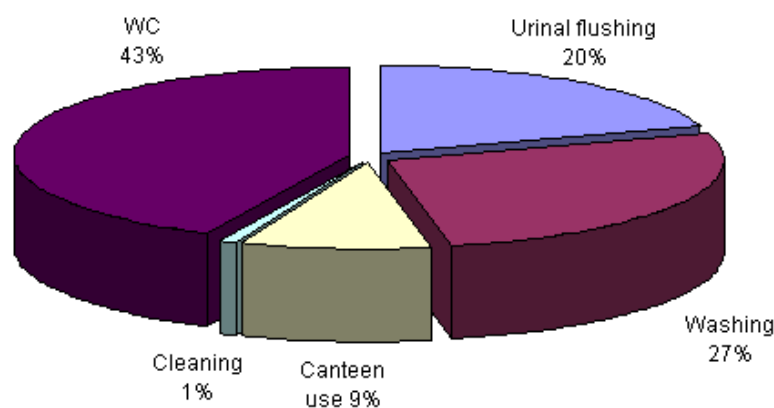


Figure 1: Water use in non-domestic buildings (Roebuck, R. (2008))

Given the distribution of water use in Figure 1 it is proposed that all the buildings in Coventry University incorporate rainwater harvesting system. HVCA (2010) summarises some of the benefits of rainwater harvesting: -

- The rising demand for water results to higher usage and increased population, it is likely that the price of mains water will rise as the demand increases. Rainwater harvesting systems are therefore useful methods to sustain the availability of water supply and reduce future costs.
- It is predicted that our annual rainfalls have increased by 30% therefore a savings can be made from collecting storm water.
- Rainwater harvesting has an environmental impact by diverting potential flood water away from the public storm drain system. The use of a rain water harvesting prevents the need for storm water attenuation to reduce the discharge into the main sewers. Rainwater harvesting helps to attenuate the flow of rainwater to the drains therefore reducing the risk of flooding.
- If the client has a metered water supply, there will be a direct cost saving from water bills.
- There are tax incentives for the use of rainwater harvesting. The Enhanced Capital Allowance (ECA) scheme enables UK businesses to claim a 100% first year capital allowance on investments in rainwater harvesting systems.

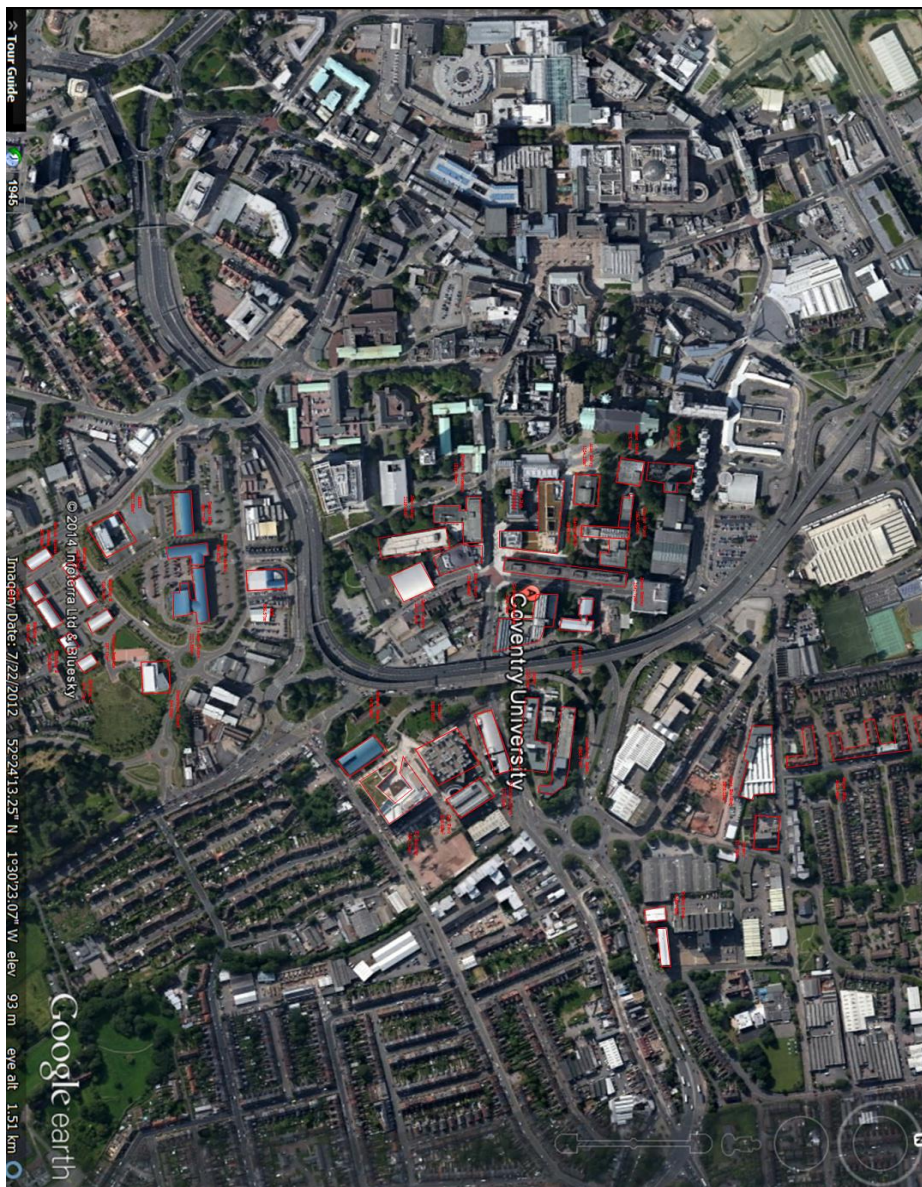
The rain water harvesting system shall be designed to meet the requirements of BS8515 (2009) which is the *Code of Practice for the Installation of Rainwater Harvesting Systems*. Rain water can be collected via various areas ideally first being the roof and secondly being paved areas. Installing a water harvesting system for the proposed new or retrofit developments has both its advantages and disadvantages, these are list below:

BREEAM credits are available for developments willing to install a rainwater and/or Greywater harvesting system. For the credits available and the low capital cost it would be advisable to install a water harvesting system to ensure a high BREEAM environmental rating. Parkes, C et al 2010 shows that a building using a rainwater harvesting system typically increases its carbon emissions compared to a building using only Mains Cold Water Supply (MCWS). Roebuck R., et al (2006) study indicates that maintenance is crucial for the water harvesting efficiency. The study lists that annual maintenance of pumps, cleaning of roof/collection area and gutters etc is vital and cleaning of the tank with 'desludging' is required every three years. Water harvesting systems require electrical energy to run the pumping and control systems. The pump energy will vary depending on the pump size and efficiency. The pump selection procedure will use the following criteria such as Water flow rate (l/s), Height at which the water will need to be lifted, Friction loss of system, Pump efficiency. Parkes C., et al (2010) study indicates that the operating energy is between 0.6 – 5 kWh/m<sup>3</sup>. This figure does not include for a UV disinfectant system, if this is required the operating energy is estimated to increase the upper energy band to 7.1 kWh/m<sup>3</sup>. Rainwater is classified as a Fluid Category 5 under the Water Supply (Water Fittings) Regulations 1999 this means that it is 'potentially dangerous to health if consumed' and must be installed by trained competent personnel. Safety requirements should be taken into consideration to ensure safe use and management of harvested rain water.



## CASE STUDY LOCATION AND BUILDINGS

Coventry University is located within inner ring road in Coventry city. The building and facilities within and around the inner ring road are mainly public buildings owned and managed by Coventry University and Coventry City Council and commercial buildings such as banks and retail outlets. Figure 1 show the footprint of Coventry University in relation to the overall density of buildings within the city center. There are a total of 36 Coventry University owned and operated buildings with a combined total roof area of about 56,000 m<sup>2</sup>. Since a few organisations own significant proportion of buildings within the city center, action or inaction by these organisations will have significant positive and negative impacts on the long term sustainability and resilience of both the organisations and the urban environment. The paper evaluates the potential impact of rain water harvesting in all of Coventry University's Estates and the urban environment within which the university is situated.



**Figure 2: Footprint of Coventry University within Coventry City Centre**

## Coventry Water Consumptions and Costs

In the year 2011 the total water consumption in Coventry University Estates is about 97,371 m<sup>3</sup> per year this total is for both residential and non-residential consumption. The total cost of the above water consumption is around £125,861 per year. While the combined cost of both water and sewerage amounts to about £215,876. There is therefore potential for long term cost saving for both mains water consumption and sewage discharge to the municipal sewers. The water consumption figures including cost and carbon implication of these has been summarised in Table 1.

	2009 -2010	2010-2011
<b>Total Water Consumption (m<sup>3</sup>)</b>	92386	97371.29
<b>Total Cost (£)</b>	118,056.35	125,861.47
<b>Total Carbon emission (MtCO<sub>2</sub>)</b>	37,324	50,848
0.404 MtCO <sub>2</sub> per m <sup>3</sup> (HEFCE, 2009)		

**Table 1: Coventry University Water Consumption and Water Cost and Carbon Emission**

## Coventry University Existing Rain Water Harvesting System

So far Coventry University have rain water harvesting installed in only two building within the whole estate, these buildings are new BREEAM excellent buildings completed in 2011 and 2012, and therefore the installation of these systems is to enable the building to achieve high environmental standards. The total combined storage capacity of the two systems is about 110,000 litres. With the university having a total building footprint of about 56,000 m<sup>2</sup> this is well below the potential harvest that can be achieved. There is adequate level of monitoring of the rain water collection and use, the benefit of these systems can only be understood if there targeted monitoring and evaluation over time. Figure 2 show the rain water tanks and associated pumping and control systems for the two buildings.



**A) The HUB: 50,000 Litres storage**



**B) EC Building: 60,000 Litres Storage**

**Figure 3: Pictures of rain water harvesting systems installed at Coventry University**

## METHODOLOGY

The work has been carried out using analytical method to determine the potential of rain water harvesting systems in the case study urban environment of Coventry city centre. Existing secondary data from Coventry University Estate Department is combined with physical survey and data from Google Street View to establish the total roof area for rain water harvesting from each building within the estate. A building inventory survey has been carried out for all Coventry University owned and operated buildings, the inventory used a selection process that involves all buildings either owned or operated by Coventry University on long tenancy. Some secondary data from the estates records and the data used for preparation of Estate Management Statistics have been used in the desk based study to establish the water consumption and the potential cost and carbon implication associated with mains water consumption. The calculation only considered rainwater collection from roof surfaces, even though paved areas around the university can also provide rain water collection.

### Rain Water Calculations

The design of a rain water harvesting system for Coventry university buildings has been carried out to estimate the total volume of rain water that can potentially be captured, the volume of water will then be an indicator of how much mains water use is avoided and how much rain water could be prevented from entering the urban drainage system. The roof areas for potential collection of rainwater is used estimate the total rain water collection using BS8515. With Coventry having an annual rain water intensity of 775mm this figure was used within the calculations. Equation 1 is used to establish the total annual rain water yield for each building.

$$YR = A \times e \times h \times \eta \quad \text{.....Equation 1}$$

The calculation methods used to size the underground tank is based on BS8515: section 4.1.2.1 which suggests an intermediate approach would be acceptable to be used, this uses formulae to calculate a more accurate estimation of storage capacity than the simplified approach. To apply the intermediate approach to sizing the rainwater harvesting system for non-potable use, storage capacity should be calculated from the following equations and should be the lesser of 5% of the annual rainwater yield or 5% of the annual non-potable water demand. 5% of the annual rainwater yield should be calculated using the equation 2:

$$YR = A \times e \times h \times \eta \times 0.05 \quad \text{.....Equation 2}$$

Where:

- YR is the annual rainwater yield (L)
- A is the collecting area (m<sup>2</sup>)
- e is the yield coefficient (%) it is assumed 70% of the water will be collected from the roof area (0.7)
- h is the depth of rainfall (mm) Coventry 775mm Annual rainfall
- η is the hydraulic filter efficiency it is taken that the efficiency is 0.8



## RESULTS AND DISCUSSION

The results of the calculation procedure as shown in Table 2 shows that Coventry University can potentially harvest up to 24,000 m<sup>3</sup> of rain water per year just from roof surfaces alone, the calculations did not consider the potential collection from paved areas around the campus. The figure above represents about 25% of the total annual water consumption in the estate.

**Table 2: Rain water Harvesting annual yield and Tank sizing**

Building	A- collecting area (m <sup>2</sup> )	e - yield coefficient (%)	of rainfall (mm)	hydraulic filter efficiency	YR-annual rainwater yield (L) YR = A × e × h × η	5% of annual yield (L) YR = A × e × h × η × 0.05	Existing systems - Tank size ( Liters)
Priory Hall	931	0.7	775	0.8	404054	20202.7	
Student Union	957	0.7	775	0.8	415338	20766.9	
Alan Berry	1254	0.7	775	0.8	544236	27211.8	
Charles Ward	1663	0.7	775	0.8	721742	36087.1	
George Elliot	1879	0.7	775	0.8	815486	40774.3	
The HUB	4094	0.7	775	0.8	1776796	88839.8	50,000
James Starley	2543	0.7	775	0.8	1103662	55183.1	
Graham Sutherland	2831	0.7	775	0.8	1228654	61432.7	
Maurise Foss	1110	0.7	775	0.8	481740	24087	
Richard Crossman	1816	0.7	775	0.8	788144	39407.2	
John Laing	2139	0.7	775	0.8	928326	46416.3	
Ellen Terry	2140	0.7	775	0.8	928760	46438	
Singer Hall	3452	0.7	775	0.8	1498168	74908.4	
Alma Building	2875	0.7	775	0.8	1247750	62387.5	
Nursery Building	618	0.7	775	0.8	268212	13410.6	
Trinity Point	1285	0.7	775	0.8	557690	27884.5	
Amstrong Sidley	1965	0.7	775	0.8	852810	42640.5	
Jaguar Building	2309	0.7	775	0.8	1002106	50105.3	
William Morris	1378	0.7	775	0.8	598052	29902.6	
University car park	1319	0.7	775	0.8	572446	28622.3	
Library	2953	0.7	775	0.8	1281602	64080.1	
Student Centre	1478	0.7	775	0.8	641452	32072.6	
EC Building	2842	0.7	775	0.8	1233428	61671.4	60,000
ICE Building	857	0.7	775	0.8	371938	18596.9	
Enterprise Centre	855	0.7	775	0.8	371070	18553.5	
Technology Centre	2227	0.7	775	0.8	966518	48325.9	
Design Hub	851	0.7	775	0.8	369334	18466.7	
HDTI	2228	0.7	775	0.8	966952	48347.6	
Futures Institute	397	0.7	775	0.8	172298	8614.9	
Buiding A	465	0.7	775	0.8	201810	10090.5	
Building B	346	0.7	775	0.8	150164	7508.2	
Building C	324	0.7	775	0.8	140616	7030.8	
Building F	337	0.7	775	0.8	146258	7312.9	
Building E	533	0.7	775	0.8	231322	11566.1	
ACUA	313	0.7	775	0.8	135842	6792.1	
Serious Games Institute	562	0.7	775	0.8	243908	12195.4	
Total	56126				24358684		
Rain Water (m3)					24358.684		
equivalent (MtCo2) @ 0.404 MtCO2 per m3					9840.908336		

The total estimated rain water yield will also potentially lead to saving of about 10,000 MtCO<sub>2</sub> per year. Coventry University will therefore make savings on the amount of carbon credit the university have to purchase under the carbon reduction commitment scheme. The total amount of rain water also demonstrates that there will be about 24,000 m<sup>3</sup> of water that will not be discharged into the drainage system during period of rainfall, this will help avoid flooding. The current rain water harvesting storage capacity of 110,000 litres is well below the university's harvesting capacity. The calculation as shown in Table 2 reveals that the university have the potential to install storage capacity of 1.2 million litres. The uptake of rain water harvesting systems by Coventry University could have potential positive influence in uptake by other organisations based in Coventry City Centre such as Coventry City Council and other commercial outlets in the city. In terms of long term benefits the Coventry University could potentially achieve significant savings in cost of mains water supply and this cost will over time payback the cost of any capital investment overtime.

It is estimated that if the university explores its maximum harvesting potential from building roof areas, it could achieve up to 25% savings in water costs which will on average amount to about £31,250 of water bills per year. As water demand increases with increasing population, it is expected that cost of water supply and waste treatment will increase, organisations that are willing to invest in rain water harvesting systems will therefore be more resilient to any potential risk of price inflation in the coming decade or at least the impact of these changes will be minimal. The drainage infrastructure of urban environments are designed to cope with certain volume waste and rain discharge, unless we have clear strategy for integrated approach to urban water drainage management, the projected increase in precipitation and increase in water demand due to projected population increases will lead to need for expansion of this drainage infrastructure to avoid flooding and other potential environmental damages at very high cost, therefore taking resources that could otherwise be used in providing other vital services. Some of the buildings around the university are clustered together providing opportunity for common water storage tank for distribution to surrounding buildings, this may provide potential capital cost savings.

## CONCLUSIONS

The pressure on the use of scarce natural resource and the finite nature of these resources should always be a trigger for optimising consumption and the use of alternative renewable resources. Rain water harvesting have many benefits in large organisations with high density of population which means that all rain water collected will be utilised quickly due to high demand. Even though the embodied energy of rain water harvesting systems may be higher than mains cold water supply, there are many other potential benefits of the systems such as cost reduction and societal benefits such as reducing flooding risk, avoid expensive expansion of drainage infrastructure and the reduction in the extraction and processing of portable cold water which is a finite resource and energy and carbon intensive. There is clear potential for long term utility cost savings of up to 25% for Coventry University and a potential reduction in the cost of purchasing carbon credits as part of the CRC scheme. The university has a corporate social responsibility to reduce the impact of its business and to be a leader within society by providing education through action. While the installed rain water collection capacity of 110,000 litres is well below capacity, the university can develop a clear monitoring and evaluation process for these systems to serve as learning tool for potential future expansion. Monitoring and data

logging equipment will be installed in the coming months to help evaluate the performance of the existing system. Frequency and cost of maintenance activities will also be monitored for detailed whole life cost evaluation of the two systems.

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## UNDERSTANDING THE IMPACTS OF DROUGHT RESTRICTIONS

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### ABSTRACT

Increasing pressure on water resources are requiring more effective interventions to manage periods of drought. The 2012 drought provided the first opportunity for water companies to implement a wider range of Temporary Use Bans (TUBs) as introduced by The Water Use (Temporary Bans) Order 2010. Seven water companies implemented TUBs affecting around 20 million customers. To date, there has been little assessment of the actual impacts on water use behaviour or the effectiveness of water company communications during the drought. UKWIR commissioned an investigation of the impacts of these restrictions. A bottom-up assessment was undertaken assessing messaging, surveying domestic and non-domestic customers, and analysing metering data. The outputs will inform drought planning, water resources planning and applications of restrictions in future drought events and will help to provide a better understanding of the direct and indirect impacts on non-domestic users. This will help support customer relationships and the existing service incentive mechanism.

**Keywords:** Ban, Drought, Messaging, Scarcity, TUB

Short duration droughts (12-18 months) similar to the major drought of 1976 are predicted to become more common. The 2011-12 drought provided the first opportunity for water companies to implement a wider range of water restrictions or Temporary Use Bans in England. Seven water companies implemented Temporary Use Bans (TUBs) affecting around 20 million customers. UKWIR commissioned an investigation of the impacts of these restrictions. The objectives were to:

- Obtain implementation data from water companies for the TUBs applied in 2012
- Analyse the impacts of the restrictions and summarise the data by customer category, in particular reviewing which type of messaging was more effective at engaging customers
- Develop, and implement a methodology for assessing how to calculate usage impacts by use category, giving consideration as to which types of user were directly impacted by the TUBs implementation
- Recommend how water companies may collect and share data in the future
- To include recommendations on how to assess 'bounce back' following removal of the TUBs restrictions
- Make recommendations how potential future misunderstandings with customers (particularly non-household) can be avoided through the use of this project.

Using three water companies as a proxy (Anglian Water, South East Water and Thames Water), domestic and non-domestic metering data, along with messaging and communications activities, were obtained on the 2012 drought.

A bottom-up approach was undertaken using a detailed stakeholder survey and an analysis of metering data. The approach attributes changes in micro-component (or end use) demand volumes to specific restriction rules and was chosen to reflect the different impacts across the customer groups (domestic and non-domestic) and across the TUB types. Telephone interviews were completed with 300 non-domestic customers and 1,000 domestic customers. Additionally, a quantification of the survey data was undertaken based on micro-component outputs from draft water company Water Resources Management Plans.

Total domestic consumption was analysed using metering data for Thames Water and South East Water. An analysis of high flow events ( $>480$  l/hr) was also undertaken for two time periods which enabled identification of potential hosepipe / external water use events.

### **Key results of the qualitative analysis (customer survey)**

Most of the domestic and non-domestic customers surveyed, recognised the need to conserve water and that the UK is affected by droughts. Awareness was highest amongst those in the South East Water region with the media being stated as the key source of information (particularly television).

The survey highlighted confusion as to what activities were restricted under the TUBs (also referred to as “hosepipe bans”) although it also appeared to show that those who had accessed information from their water company altered their behaviour to a greater extent. Most reported little change in their water use between 2012 and 2013 and relatively little impact on the use of related non-domestic services (e.g. window cleaning, valeting, and gardening). The average number of watering occasions was generally less in 2012 than 2013 for domestic outdoor activities, with any increases being attributed to changes in personal circumstances. Some increases in use were reported in 2012 compared to 2013 were cited amongst the non-domestic sectors, particularly the construction industry.

### **Key results of the quantitative analysis (metering data)**

The overall picture of the separate bottom-up assessments (survey, metering analysis, survey quantification) was that a reduction in TUB affected activities did occur during the restricted period, compared with 2011 and 2013. A reduction in the count of high evening flow activities (sprinkler use) was noted in Thames Water and Anglian Water regions. The London and Thames Valley region showed a 30-36% reduction compared with 2012 and 2013. An analysis of South East Water meter data corroborated the survey findings which showed an increase in water use in the construction, retail and sanitary services. From the volumetric quantification analysis (of the survey data) an average decrease of around 18% was observed.

Extremely high rainfall in April to June 2012 resulted in the early lifting of the TUB restrictions (in June and July 2012) and constrained the analysis of the impacts of the TUBs.

## **ANSWER (AGRICULTURAL NEED FOR SUSTAINABLE WILLOW EFFLUENT RECYCLING): AN EU FUNDED PROJECT TO ENCOURAGE THE USE OF SRC WILLOW FOR BIOREMEDIATION.**

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### **ADUVTCEV**

The ANSWER (Agricultural Need for Sustainable Willow Effluent Recycling) project has seven partners including water utilities, local government councils, higher education colleges and science organisations from both sides of the Irish border. The total value of the project is around £2m. Ireland has numerous small rural Waste Water Treatment Works (WWTWs) which are costly to upgrade and discharging borderline or non-EU compliant discharges. This project has enabled ‘proof of concept’ schemes to be established using Short Rotation Coppice Willow (SRC willow) to treat primary and secondary sewage WWTW effluents, commencing summer 2014. The process to get to this point has been complex in terms of identification of suitable WWTWs and negotiations with land-lords/land-owners, regulators and the community. The accumulation of scientific data is essential in order to give the environmental regulators the confidence to proceed with a technology with which they had little or no experience. In three of the schemes, SRC Willow had to be established and in the fourth case an already mature SRC Willow plantation was used. Zoned area irrigation systems were then designed, built and commissioned for irrigation rates of approximately 1 mm day<sup>-1</sup>, (10 m<sup>3</sup> ha<sup>-1</sup> day<sup>-1</sup>, up to approx 3,500 m<sup>3</sup> ha<sup>-1</sup> yr<sup>-1</sup>). A system of environmental controls, water monitoring and data acquisition software was also incorporated to ensure appropriate weather related irrigation and ongoing monitoring of system loading.

**Key words:** Bioremediation, SRC willow, Regulations

### **INTRODUCTION**

The treatment of wastewater in conventional Wastewater Treatment Works (WWTWs) is highly effective and in modern works will produce an effluent which is non-polluting when discharged into waterways. However, WWTWs are expensive to build and run. They require major electrical power inputs to run pumps, aerators and other equipment - water utilities are, in many countries, the single greatest users of electricity. For example, in the UK the water utilities account for 3% of the total UK electricity demand (ANON 2009). In addition to financial costs, most of this energy

comes from fossil fuel sources and hence water treatment is therefore contributing large quantities of damaging greenhouse gas emissions to the atmosphere (ANON 2008). Large WWTWs are required to treat the municipal effluent from large towns and cities. There are however hundreds of small treatment works dealing with effluent, often from only a few homes and people living in small rural settlements. It is therefore essential to develop cost-effective, environmentally sound, sustainable and low carbon approaches to wastewater management appropriate to rural communities (ANON 2014). The use of fast growing woody plants for the bioremediation/phytoremediation of wastewater is a potentially useful approach to this problem.

### **Bioremediation / Phytoremediation**

Fast growing plants will utilise available nutrients in the soil. Willow (*Salix spp.*) genotypes bred for high biomass production are particularly productive, consistently yielding in excess of 10 dry t ha<sup>-1</sup> yr<sup>-1</sup> in most sites. Willow is a temperate plant well suited to a maritime climate and to wet soils. It has a long growing season, is easily coppiced (i.e. can be cut back regularly to ground level), is tolerant to many soil contaminants and is currently grown commercially for biomass as a fuel for wood-fired boilers producing renewable heat. The fact that willow has a higher water demand than almost any other agricultural crop means that significant volumes of effluent can be applied. The type of willow used in coppice plantations generally has a fine shallow root system with 85% situated in the top 20 cm of the soil profile. This not only improves stability but also provides an excellent receptive surface for the application of effluents and other wastewater streams.

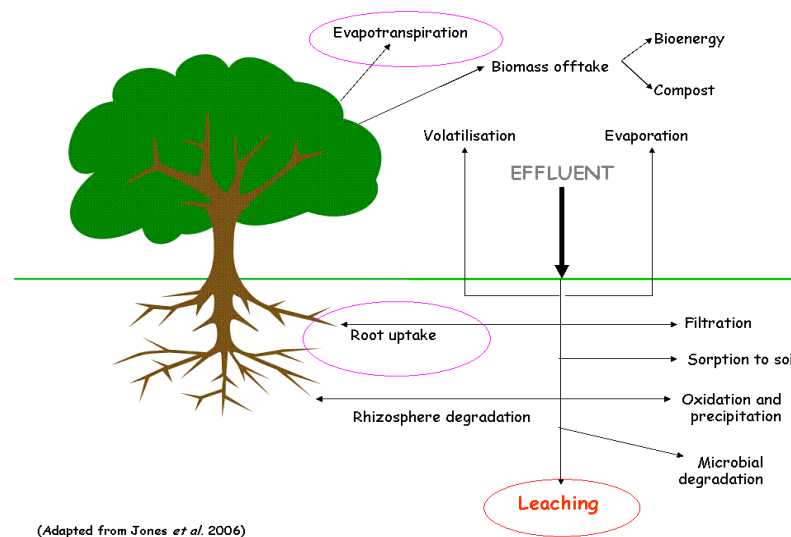
Bioremediation is the use of living organisms to break down or remove toxins and other harmful substances from soil and water. When plants are used, 'phytoremediation' is the preferred terminology. Many plants when they are growing actively take up large volumes of water from the soil. This is driven by 'evapotranspiration'. Evapotranspiration refers to loss of water from the soil both by evaporation and by transpiration from growing plants. Plants utilise water from the soil, which is then lost to the atmosphere through the stomata in the leaves. If the water that is taken up by the plants is high in plant nutrients such as nitrogen (N) and phosphorus (P) then there will often be increased plant growth. In the rhizosphere (the plant root/soil interface) the plants act as a biofiltration systems which enables soil bacteria and other soil mechanisms to breakdown nutrients and contaminants before they can reach the groundwater. These processes are illustrated in Fig. 1.

### **PROOF OF CONCEPT BIOREMEDIATION SITES**

One of the primary objectives of the ANSWER project was to establish at least three commercial scale 'proof-of-concept' sites which would be irrigated with effluent from non-compliant WWTWs. Three of the project partners have built effluent irrigation schemes on which irrigation started in spring 2014.

#### **Bridgend, County Donegal**

The WWTWs at Bridgend, Co. Donegal (Irish Grid: C397 244) serves approximately 500 population equivalent (PEs) which produces an effluent inflow volume of averaging approximately 80 m<sup>3</sup> day<sup>-1</sup>.



**Figure 1.** Principle of SRC willow biofiltration (Jones et al. 2006)

### Adaptations at treatment works

Originally, this WWTW was constructed to a design capacity of 250 PE where the inflow was subject to aeration followed by settlement and subsequently discharged to a small stream. As the ANSWER project developed, in line with requirement of the Environmental Protection Agency (EPA), a 400 m<sup>3</sup> storage tank was constructed to hold effluent during periods when irrigation to the SRC Willow cannot occur. Currently, the effluent following aeration and settlement enters a sump where it is regularly pumped to the main storage tank. SRC Willow irrigation occurs from this tank. In circumstances where irrigation cannot occur (e.g. climatic or equipment failure), the storage tank will fill to 95% at which point the sump uplift pumps will stop allowing treated effluent to overflow from the low level sump and discharge into the stream.

### Willow planting

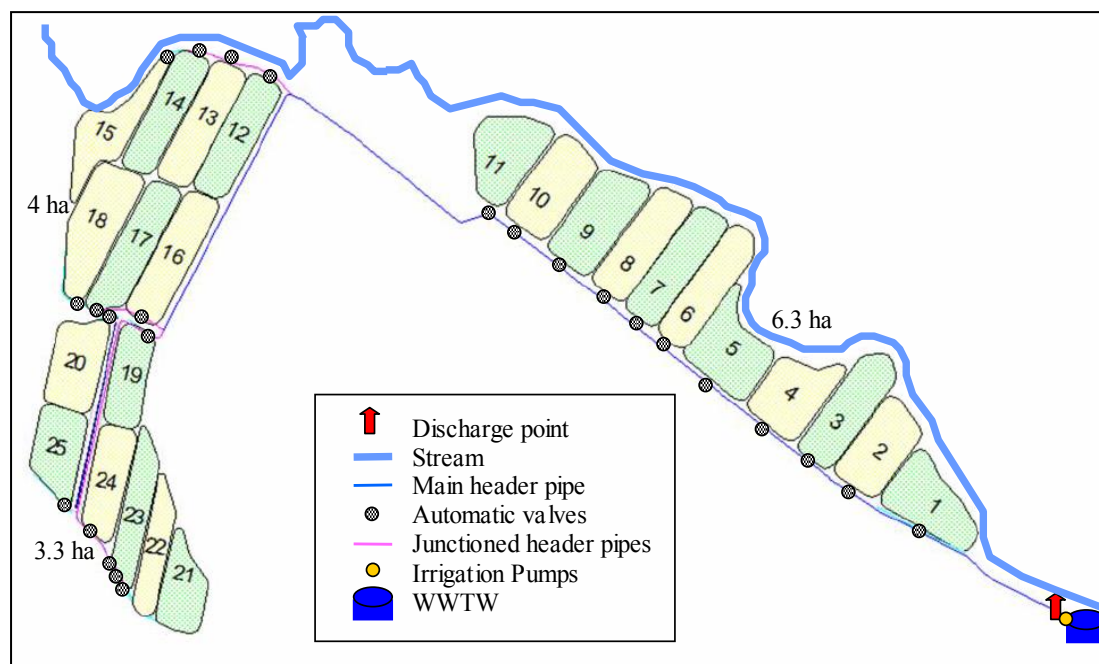
Donegal County Council obtained a long term lease of around 15 ha of land adjacent to the treatment works. This was in three blocks of 10, 3 and 2 ha. In spring 2013 the ground was prepared according to the SRC Willow Best Practice Guidelines (Caslin et al. 2011). Willows were planted using a step planter with 1.50 m between double rows in genotype mixtures at 15,000 cuttings per hectare. The plantation was assessed in winter 2013/14 and in response to good establishment but relatively heavy weed infestation, the plants were cut back in the spring 2014 to allow the plants to coppice. The area was then treated with herbicide which ensured vigorous willow growth and the development of strong root systems. Regrowth in Spring of 2014 produced a healthy and even crop.

### Irrigation system

Irrigation pipes were laid during winter and spring 2013/14 in every fourth double row of SRC Willow with emitter orifices every 10 m. The irrigation system consists of a storage facility, pump, valves, filter, flow meters, main header pipes and irrigation pipe work. The main 90 mm header line stretches the entire length of the plantation approximately 1400 m, into which 25 independently controlled solenoid valves were



incorporated [Fig.2]. Each valve, controlled by the central computer system, enables individual zones to be independently irrigated according to a pre-programmed irrigation protocol.



**Figure 2.** The 14 ha field layout indicating the main pipeline, 25 zones and valves.

The irrigation protocol can be edited simply to enable the most suitable irrigation regime for the plantation (reference crop establishment, climate, season, ground conditions, hydrogeology and other aspects). The following information is measured and data uploaded (SCADA): Incoming and irrigated flow totals and rates, section irrigation totals, rainfall totals and irrigation pump activity times. The following information is also measured and recorded and used to control whether the irrigation system runs or not: irrigation section accumulators, flow rate, flow pressure, clock timing, storage tank level, rainfall intensity and amount and soil temperature. These values can be used to trigger a sms or email alarm to notify of a possible issue for attention.

### **Irrigation protocol:**

Each zone is irrigated for a preset length of time which is a function of its distance from the irrigation pump (flow rate), soil conditions and associated hydrogeology. The current protocol allows for the irrigation of up to  $9 \text{ m}^3 \text{ ha}^{-1} \text{ day}^{-1}$  which is split into a number of smaller irrigation subsets. This results in a total daily irrigation volume of up to  $130 \text{ m}^3$  or less to match the normal WWTW inflow rate and equates to an effluent application of up to 0.9 mm over the full 14 ha site. The irrigation cycle is flexible however is currently set to run 3 times during the day. Each cycle irrigates on average  $43 \text{ m}^3$ . In accordance with the Nitrates Directive, it is recognised that the application of effluent to the SRC Willow plantation will be performed in a uniform manner and is not permitted when the soil is waterlogged, likely to flood, has been frozen for 12 hours or longer, is snow-covered or when heavy rain is forecast within 48 hours.

### Regulations:

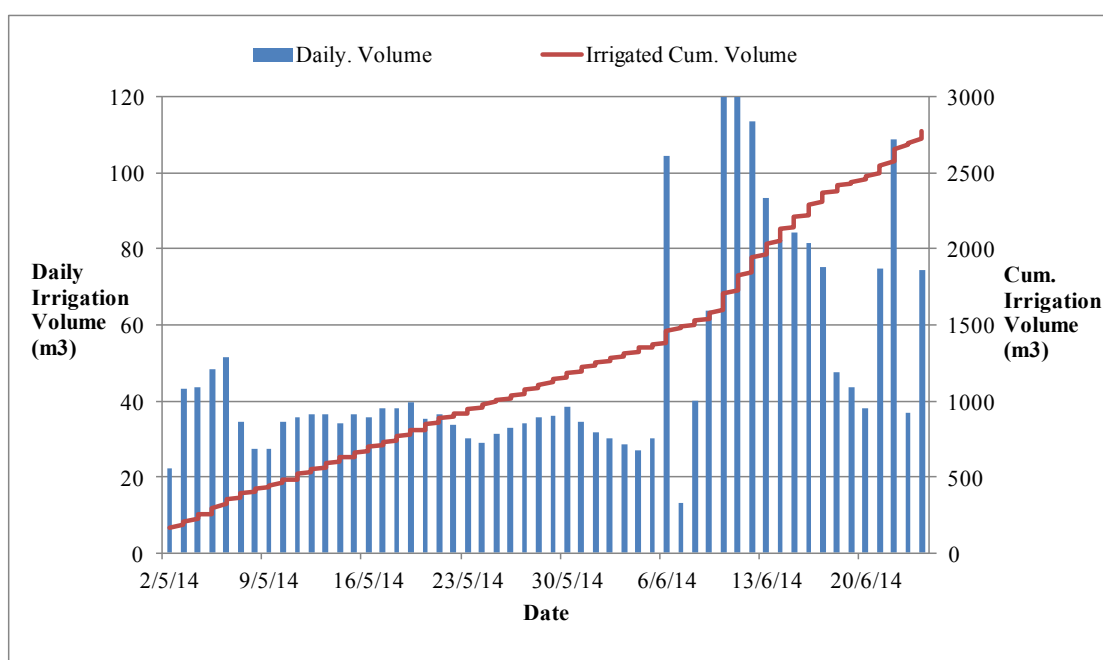
Throughout the project planning process the Local Authority Environment Section investigated the proposal thoroughly in order to ensure compliance with regulation and good practice. Local community groups were consulted and their concerns addressed. Potential risks (the consideration of sensitivity of location with regard to site suitability, groundwater vulnerability, sensitive buildings and proximity to populations and protected areas including water supply sources) associated with the irrigation of treated waste waters to a SRC Willow plantation were considered in the context of the following pieces of legislation:

- S.I 31/2014 - European Union (Good Agricultural Practice for the Protection of Waters) Regulations 2014, and
- SI 272/2009 - European Communities Environmental Objectives (Surface Waters) Regulations 2009 (as amended), and
- SI 9/2010 - European Communities Environmental Objectives (Groundwater) Regulations 2010 (as amended).
- Article 8(1) of the Planning and Development Regulations, 2001 (S.I. No. 600 of 2001).

There are other significant areas of legislation such as the Ground Water Regulations, the Urban Wastewater Treatment Regulations, Environment impact - uncultivated semi-natural areas regulations, Shellfish and bathing waters Directives which are involved but relate more directly to specific situations.

### Results

The irrigation system was commissioned at the beginning of May 2014 and the irrigated total to 24<sup>th</sup> June was 2,670 m<sup>3</sup> (over a period of 54 days). The irrigation regime shows the beginning commissioning period at approx 30 m<sup>3</sup> day<sup>-1</sup>, the readjusting between 6<sup>th</sup> to 8<sup>th</sup> June and the subsequent equalisation of the irrigation rate to manage the inflow to the WWTW [Fig 3].



**Figure 3.** Daily and cumulative irrigation pattern

## **Clontibret and Knockatallon, Co. Monaghan**

The WWTWs at Clontibret (Irish Grid: H752 289) serves a PE of 200 and the works at Knockatallon (Irish Grid: H558 391) serves a PE of 105.

### **Adaptations at treatment works:**

In line with requirement of the Environmental Protection Agency (EPA) 205 m<sup>3</sup> storage tanks were constructed at both the Clontibret and Knockatallon sites in order to act as the accumulation tank for SRC Willow irrigation and as the buffer to store effluent during periods when irrigation to the SRC Willow cannot occur. Currently, in both sites, the effluent enters the works through a screen, receives aeration and subsequent settlement. The settled effluent then enters an uplift pump sump where duty and standby pumps pump the effluent to the buffer/storage tank. The effluent is irrigated from this tank. There is approximately 7 days storage at Clontibret (30 m<sup>3</sup> day<sup>-1</sup> average Inflow) and 10 days storage at Knockatallon (20 m<sup>3</sup> day<sup>-1</sup> average Inflow). However, if climatic circumstances exist to restrict SRC Willow irrigation, the effluent will reach the tank overflow point where it resumes discharge to the stream (as it did before the adaptations were made to the works).

### **Willow planting:**

Monaghan County Council obtained long term leases of around 5 ha and 7 ha of land as adjacent to the treatment works as possible at both Knockatallon and Clontibret respectively. The willows were established as outlined in (2.1.2).

### **Irrigation systems:**

Irrigation pipes were laid as outlined in (2.1.3). The main 90 mm header lines stretched the entire length of the plantations into which 11 and 14 independently controlled solenoid valves are incorporated at Knockatallon and Clontibret respectively. Each valve, controlled by the central computer system, enables zones to be independently irrigated according to a pre-programmed irrigation protocol.

### **Irrigation protocol**

As in (2.1.4), each zone is irrigated for a preset length of time. The current protocol allows for the irrigation of approximately 20 m<sup>3</sup> day<sup>-1</sup> and 30 m<sup>3</sup> day<sup>-1</sup> at the Knockatallon and Clontibret sites respectively. This results in an average irrigation rate of approximately 4 m<sup>3</sup> ha<sup>-1</sup> day<sup>-1</sup>. The irrigation cycle is flexible however is currently set to run 2 times during the day. Each cycle irrigating 2 m<sup>3</sup> ha<sup>-1</sup>.

## **Results**

The irrigation system was commissioned mid May 2014 and the irrigated total at Clontibret to 14<sup>th</sup> June was 1333 m<sup>3</sup> (over a period of 42 days). This is an average application of 32 m<sup>3</sup> day<sup>-1</sup> which has been the average daily inflow into the treatment works. There has been zero discharge to the stream during this period.

## **Dromore, Co. Tyrone**

The WWTWs at Dromore, Co. Tyrone (Irish Grid: H340 671) serves approximately 2,500 PE. Dromore is situated in Northern Ireland, UK and is managed by NI Water as the primary water utility. There were some differences from Donegal and Monaghan (Republic of Ireland) in the ways in which this particular scheme was

procured and regulated reflecting some differences between the two EU member states. This SRC Willow treatment module is not essential to the regulatory compliance of the Dromore WWTW however it does provide a very beneficial commercial scale proof of concept scheme for the application of this technology. It is estimated that the SRC Willow module will be capable of taking approx. 15% to 20% of the full yearly load (full load estimated 220,000 m<sup>3</sup> year<sup>-1</sup>). In order to make the smartest use of this facility however, NI Water will be investigating the efficacy of pumping the effluent to the SRC Willow during different scenarios as follows:

- During the WWTW peak loading times (morning and evening), to reduce the flow through the treatment works.
- When the flow in the river is lower - to reduce the impact of discharge on river water quality.
- When there are elevated nutrient levels in the discharge - to reduce the impact of discharge on river water quality.
- Ultimately, at a future date, to investigate the effect that the extraction of primary effluent (reducing the flow through the works) has on the overall running of the WWTW, the discharge quality and overall energy usage and carbon emissions.

### **Adaptations at the treatment works**

The effluent is presently treated to secondary treatment level at which point it is discharged into the Owenreagh river. The only adaptation at the treatment works required was a pump system for extraction of secondary effluent for irrigation to the SRC Willow plantation. This pumping station is flexible for future trials on the extraction of primary effluent.

### **Willow planting**

In contrast with the three schemes in the ROI the SRC Willow used for irrigation were already well established. There were 15 ha of SRC Willow planted in 2007 and which had been harvested twice on a three-year rotation. This approach has many advantages in particular that the root systems of the plants were well developed and there was complete site capture by the SRC Willow.

### **Irrigation system**

Irrigation pipes were laid as outlined in (2.1.3) during the Summer of 2014. The main 90 mm header line stretches the entire length of the plantation into which 28 independently controlled solenoid valves were incorporated. Each valve, controlled by the central computer system, enables zones to be independently irrigated according to a pre-programmed irrigation protocol.

### **Irrigation protocol**

As in (2.1.4), each zone is irrigated for a preset length of time allowing a subset of the total zone application quantity to be irrigated before automatically moving on to the next zone. An estimated 10 m<sup>3</sup> ha<sup>-1</sup> day<sup>-1</sup> irrigated in 2 m<sup>3</sup> subsets is the commissioning starting point for this project.

### **Regulations**

The irrigation of Waste water from the Dromore WWTW to this particular SRC Willow plantation is licensed and consented to discharge under the “Water (Northern Ireland) Order 1999”, as amended by the “Water and Sewerage Services (Northern Ireland) Order 2006” by the Department of the Environment. The Dromore treatment

works is compliant with its licence and in the event that effluent cannot be applied to the SRC Willow due to climate, regulation, technical breakdown etc, the effluent can continue to be discharged to the river.

## NUTRIENT LOADING

The quality of the discharge from the treatment works (Table 1) is from the most recent data available from Donegal and Monaghan Local Authorities and NIWater. The proposed hydraulic and nutrient loadings are calculated (Table 2) and are within recommendations for the application of both nitrogen and phosphorus within the nutrient guidance for SRC Willow as advised by Teagasc (Caslin et al. 2010). The current nutrient guidance considered appropriate by the Northern Ireland Environment Agency (NIEA), interpreting the guidance given in RB209 (ANON 2010) and the data available on crop nutrient off-takes, allows for the application of 180 kg N ha<sup>-1</sup> year<sup>-1</sup> and 24 kg P ha<sup>-1</sup> year<sup>-1</sup>.

**Table 1.** Effluent Discharge Quality

Determinand	Bridgend WWTW <sup>a</sup> (mg/l)	Dromore WWTW <sup>b</sup> (mg/l)
NH3	10.6	1.1
Nitrate-N	0.0	n/a
Nitrite-N	0.0	n/a
Total - N	31.6	11.3
Total - P	1.5	1.55
ss	50.0	17
BOD	22.4	10
COD	93.0	n/a
pH	7.3	7.5

<sup>a</sup> Estimated quality for Knockatallon and Clontibbret as similar as no qualitative data exists

<sup>b</sup> Data averaged from 2011 and 2012

**Table 2.** Estimated nutrient and hydraulic loading as spread throughout the year.

WWTW Site	Willow irrigated (ha)	Hydraulic Loading (m <sup>3</sup> ha <sup>-1</sup> )	Suspended Solids (kg ha <sup>-1</sup> year <sup>-1</sup> )	Nitrogen (kg ha <sup>-1</sup> year <sup>-1</sup> )	Phosphorus (kg ha <sup>-1</sup> year <sup>-1</sup> )
Bridgend	Total Load	31025	1551	980	46
	per ha load	14	2216	111	70
Clontibbret	Total Load	10950	548	346	16
	per ha load	7	1564	78	49
Knockatallon	Total Load	7300	365	231	11
	per ha load	5	1460	73	46
Dromore	Total Load	37000	629	418	57
	per ha load	15	2467	42	28

## MONITORING

Monitoring programmes are in place to ensure that the volume of effluent being applied does not cause any uncontained pollution or indeed soil nutrient build up. The

stream water and groundwater monitoring points (bore holes) are tested bi-monthly to ascertain the levels of BOD, suspended solids, Total Nitrogen, Total Phosphorous, pH and Dissolved Oxygen.

## CONCLUSIONS

Bio(phyto)remediation of effluents offers a cost effective, environmentally safe, low carbon and sustainable approach to the management of wastewater (Biopros 2008), however the system must be well designed ensuring environmentally safe and reliable operation and the protection of the system's individual components over the long term (Riddell-Black et al. 2008). It has particular application to small scale rural treatment works handling the effluent loading from a small (< 500PEs) settlements. In the majority of these cases it is unlikely that it will be economically viable or practical to upgrade such works to make them compliant. Research in Sweden (Hasselgren 1998, Rosenqvist et al. 1997) and in Northern Ireland (Rosenqvist and Dawson 2005, Werner and McCracken 2008) has shown that SRC Willow is highly effective in dealing with high volume high nutrient effluents. In a number of trials there has been no evidence of leaching of N to groundwater, or issues of P contamination due to overland flow. Some of the nutrients are taken up by the plants and result in nutrient off-take when the SRC Willow is harvested every three years. The willow root systems act as a filter to enable soil microbial processes to metabolise the nutrients, while at the same time enriching the soil. Often, the limiting factor to irrigation is the site relief, hydrogeology and the success of the establishment of the SRC Willow plantation.

It is best if the SRC Willow plantation is adjacent to the WWTWs however if the plantation is within 1 - 2 Km it is still viable as the feeder pipe is normally laid on top of the ground which reduces costs. In all four sites described within the ANSWER project, the pipe from the treatment works to the SRC Willows was above ground. In the Monaghan sites, at Clontibret and Knockatallon, it was necessary to directionally drill the pipes beneath a small country road. This was achieved with minimum disruption and at low cost.

NI Water is Northern Ireland's largest electricity consumer (ANON 2014) and given N.Ireland's high dependence on fossil fuel imports (ANON 2008), can make a significant contribution to green house gas emission by incorporating more sustainable waste water treatment technologies and transforming the WWTW asset base to use less energy and emit less carbon. This can be done while improving compliance. The only power requirements for SRC Willow irrigation of waste water are for running a low specification pump which is required to pump the effluent to the irrigation system and the power to run the small computer control and automatic valve system. NI Water collects and treats 300,000 m<sup>3</sup> of waste water every day which involves the maintenance and operation of over 1,100 WWTWs and around 1,200 pumping stations. If a number of these smaller WWTWs were to be transformed to sustainable low carbon processes such as SRC Willow bioremediation technology, the overall energy savings to the water company could be significant along with an increasing input into this sector's contribution to renewable energy production, agricultural and biomass energy supply chain employment.

## Acknowledgements

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# WATER-ENERGY NEXUS, PROBLEMS AND PROSPECTS FOR THE UK

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## ABSTRACT

Globally, water and energy have been treated autonomously by numerous authors either due to the complex challenges associated with assessing both in concert or given their discrete economic roles. However, contemporary issues of phenomenal climate variability, sustainability, industrialization, population growth and security of supply, present a dire need for an integrated approach to policy formulation and design of water-energy systems in the UK. Water is a key resource in most sources of energy generation including hydro, thermal and nuclear; in turn, great and growing measure of energy is required to operate and maintain water treatment and distribution facilities. This inextricable but intricate link between water and energy clearly presents both problems and prospects for assessment.

From the study, both sectors heavily rely on each other, as the output of one is the input of the other. Albeit, greater concern is raised in the trend of water sector energy use which is consistently increasing subsequent to the implementation of strict regulatory water regimes that have necessitated the use of more advanced but energy-intensive water and wastewater treatment facilities. It is believed that this assessment of water and energy resources in tandem will help improve on the design and operation of water-energy systems, enhance the sustainability credential of the undertakings and create more secure integrated services in UK.

**Keywords:** Water, Energy, Nexus, Problems, Prospects

## INTRODUCTION

Water, energy, waste, transportation, Information and Communication Technology (ICT), etc., all constitute the national infrastructure in UK (Watson and Rai, 2013). These infrastructure sectors contribute in distinct ways to the value chain of each other, giving rise to a complementary relationship which entails a form of support to ailing sectors. It also means that failure of a sector which is heavily relied upon by other sectors will induce a cascade of failures or poor productivity in the dependent sector(s). For instance, electricity failure will critically impact on water processes, while ICT failure will have severe effects on water and power sectors as these greatly rely on ICT (Buldyrev *et al.*, 2010). Accordingly, Watson and Rai (2013) have reasoned that a plan to improve drinking water quality or upgrade a wastewater infrastructure may in turn intensify energy

input or GHG emissions. Thus, the need to explore the water-energy tie is intensified by the heavy reliance of other sectors on both water and energy. Water, next to air as the most fundamental requirement of life, is both a human right and an economic good (UNESCO, 2003), while energy is critical to the provision of water. Whereas, water is important in energy production and energy plays a great role in water management, the interdependence of these two resources is known as “water-energy nexus” (Siddiqi and Anadon, 2011).

Several authors have claimed that relative to the significant research efforts in water and energy in isolation, the water-energy nexus remains under-explored globally (Gleick, 1993; Webber, 2008 and Siddiqi & Anadon, 2011). Only a few peer-reviewed literature highlight energy intensities of water abstraction, purification and distribution in UK, as most researches on the water-energy relationship focus on water use in electricity production (Watson & Rai, 2013). It is therefore the ultimate aim of this study to bridge this gap in knowledge in order to address the imminent challenges of water and energy insecurity in the wake of the ever-increasing demand for these resources. In order to achieve this goal, this paper will develop a comprehensive link between energy and water, so as to clearly understand where barriers exist in the integration strategy and identify best practice approaches that could be applied to optimally harness this relationship in UK. This will involve assessing the economic and empirical dependence of one on the other.

## REVIEW OF PAST LITERATURE

### Overview

In recent times, there have been studies and reports integrating the old isolated issues of energy and water under the spectrum of planning, policy formulations, facility designs and operations. Although, research on the interdependencies of these resources only started proliferating in the past few decades, Gleick (1993) concedes that America long realised the need to assess the problems and prospects of this bond, and proactively structured policies and projects to ensure that potential phenomenal challenges to either of the regimes (water or energy) do not uncontrollably impact on the other.

Various universities have also initiated programs to research into the predominant links between water and energy. Regarded as a crucial and unacknowledged linkage, the Australian National University recently launched a collaborative research programme called the Australia-United States Climate Energy and Water Nexus (AUSCEW), aimed at exploring the water-energy link relative to climate change, and identifying holistic policy recommendations that will help evade adverse impacts of resource insufficiency and favour mutually beneficial solutions (AUSCEW, 2012). More so, in the United States, Harvard University has advanced scientific research on the theme: Energy’s growing need for water; targeted at deducing prevailing constraints to sustainable development which lie in the interconnections of individual sectors (SSP, 2013).

## Availability and Sustainability

In order to undertake processes that heavily rely on water or energy, there is need to establish the sustainability credential of the resource to be used. Numerous events in different parts of the world serve to underscore the energy and water interdependence in terms of resource availability and sustainability. A resource may be available but not sustainable; this automatically means that processes reliant on such resource stand to be unsustainable accordingly. For instance, whereas, coal-to-liquid (CTL) plants are extensively water intensive processes, according to reports, china suspended its plans to construct a CTL given its potential long term effect of drought and negative impacts on the quality and availability of the already over-stressed Chinese water resource (Xinhua News, 2006).

It is pertinent to state that in 2005; about 49% of all water withdrawals or 41% of all freshwater withdrawals were used by the US thermoelectric power plants alone (Kenny *et al.*, 2005). Consequently, Lake Mead which is the largest reservoir in the US is currently reported to be 100 feet lower than its historic levels, with a further reduction of 50 feet predicted to cause the Hoover Dam hydroelectric turbines to produce very little or even no power; thus placing Las Vegas in a state of critical resource reduction and potential need for cross-border trade, if the water continues diminishing (Webber, 2008).

It will also be recalled that in July 2009, France had to import power from UK. This followed the cooling water temperature remarkably exceeding the permitted discharge temperature of 24°C due to the prolonged heat wave of the nuclear plant which eventually led to the shutdown of 20GW of the 63GW nuclear power capacity of France (Pagnamenta, 2009). Yet, earlier in summer 2003, the same effect of intense heat wave compelled French regulators to grant an official approval which allowed nuclear plants to discharge their cooling water at about 40°C (Siddiqi and Anadon, 2011). These coevolving relationships have prompted Governments in Countries like US, China, Canada, Australia and Spain to initiate formal strategies to detail this water-energy nexus. The ultimate goals being to develop integrated policies and more robust technologies that will help secure the availability of these resources in the future.

## Water Use in Energy Sector

The study on Water Use by Gleick (1993) has been one of the pioneer research efforts which provided an insight into the quantities of water used for various power generation processes, while a detailed set of water use benchmarks for comparing performance in thermoelectric power generation was first published by Dziegielewski *et al.* (2006). Accordingly, the DOE (2006) came up with comprehensive estimates of water use by major power generation types which incorporated contemporary technologies and renewable sources of energy.

An in-depth quantitative analysis of water use requires a clear understanding of the distinction between water withdrawn and water consumed. Water withdrawn means abstracting water from the ground or diverting same from a surface source. On the other

hand, water consumed is that “part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock or otherwise removed from the immediate water environment” (Kenny *et al.* 2005, p.47). However, water can still be withdrawn and not necessarily consumed. This is regarded as non-consumptive water. The non-consumptive water is withdrawn and returned to its source or near the withdrawal point, although, most often with its chemical, physical or thermal properties altered (Glassman *et al.*, 2011).

Table 1: Consumptive and non-consumptive uses of water (Hall *et al.* 2012, p.70)

Consumptive uses of water	Non-consumptive uses of water
Agriculture and irrigation	Environmental regulation
Electricity generation (as cooling)	Hydroelectric electricity generation
Industry and manufacturing	Recreation
Public water supply	Transportation

In the field of energy, the research conducted by Schoonbaert (2012) reveals that the quantity of water consumed in power generation is majorly a function of the generation type, fuel type, cooling technology used for the thermoelectric power generation, or the carbon capture and storage facility (CSF) used in the fossil fuel power plants. A summary of water use by various technologies is depicted in Table 2. The table provides an estimate of water consumption rates for different power generation technologies.

Table 2: Water withdrawal and consumption rates for major power generation sources (Macnick *et al.*, 2011)

Fuel Type	Cooling	Technology	Withdrawal (Litre / MWh)			Consumption (Litre / MWh)		
			Median	Min	Max	Median	Min	Max
Nuclear	Tower	Generic	5,005	3,637	11,820	3,055	2,641	3,841
	Once-through	Generic	201,619	113,652	272,765	1,223	455	1,818
	Pond	Generic	32,050	2,273	59,099	2,773	2,546	3,273
Natural Gas	Tower	Combined Cycle	1,150	682	1,287	900	591	1,364
		Steam	5,469	4,319	6,637	3,755	3,010	5,319
		Combined Cycle with CCS	2,255	2,214	2,300	1,718	1,718	1,718
		Once-through	Combined Cycle	51,735	34,096	90,922	455	91
	Once-through	Steam	159,113	45,461	272,765	1,091	432	1,323
	Pond	Combined Cycle	159,113	45,461	272,765	1,091	1,091	1,091
	Dry	Combined Cycle	27,049	27,049	27,049	9	0	18
	Inlet	Steam	9	0	18	1,546	364	2,728
	Coal	Tower	Generic	1,932	455	3,410	3,123	2,182
Subcritical			4,569	2,273	5,455	2,141	1,791	3,019
Supercritical			2,414	2,105	3,082	2,241	2,082	2,700
IGCC			2,769	2,646	3,041	1,691	1,446	1,996

		Subcritical with CCS	1,773	1,628	2,750	4,282	4,282	4,282
		Supercritical with CCS	5,805	5,564	6,042	3,846	3,846	3,846
		IGCC with CCS	5,105	4,992	5,219	2,455	2,373	2,537
	<b>Once-through</b>	Generic	2,664	2,178	3,082	1,137	455	1,441
		Subcritical	165,250	90,922	227,305	514	323	627
		Supercritical	123,144	122,954	123,258	468	291	564
	<b>Pond</b>	Generic	102,696	102,519	102,792	2,478	1,364	3,182
		Subcritical	55,576	1,364	109,106	3,541	3,350	3,655
		Supercritical	81,439	81,189	81,498	191	18	291
<b>Biopower</b>	<b>Tower</b>	Steam	68,400	68,173	68,450	2,514	2,182	4,387
	<b>Once-through</b>	Steam	3,991	2,273	6,637	1,068	1,068	1,068
	<b>Pond</b>	Steam	159,113	90,922	227,305	1,364	1,364	2,182
	<b>Dry</b>	Biogas	-	-	-	159	159	159
<b>Hydropower</b>	<b>N/A</b>	Aggregated in-stream & reservoir	2,046	1,364	2,728	-	-	-

Sampling part of UK, the abstraction rates for various purposes in 2008 alone, are revealed in figure 1. In England and Wales, a high percentage of water licensed for abstraction is actually not abstracted. According to the UK Environment Agency (2011), a total of 34,500 MI/d of water was abstracted out of the 75,000 MI/d of water licensed for abstraction; that is, 46.01% was actually abstracted. Water abstracted for public water supply totalled 46.6% (almost half of the actual water abstracted) although, more than 70% was returned as treated effluent (EA, 2011).

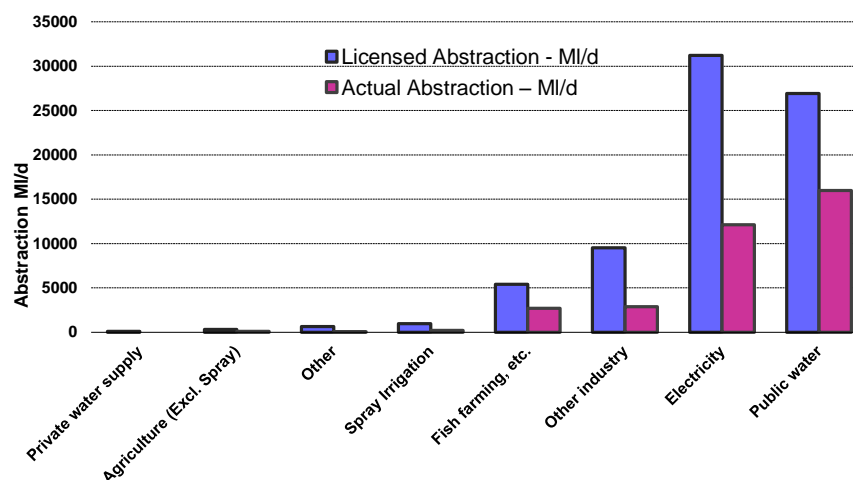


Figure 1: Water abstraction by various sectors (Source: Environmental Agency, 2011)

Being a projected quantity, the licensed abstraction is estimated to take care of contingencies or variations in outcome. Thus, it is considered that water used for electricity generation varies according to annual run-offs and could peak in very wet years like 2012. Although it is noted that water abstracted for electricity was 35.35% in England and Wales, but in Wales alone, over 80% of abstracted water is used for electricity generation, while about 15% is withdrawn for public water supply (EA, 2011).

## Energy Use in Water Sector

Several researchers have variously highlighted the roles of energy in water management. Water abstraction, treatment, desalination and distribution are very energy-intensive processes and these energy implications of water processes are often predicated on the original status (fresh or sea water) and location of the resource.

Concise uses of energy in water processes have been summarised by Watson and Rai (2013) as follows:

- Water abstraction and conveyance: Pumping from source (Ground or Surface) and transfer to reservoir or treatment plant.
- Treatment or purification and distribution of water: Advanced processes such as UV and Ozone applications require greater energy application, while distribution requires lots of energy for pumping.
- Heating, cooling and use of water in facilities for domestic, commercial and industrial purposes; these require varying amounts of energy.
- Wastewater treatments; often requiring highly energy intensive processes to collect, physically segregate, chemically treat, discharge treated effluent and landfill sludge.

## Problems and Prospects of the Energy-Water Nexus in UK

As posited by DETR (1998, p.1), “Pumping costs UK industry over £1,400 million in electricity each year, mostly for pumping water, and estimates suggest that over 20% of this figure could be saved”. Accordingly, in the food manufacturing sector alone, the water expenditure is approximately £300 million annually, while energy is £800 million and estimates indicate that a 20% reduction in water use could save the food industry £60 million a year (FISS, 2007).

Worthy of note is that the water-energy links vary with the availability and nature of the water resource which is often a function of climate variability. With the Atlantic Ocean bordering Scotland, 70% of the surface area and 90% volume of the water in the entire UK is providentially located in Scotland (Scottish Natural Heritage, 2001). This condition underscores the great hydro potentials of Scotland and has led to the formulation of frameworks and design of strategies to harness the water resource, including its tides and waterways. Typical examples are the Scottish Renewables Obligations (SRO) which is Scottish Government’s main means of increasing electricity generation from renewable sources – legislated for in the Renewals Obligation (Scottish) Order 2006 (SI) 2006 No. 1004 (The Scottish Government, 2013); and the recent Scottish Hydro Agenda aimed at harnessing Scotland’s vast water resource, advancing water technologies and delivering economic gains (Scottish Government, 2012). The need to align this water-energy scrutiny becomes even more intensified following the prediction that “by 2030, hydropower will become the world’s dominant renewable energy source, providing more than twice the amount of its nearest rival, on shore wind power” (Waughray 2011, p.10).

From estimates, hydropower evaporates approximately  $17\text{m}^3$  of water per Mega Watt Hours of energy generated (ADB 2013, p.14) and 'UK's energy demand is forecast to increase by 36% between 2011 and 2030 (BP, 2013, p.4)', with 15% projected to be supplied from the renewable sources by 2020 (DECC 2011, p.5). But the UK with  $2650\text{m}^3/\text{year}$  of water per person (Kaczmarck, 1995) is already classified as a country with 'low' water availability (Holt *et al.*, 2000). Where UK is faced with any spike in water-energy demand, the potential aftermaths may include: cross-border trade or trade-offs, or desalination of sea water.

Thermoelectric power plant cooling takes great amount of water. New technologies such as the combined cycle gas turbine power plants are acclaimed low water intake technologies, yet they end up having higher net water consumption. Also Biofuel use has been considered as a strategy to reduce carbon dioxide emissions and oil import; however biofuel is the most water-intensive source of fuel, and its use in large scale means increasing water consumption in energy production (Mielke *et al.*, 2010).

## QUANTIFYING THE UK WATER-ENERGY NEXUS

### Energy use in water processes

A clear summary of energy intensities of water and waste water treatments has been presented Figure 2. Critically analysing the trend, it is established that except in 2002/03 when energy used in treating 1ML of water slightly rose by 18kWh above that used for treating 1ML of sewage, wastewater treatment energy intensities have remained higher over the other years. Water treatment energy intensities have been on the decline from 2003/04 to 2006/07. It took 559 KWh of energy to treat one Mega litre (1ML) of water and 756 kWh of energy to treat 1ML of sewage in the year 2006/07. Relative to the previous year (2005/06), energy used in treating wastewater increased by 122kWh/ML while energy used in treating water reduced by 27kWh/ML following an earlier drop between 2004/05 and 2005/06 by 77kWh/ML. Sludge aeration has been considered the most energy intensive process in wastewater treatment (Caffoor, 2008).

A major reason for the increasing energy usage in wastewater treatment is the implementation of the stringent WFD quality requirements of 'good ecological status for UK waters by 2015. The directive according to Watson and Rai (2013) is predicted to cause further increase in the energy intensities of water and wastewater treatment to almost 100%.

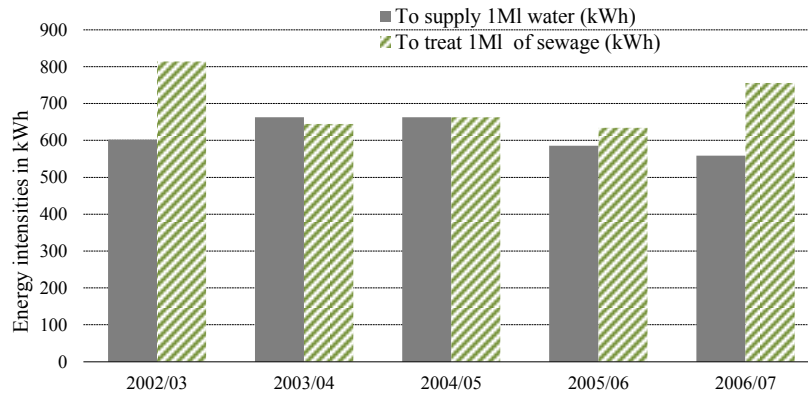


Fig 2: Energy intensities of treating 1ML of Water and Sewage (Data source: Water UK, 2007)

Figure 3 indicates electricity generated in UK from major fuel types. Between 1999 and 2011, natural gas constituted the dominant fuel in relative terms, representing 40.04% of all UK energy generation; while solid fuel produced a total of 35.11% of the UK energy. Although the decline in coal usage between 2006 and 2011 may be due to the high prices of coal especially relative to gas; however, in 2012 solid fuel accounted for the main electricity generation, with an increase by 53.93TWh above that generated from gas.

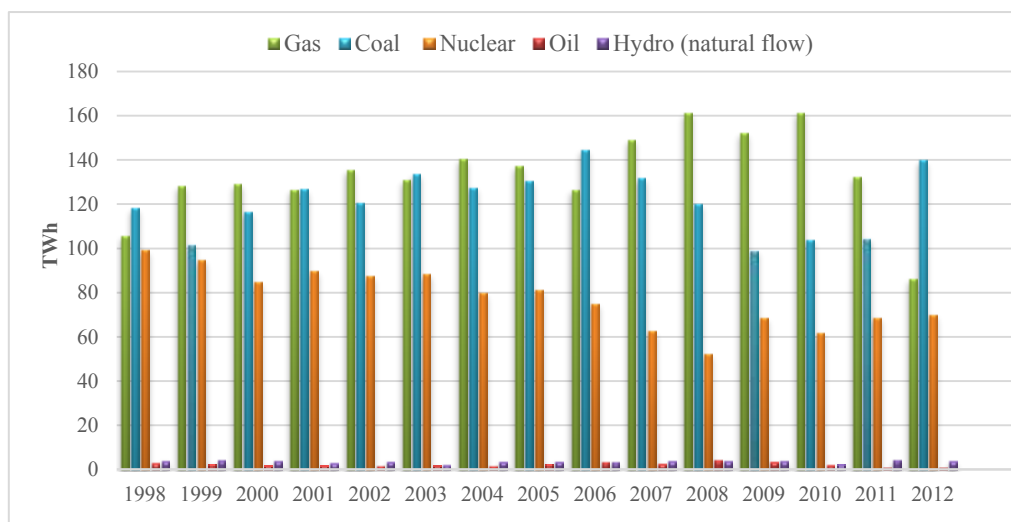


Fig 3: Total electricity generated in UK from major fuel types (Data Source: DECC, 2014)

From this account, it is inferred that the UK fossil capacity is still high, representing 75.92% of the total energy generation, while, electricity from the nuclear source stood at 22.94%. Nuclear energy has remained less than the 99.49TWh generated in 1998, although it increased by 8.27TWh between 2010 and 2012. The hydro energy constitutes only 1.14% of the energy generation, while the share of oil has remained insignificant. In a nutshell, the chart shows that UK energy sector is heavily reliant on the Gas, Coal and Nuclear fuel sources, and explores less of the Oil and Hydro sources of energy.

The sharp increases and declines in UK Hydro energy generation from 1998 to 2012 as shown in figure 4, is majorly attributed to external factors such as annual rainfall averages and seasonal variations like heavy rains in winter. From figure 4, it is deduced that 69.95% increase in electricity generation happened between 2010 and 2011, then a 9.24%



decrease in 2012 and a further decline by about 13.45% (0.54 TWh) in 2013. The high energy generation between 2011 and 2013 follows the heavy rain in UK during these periods especially in 2012.

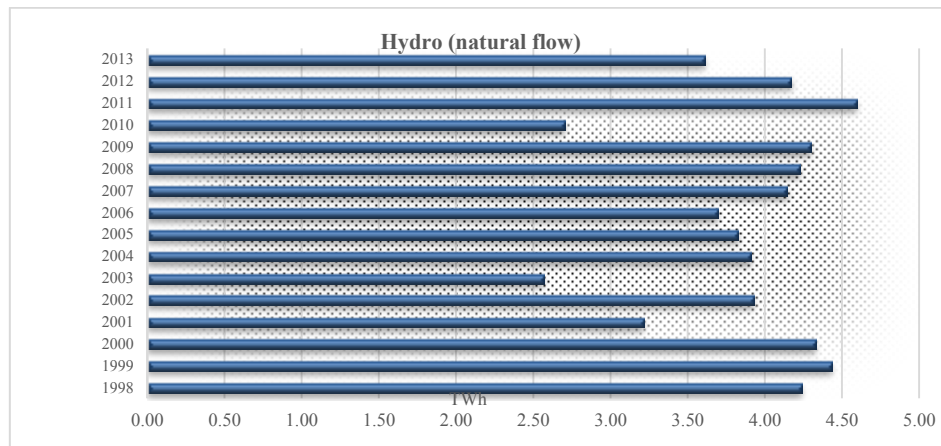


Fig 4: Total hydro electricity generated in uk (1998-2013) (Data Source: DECC, 2014)

Hydropower with a conversion efficiency of above 85% remains a predictable and reliable source of energy in the UK. The hydro resources of the UK can still be further harnessed through extra development of small and micro-scale hydro schemes from municipal to national level.

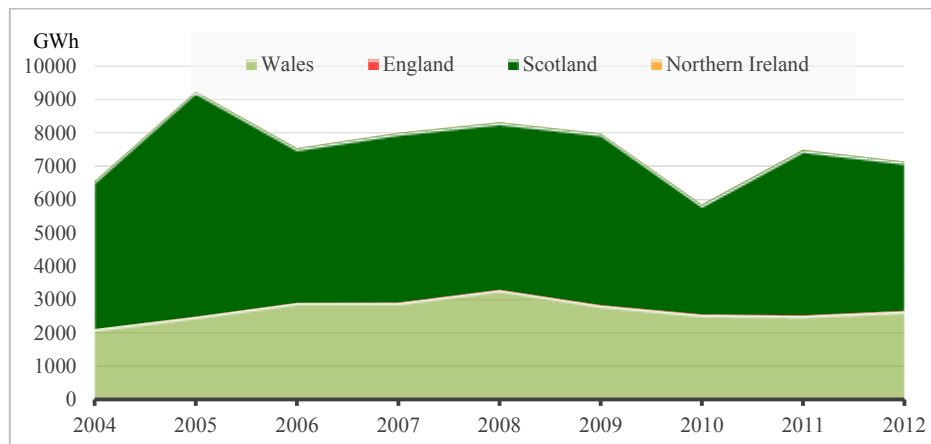


Fig 5: Electricity generation and supply from Hydro flow for Scotland, Wales, Northern Ireland and England, 2004 to 2012 (Data Source: DECC, 2013a)

Figure 5 reveals how UK regions generate their hydroelectricity. It can be seen that the energy generated by Scotland peaked in 2005 totalling 6756GWh then sharply dropped in 2010. This decline is traced to the average rainfall in UK averaging 952mm in 2010 and increasing to 1331mm in 2012 (Met Office, 2014); this condition is actually consistent with the impact of annual run-off on hydro energy generation.

In Wales, there is a relatively consistent trend in the energy generated. The generation gradually kept increasing from 2004 to 2008, after which it started to decline, but has risen again from 2011. The chart therefore shows that Scotland has the highest and growing hydro potential while Northern Ireland has the least contribution to hydro energy

generation. This supports the claim that England and Wales has hydro potentials in the range of 146 to 248 MW (British Hydro Association, 2010) while Scotland's hydro potential is in the region of 2,593 MW (BHA, 2008).

The report by UK Water (2010) reveals that renewable energy generated by water and wastewater companies in the UK totalled 665 GWh in 09/10 relative to the 742 GWh generated in 08/09. This been a downward trend, strongly challenges the goal of generating 15% of UK's energy from renewable sources in 2020. Although, UK has put in place renewable financial incentives through the Renewables Obligation (RO) Scheme which provides renewable electricity generators with financial support more than what they receive from selling same to the wholesale market (The Scottish Government, 2013).

At the moment, UK hydro receives financial support from Government through the RO. It is reckoned that the RO will help reduce the investment cost and boost the overall competitiveness of the hydro technology relative to other established sources of electricity (HM Government, 2009). In total, energy use by the UK water sector increased by 4% between 2008/09 (8160GWh) and 2009/10 (9012GWh) with the trend presenting high possibility of future growth in the energy intensities as revealed in figure 6. This energy use is the energy from electricity and gas for water and wastewater pumping and treatment (operational purposes), and for administrative functions, excluding transport (UK water, 2010).

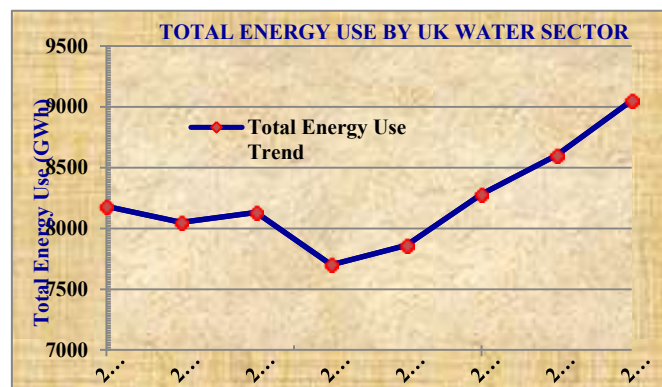


Fig 6: Total energy use by UK water sector (UK Water, 2010)

With the increasing stringent quality standards for water and wastewater processes, energy use in the water sector is predicted to keep increasing. However, with the technological advancement in water and wastewater treatment facilities, the industry is set to identify best strategies to reduce this rising energy and minimise or eliminate such negative impacts as GHGs emission.

### Water Use in Energy Processes

Figure 7 provides estimates of total licensed abstractions in England and Wales. It shows that for electricity supply, after a 2,525 Million cubic meters increase in water abstraction between 2000 and 2001, the abstraction volume had fallen steadily from 29,571 Million

cubic meters in 2001 to 27,471 Million cubic meters in 2006; while from 2007 – 2012, water abstraction volume increased by 7,699 Million cubic meters for electricity supply. Water abstraction for public water supply had been fairly steady with difference between the highest (in 2005) and lowest (in 2009) abstraction totalling 573 Million cubic meters. Water used in fish farming has drop from 1723 Million cubic meters in 2000 to 974 Million cubic meters in 2012, while industrial water use had relatively reduced after it peaked by 2418 Million cubic meters in 2003.



Fig 7: Estimates of total licensed abstractions in England and Wales.

On the average, 76.03% of the total water abstraction was used for electricity supply, 15.51% for public water supply, 5.20% by industry, and 3.15% for fish farming, while ‘other’ water uses constituted 0.11%. Thus, water abstraction by the electricity sector of England and Wales was the largest, and has continued to grow remarkably. Whereas, more rainfall leads to reduction in water abstraction for irrigation and fishing, the mark increase in water use for electricity supply between 2011 and 2012 can be attributed basically to 2012 been the second wettest year in UK since 1910, with rainfall average of 1,330.7mm preceding the 1172.5mm of the previous year – 2011 (Met Office, 2014). Reduction in water use in the industrial sector can be linked with the application of more efficient water and wastewater facilities in recent times.

## SUMMARY AND RECOMMENDATIONS

Results of the water-energy nexus appraisal reveal that energy use in the water sector has intensified by about 10% over the last eight years, with a 4% escalation to 9.012 TWh between 2009 and 2010 (Water UK, 2010). Also, the energy sector’s water demand has continued to increase with the nation’s growing energy needs, and accounts for approximately 32% of total freshwater abstraction in UK (Watson and Rai, 2013). In England and Wales alone, between 2000 and 2012, 76.03% of the total water abstraction was used for electricity supply, 15.51% for public water supply, 5.20% by industry, 3.15% for fish farming, while ‘other water uses’ constituted 0.11%.

Scotland's hydro potential should be further harnessed. Cleaner energy sources should be encouraged and incentivised if UK must meet its 15% energy from renewable sources in 2020. Water harvesting and reuse should be highly promoted both at the local and industrial levels, to minimise overall water demand and volume of sewage treated at the wastewater treatment plants.

Accordingly, whereas thermoelectric and nuclear plants take up as much as 90% of fresh water abstracted for energy purposes, and air cooling is relatively not an efficient cooling strategy, the use of a hybrid system (encompassing water and air) will help reduce the water taken up by the energy sector.

There is need for a standard accounting system by both the energy and water undertakings. This will serve as a gauge for measuring the consumption rates of these resources and identifying possible best practices. A department should be created to oversee the implementation of this water-energy integration strategy; this unit should work closely with Ofwat and Ofgem (the UK water and energy regulators respectively) to identify possible problems and prospects of any planning or provision of either the water or energy resource.

An integrated approach to assessing infrastructure sectors will help eliminate any wasteful or unnecessary duplication of ideas and reduce conflicts of interest which are often associated with isolated strategies.

Lastly, further researches on the design of low-energy facilities for water and wastewater treatments should be encouraged.

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## ENERGY BALANCE OF SRC WILLOW USED FOR MANAGING FARMYARD WASHINGS – HOW DOES IT COMPARE TO A CONVENTIONAL WASTEWATER TREATMENT WORKS?

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### ABSTRACT

The water and wastewater industry in the UK accounts for around 3% of total energy use and just over 1% of total UK greenhouse gas emissions. Targets for greenhouse gas emissions reduction and higher renewable energy penetration, coupled with rising energy costs, growing demand for wastewater services and tightening EU water quality requirements, have led to an increased interest in alternative wastewater treatment methods. The use of short rotation coppice (SRC) willow for the treatment of wastewater effluent is one such alternative, which brings with it the dual benefits of wastewater treatment and production of biomass for energy. In order to assess the effectiveness of SRC willow, it is important to analyse the overall energy balance in terms of energy input versus energy output. This paper carries out an energy life cycle analysis of a specific SRC willow plantation in Northern Ireland to which farmyard washings (dirty water) are applied. The system boundaries include the establishment, maintenance, and harvesting of the plantation, along with the transport and drying of the wood for biomass combustion. The analysis shows that the overall energy balance is positive, and that the direct and indirect energy demands are 12% and 8% of gross energy production respectively. The energy demands of the plantation are compared with the energy required to treat an equivalent nutrient load in a conventional wastewater treatment plant. While a conventional plant consumes 2.6 MJ/m<sup>3</sup>, the irrigation system consumes 1.6 MJ/m<sup>3</sup> and the net energy production of the scenario is 48 MJ/m<sup>3</sup>.

**Keywords:** Energy balance, Farmyard washings, Life cycle analysis (LCA), SRC willow, Wastewater treatment

### INTRODUCTION

The water and wastewater industry accounts for around 3% of total energy use and just over 1% of total greenhouse gas emissions (GHG) in the UK (Water UK, 2012). The UK Climate Change Act 2008 set a legally binding target for at least an 80% cut in GHG emissions by 2050 (DECC, 2012) and, although UK water and wastewater companies are not subject to specific GHG emission targets, the Environment Agency has stated that the sector has an important role to play in reducing its emissions and contributing to the national target (Environment Agency, 2012). Linked to GHG



reduction targets are targets for increased penetration of renewable energy, and the UK is legally committed to meeting 15% of the country's energy demand from renewable sources by 2020 (DECC, 2014).

Due to population growth and urbanisation across the UK, there is predicted to be increased demand for wastewater services in the future (Defra, 2012a). Wastewater treatment is subject to a suite of European Directives which aim to limit pollution and improve water quality in the natural environment. The government is committed to continue to meet its obligations under these directives, which include the Urban Waste Water Treatment Directive, the Habitats Directive and the Water Framework Directive (Defra, 2012a).

Northern Ireland (NI) Water is the sole provider of water and sewerage services and the largest single electricity user in Northern (N) Ireland (DOENI, 2011). In 2012-13, the company's total electricity consumption was almost 300,000 MWh, 87% of which was non-renewable grid electricity (NI Water, 2014). NI Water's annual energy bill is around £34 million, and the cost of power to the sewerage service (including sewerage, sewage treatment, and sludge treatment and disposal) was over £19 million in 2012-13, accounting for 46% of direct costs in the sewerage service (NI Water, 2014). NI Water has in place an Energy Implementation Strategy, one of the key objectives of which is to reduce the number of energy units used (NI Water, undated).

The combined drivers of targets for increased penetration of renewable energy and reductions in GHG emissions, concerns over rising energy costs and growing demand for wastewater services, have led to an increased interest in alternative wastewater treatment methods. Short rotation coppice (SRC) willow is an energy crop which can be used for the management of wastewater effluent, thus bringing with it the dual benefits of wastewater treatment (reducing demand on conventional wastewater services) and production of biomass for energy. Willow is commonly combusted and used as a source of heat and/or for electricity production.

Willow grows well in temperate climates, such as in Ireland and the UK. SRC willow has a good energy balance, performs well environmentally and has been recommended over liquid biofuel crops in Irish conditions (Styles & Jones, 2007). While the energy balance of willow is good, hot spots can be targeted to improve the energy efficiency of the system. A review of SRC willow energy balance studies found that fertilisation was one of the main energy demands, accounting for 10-64% of the energy input, with fertiliser production responsible for around 90% of the energy consumed in this phase (Njakou Djomo *et al.*, 2011). Replacing fossil fertiliser with an alternative such as wastewater can improve the energy balance of the willow system, reduce the energy demand of the wastewater treatment works (WWTW), increase biomass yields (Larsson *et al.*, 2003; Perttu & Kowalik, 1997), reduce costs to the farm and significantly reduce costs to the WWTW (Rosenqvist & Dawson, 2005a, 2005b).

There is considerable knowledge of the energy balance (energy inputs vs outputs) of SRC willow (Njakou Djomo *et al.*, 2011), and numerous trials have investigated the use of wastewater, sewage sludge, and landfill leachate as fertiliser (Larsson *et al.*, 2003). There has, however, been limited work to date on comparing the energy LCA of alternative fertilisation strategies with conventional wastewater treatment, or on the

use of dirty water (farmyard washings). As a consequence of the large agricultural sector and tightening agri-environmental legislation in N Ireland, there is particular interest in alternative uses for dirty water. The aims of this paper are to analyse the energy balance of an SRC willow plantation to which farmyard washings are applied, and to compare the energy demand with that of a conventional WWTW. The analysis is based on data from an experimental plantation at the Agri-Food and Biosciences Institute (AFBI) in Hillsborough, N Ireland, which is part of the Department of Agriculture and Rural Development (DARD) funded research programme on the use of SRC willow for bioremediation of farm wastewater.

## METHODOLOGY

The energy analysis of the SRC willow system was conducted using life cycle assessment (LCA). LCA is defined as a technique to address the environmental aspects and potential impacts associated with a product, process or service (USEPA, 2006). The LCA was carried out using the standard LCA framework, which consists of four main steps: goal and scope definition; inventory analysis; impact assessment; and interpretation.

The first step is to define the goal and scope, i.e. the reasons for carrying out the assessment. For the inventory analysis, a flow diagram of the system is produced. The boundaries of the assessment are defined and the energy inputs and outputs are identified. Both direct and indirect energy were considered. Direct energy is that used directly in the system (e.g. diesel for fuelling tractors), while indirect energy is that used to produce something which is then used within the system boundaries (e.g. energy to produce herbicide). The functional unit is defined and the impacts quantified. The functional unit defines precisely what is being studied, and is the unit through which the system is analysed. Impacts were quantified using site specific data, where available, supplemented by information from the literature. Following the impact assessment, results are interpreted. The energy balance of the plantation was compared to that of a conventional WWTW used to treat an equivalent nutrient load.

## ANALYSIS AND RESULTS

### Goal and scope

The goal of this LCA is to investigate the energy balance of an SRC willow plantation to which farmyard washings are applied, and to make recommendations regarding the treatment of wastewater using this method versus treatment in a conventional WWTW. The scope can be considered using the cradle-to-grave analogy, the cradle being the production of SRC willow in the field, and the grave being the use of the resulting wood chip for energy.

### Description of system

The analysis is based on a 4 ha experimental site irrigated with farmyard washings. The plantation is split into eight approximately 0.5 ha plots, and each plot is surrounded by guard rows that prevent any external influences affecting the research. The willow was first established in 2008. As per standard practice, after the first growth season (in early 2009), the crop was cut back to ground level (coppiced),

before being allowed to grow for three years for harvesting in year 4. The three year rotation cycle used in Hillsborough is typical for SRC willow, although the cycle length can vary between sites depending on site quality, weather, soil, and fertilisation practices. The expected lifetime of a willow plantation is 19-25 years. A 25 year life cycle is assumed in this analysis (one year establishment phase plus eight growth/harvest phases on a three year cycle). The harvested willow is chipped and then transported to a drying/storage building approximately 2 km from the plantation. The willow chips are combusted in a biomass boiler and used as a source of heat on site.

The inputs and outputs of the analysis are presented in Figure 1. Both direct and indirect operational energy inputs were included within the boundary of the system (with some minor exceptions), as was the energy associated with the establishment of the plantation. End of life operations were excluded, as they are assumed to form part of the next lifecycle. Lubrication oil for machinery was excluded, as the quantities are small in comparison to diesel consumption (Goglio & Owende, 2010). The embodied energy associated with construction activities and the manufacture of machinery was also excluded. This is in line with the EU Renewable Energy Directive (EC, 2009), which states that the manufacture of machinery and equipment is not to be included when assessing the GHG impact of biofuels (EC, 2009).

The SRC willow system was analysed in four phases (establishment, growth, harvesting and use), which were then combined to determine the overall energy balance of the system. For the overall energy balance, the functional unit was taken as energy input or output per ha per year, i.e. MJ/ha/yr. The yields, energy inputs and energy outputs were averaged over the 25 year plantation lifetime. For comparing the willow system to a conventional WWTW, the functional unit was MJ/m<sup>3</sup> of effluent.

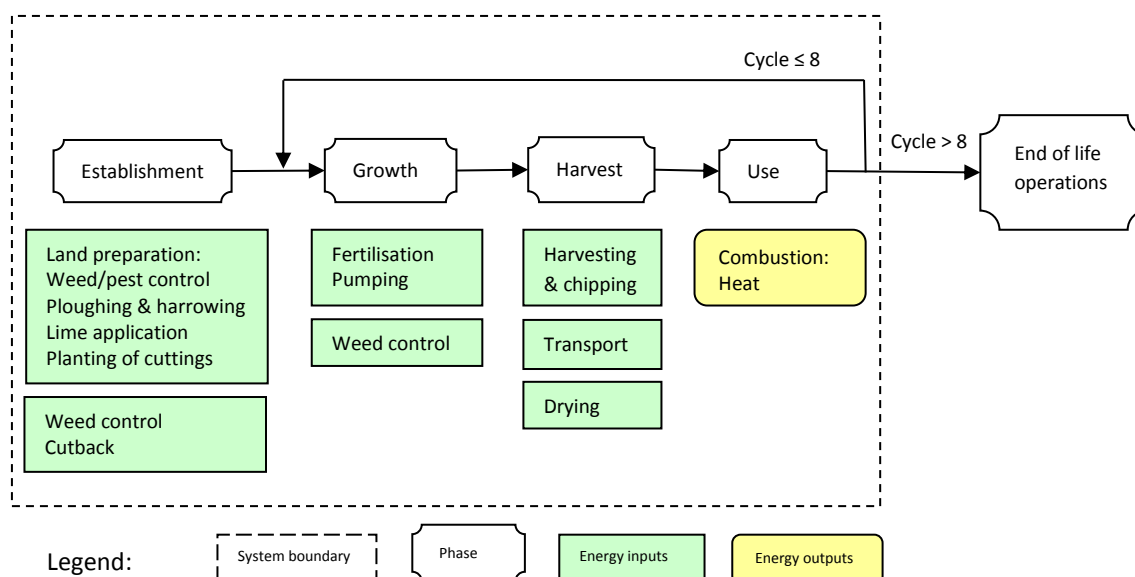


Figure 1 Energy inputs and outputs to LCA of SRC willow system

### Direct energy demand over plantation lifetime

The direct energy demands in the establishment, growth and harvesting phases are summarised in Table 1. The plantation is managed largely in accordance with best practice guidelines for SRC willow, but there are some deviations, as it is an

experimental rather than commercial plantation. The most notable difference is regarding herbicide and insecticide applications (Table 2), which are more stringent than for a typical commercial plantation (due to the use of the plantation as a demonstration site). In line with the guidelines, fertilisation did not occur in the establishment year; this is to prevent excessive growth of weeds (Lazdina *et al.*, 2007) and to mitigate the risk of nitrogen leaching to waterways (Rosenqvist & Dawson, 2005a).

Table 1 Direct energy demand over plantation lifetime

Operation	Method <sup>a</sup>	Fuel	Diesel consumption <sup>a</sup> (kg/ha)	Energy per phase <sup>b</sup> (MJ/ha)	Energy in lifetime <sup>c</sup> (MJ/ha)
<b>Establishment phase</b>					
Pre-ploughing herbicide spraying	T + sprayer	Diesel	11.6	496	496
Ploughing	T + plough	Diesel	43.1	1,841	1,841
Harrowing	T + harrow	Diesel	9.7	415	415
Lime application	T + dispenser	Diesel	1.5	64	64
Planting (step planter)	T + planter	Diesel	45.9	1,961	1,961
Post-planting herbicide & insecticide spraying <sup>d</sup>	T + sprayer	Diesel	11.6	496	496
Herbicide spot treatment	Hand spraying	N/a	-	-	-
Herbicide spraying	T + sprayer	Diesel	11.6	496	496
Cutback	Mower	Diesel	3.1	132	132
Establishment phase total			136.0	5,901	5,901
<b>Growth phase</b>					
Effluent pumping	Electric pump	Grid elec.	-	4,200	33,600
Herbicide spraying	Q + sprayer	Petrol	-	248	1,982
Herbicide spot treatment	Hand spraying	N/a	-	-	-
Growth phase total				4,448	35,582
<b>Harvesting phase</b>					
Harvesting & chipping	Wood chipping harvester	Diesel	16.6	709	5,673
Transport to store	T + trailer	Diesel	5.0	216	1,725
Drying willow chips - fans	Fans	Grid elec.	-	19,334	154,673
Drying willow chips - heat	Combustion	Willow chips	-	51,178	409,427
Harvesting phase total				71,437	571,498
<b>Direct energy during plantation lifetime</b>					612,981
<b>Direct energy during plantation lifetime (MJ/ha/yr)</b>					24,519

<sup>a</sup>T = tractor; Q = quad bike. Diesel consumption figures for all operations (except transport to store) are from a review by Goglio & Owende (2009). Diesel consumption for transport to store is from site specific data. The transport distance from the willow plantation to the store is 2 km and the associated diesel requirement was estimated as 6 L/ha. The density of diesel is calculated from values in Defra (2012), assuming the average UK biodiesel blend (3.3% biodiesel, 96.7% mineral diesel).

<sup>b</sup>The energy content of diesel is taken as 42.72 MJ/kg. This is the net calorific value and is calculated from values in Defra (2012), assuming the average UK diesel blend. The energy demand of the quad bike + sprayer is assumed to be half that of the tractor + sprayer (MAF, undated). Electricity (for pumping and fans) and willow chip demand are site specific data (to dry chips from 55% to 22.9% moisture content, electricity and heat demand are 437 MJ/t and 1157 MJ/t respectively at 22.9% moisture content; gross yield per harvest = 34.1 tDM/ha).

<sup>c</sup>A plantation lifetime of 25 years is assumed (one year establishment phase plus eight three-year growth/harvesting phases).

<sup>d</sup>The herbicide and insecticide are assumed to be sprayed in the same application.

Numbers may not sum exactly due to rounding.

During the growth phase, the plantation is fertilised with dirty water (a mixture of dairy parlour and farmyard washings) from the adjacent farm on the AFBI site. This effluent is collected and pumped to a storage silo next to the plantation. Next to the silo is a control room, from where the quantity of effluent applied to the plantation is controlled. The effluent is pumped from the silo to the plantation, which is irrigated via a pressure equalised irrigation system. The system consists of plastic pipe laid on the soil surface along the rows of willow, with a small perforation in the pipe approximately every 10 m to release the effluent. Irrigation on this particular site is not carried out for the six months of the year when there is little or no growth and when poor weather conditions can cause problems with surface run-off. As a further precaution, pumping is automatically stopped if the level of rainfall exceeds a certain limit. The electricity consumption of the irrigation pump is estimated in Box 1.

Table 2 Herbicide and insecticide demand over plantation lifetime

Phase	Method <sup>a</sup>	Herbicide <sup>b</sup>				Insecticide <sup>b</sup>	
		Glyp- hosate (L/ha)	Pendim- ethalin (L/ha)	Iso- xaben (L/ha)	Propaq- uizafof (L/ha)	Amit- rol (L/ha)	Chlor- pyrifos (L/ha)
<b>Establishment</b>							
Pre-ploughing	T + sprayer	3					
Post planting <sup>c</sup>	T + sprayer		3	2			1.5
Once in year 1	Spot treatment	4					
Once in year 1	T + sprayer				1.5		
Total		7	3	2	1.5	-	1.5
<b>Growth</b>							
Once in phase	Q + sprayer					20	
Twice in phase <sup>d</sup>	Spot treatment	8					
Total one phase		8				20	
Total all growth phases <sup>c</sup>		64				160	
<b>Total over lifetime</b>		71	3	2	1.5	160	1.5

<sup>a</sup>T = tractor; Q = quad bike.

<sup>b</sup>Herbicides and insecticides are delivered to site in concentrated liquid form, and are diluted on site for use in the sprayer. The volumes (L/ha) in this table refer to the concentrated liquid form. The chemical names refer to the active ingredient. Active ingredient content is given in Table 3.

<sup>c</sup>The herbicides and insecticides are sprayed in the same application.

<sup>d</sup>4L/ha is applied on each occasion.

<sup>e</sup>There are eight growth phases during the lifetime of the plantation.

Box 1 Direct energy consumption of pump for irrigation system on 4 ha site<sup>a</sup>

Pump size	4	kW
Pumping rate	9	m <sup>3</sup> /hr
Effluent applied to 4 ha site	3,500	m <sup>3</sup> /yr
Hours pump running annually	389	hr/yr
Energy (electricity) consumption	1,556	kWh/yr
Energy consumption per growth phase	16,800	MJ
Energy consumption per growth phase	4,200	MJ/ha

<sup>a</sup>The figures do not include pumping from the source of dirty water to the silo; this would be carried out regardless of the whether or not the willow plantation were in place and is therefore considered to be outside the system boundary.

At the end of each three year growth phase, the willow crop is harvested. Harvesting takes place between autumn and spring, after leaf fall, so as to limit the problems

associated with leaves during storage, drying and combustion. The harvesting method used in the Hillsborough site is harvesting and chipping in one operation. This is the most efficient and widely adopted system in Ireland to date (Kofman, 2012), but does require dedicated drying facilities for the chips to prevent excess heat build-up from natural degradation.

Table 3 Indirect energy demand over plantation lifetime

Input	Lifetime demand <sup>a</sup>		Active ingredient <sup>b</sup>	Embodied energy <sup>c</sup>		Indirect energy during lifetime <sup>d</sup>
	(unit)	(unit)	(kg/ha)	(unit)	(unit)	(MJ/ha)
<b>Establish. phase</b>						
Willow cuttings	15,000	cuttings /ha	-	0.678	MJ/cutting	10,171
Herbicide						
- Glyphosate	7	L/ha	3.36	454	MJ/kg ai	1,525
- Pendimethalin	3	L/ha	1.37	150	MJ/kg ai	205
- Isoxaben	2	L/ha	0.25	214	MJ/kg ai	54
- Propaquizafop	1.5	L/ha	0.15	214	MJ/kg ai	32
Insecticide						
- Chlorpyrifos	1.5	L/ha	0.72	250	MJ/kg ai	180
Lime	2.5	t/ha	-	5,300	MJ/t	13,250
Diesel	5,901	MJ/ha	-	0.24	MJ/MJ	1,394
Total						26,811
<b>Growth phase</b>						
Electricity	33,600	MJ/ha	-	2.07	MJ/MJ	69,552
Petrol	1,982	MJ/ha	-	0.18	MJ/MJ	357
Herbicide						
- Glyphosate	64	L/ha	30.72	454	MJ/kg ai	13,947
- Amitrol	160	L/ha	36.00	250	MJ/kg ai	9,000
Total						92,856
<b>Harvesting phase</b>						
Diesel	7,398	MJ/ha	-	0.24	MJ/MJ	1,748
Electricity	154,673	MJ/ha	-	2.07	MJ/MJ	320,172
Willow chips <sup>e</sup>	409,427	MJ/ha	-	-		-
Total						321,921
<b>Indirect energy during plantation lifetime</b>						441,588
<b>Indirect energy during plantation lifetime (MJ/ha/yr)</b>						17,664

<sup>a</sup>Herbicide and insecticide quantities refer to the concentrated liquid form (see Table 2 for details). Diesel, electricity and willow chip usage are from Table 1. The quantities of willow cuttings and lime are from site data.

<sup>b</sup>Active ingredient (ai) content was chosen based on data sheets for typical products used on site (glyphosate = 0.48 kg/L; pendimethalin = 0.455 kg/L; chlorpyrifos = 0.48 kg/L; propaquizafop = 0.1 kg/L; isoxaben = 0.125 kg/L; amitrol = 0.225 kg/L).

<sup>c</sup>Embodied energy data is from the following sources: willow cuttings from Table 4; herbicide and insecticide from Bhat *et al.* (1994) (specific values are used for glyphosate, pendimethalin, chlorpyrifos; an average herbicide value is used for isoxaben and propaquizafop); lime from Hammond & Jones (2011); diesel, electricity and petrol from Edwards *et al.* (2014) (values are per MJ of final fuel; the value for diesel was calculated based on the average UK biodiesel blend; the value for petrol is for fossil petrol; the energy in electricity production is the EU mix average for medium voltage).

<sup>d</sup>A plantation lifetime of 25 years is assumed (one year establishment phase plus eight three-year growth/harvesting phases).

<sup>e</sup>Willow chips from the Hillsborough plantation are used for drying. The embodied energy is neglected to avoid double counting.

### Indirect energy demand over plantation lifetime

The indirect energy (Table 3) is calculated by multiplying the lifetime demand for an input by its embodied energy (the energy required to produce the input). The energy

associated with the transport of inputs from their respective production sites to Hillsborough was neglected (unless it was already included in the value referenced). For herbicides, pesticides, lime and willow cuttings, correspondence with suppliers and reference to the literature showed that the majority of inputs are produced in England, The Netherlands and Germany, and are transported by road, rail and sea. The energy from transport can be difficult to quantify accurately due to the large number of variables (e.g. type and size of vehicle, loading rate), but typically constitutes only a small portion of overall energy, particularly when transport is by road/rail/sea over relatively short distances. The exclusion of the energy associated with transport is therefore not expected to have a significant impact on the overall energy balance.

Table 4 Energy in nursery production of 15,000 willow cuttings (adapted from Heller *et al.*, 2003)

Inputs <sup>a</sup>	Quantity required <sup>a</sup>		Energy content <sup>b</sup>	Energy demand <sup>c</sup>	Embodied energy <sup>d</sup>		Total <sup>c</sup>
		(unit)	(MJ/unit)	(MJ/ha)		(unit)	(MJ/ha)
Diesel (used as fuel)	6.3	kg	42.72	268	0.24	MJ/MJ	331
LPG (used as fuel)	1.0	kg	45.90	46	0.12	MJ/MJ	51
Petrol (used as fuel)	18.3	kg	44.74	818	0.18	MJ/MJ	966
Electricity	296	kWh	3.60	1,065	2.07	MJ/MJ	3,269
Heavy fuel oil (used for heat)	73.5	kg	40.72	2,994	0.20	MJ/MJ	3,593
Wood (used for heat)	42.6	kg	14.00	596	0.30	MJ/MJ	775
Carbaryl (insecticide)	0.2	kg ai	-	-	250	MJ/kg ai	54
Glyphosate (herbicide)	0.1	kg ai	-	-	454	MJ/kg ai	54
Granular fertiliser (15-15-15)	108	kg	-	-	7.59	MJ/kg	820
Ammonium sulphate fertiliser	8.2	kg	-	-	8.07	MJ/kg	66
Urea fertiliser	8.2	kg	-	-	23.45	MJ/kg	192
Surface water (for irrigation)	358	m <sup>3</sup>	-	-	-		-
Total				5,787			10,171
Energy demand per cutting (MJ/cutting)							0.678

<sup>a</sup>Inputs were adapted from Heller *et al.* (2003). Litres of fuel were converted to mass using densities from Defra (2012) (fossil petrol and fossil heavy fuel oil were assumed; the average UK diesel blend was assumed). LPG = liquefied petroleum gas.

<sup>b</sup>Net calorific values are from Defra (2012). Wood chips at 25% moisture content are assumed.

<sup>c</sup>MJ/ha refers to the energy required per ha of plantation in Hillsborough. 15,000 cuttings were planted per ha in Hillsborough.

<sup>d</sup>Embodied energy data is from the following sources: diesel, LPG, petrol, electricity, heavy fuel oil and wood from Edwards *et al.* (2014) (values are per MJ of final fuel; the value for diesel was calculated based on the average UK biodiesel blend; the value for petrol is for fossil petrol; the energy in electricity production is the EU mix average for medium voltage; for wood, industrial farmed wood is assumed; for fuel oil, the energy of mineral diesel is assumed); herbicide and insecticide from Bhat *et al.* (1994) (specific value is used for glyphosate; the average insecticide value is used for carbaryl); fertilisers from Brentrup & Pallière (2008). The embodied energy of surface water assumed to be zero.

### Energy balance over plantation lifetime

A summary of the energy balance is presented in Table 5. The average yield per harvest from the site to date is 34.11 tDM/ha from a three year cycle, giving a gross energy production of 5,239 GJ/ha (or 210 GJ/ha/yr) over the project lifetime. The direct and indirect energy demands are 12% and 8% of gross energy respectively. Harvesting is the biggest energy demand on the system, accounting for 85% of total energy demand and over 90% of direct energy. The drying of willow chips is the largest contributor to both direct and indirect energy demands, accounting for 92%

and 73% of total direct and indirect energy respectively. Establishment and the growth phases account for 3% and 12% of total energy demand respectively.

Table 5 Energy balance over 25 year plantation lifetime

	Direct energy (MJ/ha/yr)	Indirect energy (MJ/ha/yr)	Direct + indirect energy (MJ/ha/yr)
<b>Gross energy production</b>	209,572	-	209,572
<b>Energy demands</b>			
Establishment	236	1,072	1,308
Growth	1,423	3,714	5,138
Harvesting	22,860	12,877	35,737
<b>Total energy demand</b>	24,519	17,877	42,183
<b>Net energy production</b>	185,053	-	167,389

### Comparison with a conventional WWTW

Based on the nutrient content of the dirty water applied to the plantation, the equivalent quantity of raw domestic wastewater is calculated (Table 6). Due to the lower concentration of nutrients in wastewater, the associated energy demand for pumping is over four times that for dirty water, but when included in the overall energy balance, direct energy increases by only 2% (from 12% to 14% of gross energy), and the overall energy balance remains positive. Overall net direct energy production in the willow-domestic wastewater system is 48 MJ/m<sup>3</sup>, compared to an energy demand of 2.6 MJ/m<sup>3</sup> in a typical WWTW (calculated from NI Water (2013) and associated background information). The energy demand for pumping in the willow plantation is 1.6 MJ/m<sup>3</sup>.

Table 6 Dirty water NPK values and equivalent volume of domestic wastewater

	Quantity <sup>a</sup>		Nutrient content <sup>b</sup>			
		(units)	N	P	K	(units)
<b>Dirty water</b>						
Vol. applied to 4 ha willow plantation	3,500,000	L/ha/yr				
Vol. applied per ha willow plantation	875,000	L/ha/yr				
Nutrient content of dirty water			178	56	542	mg/L
Nutrients applied to willow			155	49	474	kg/ha/yr
<b>Typical raw domestic wastewater</b>						
Nutrient content of raw wastewater <sup>c</sup>			40	9	20	mg/L
Max equivalent vol. wastewater/yr <sup>d</sup>	3,883,869	L/ha/yr				
Nutrients in max equivalent volume			155	35	78	kg/ha/yr
Average raw domestic wastewater production <sup>e</sup>	54,916	L/PE/yr				
Potential population served by willow plantation	71	PE/ha/yr				

<sup>a</sup>This is during growth/harvest phases only. The establishment year is not included.

<sup>b</sup>N = nitrogen, P = phosphorous, K = potassium.

<sup>c</sup>N and P values from Kiely (1997, p. 500); K value from Arienzo *et al.* (2008).

<sup>d</sup>Due to the composition of raw wastewater, N is the limiting factor when calculating an equivalent volume. To match the N content in the dirty water, no more than 155 kg N/ha/yr can be applied.

<sup>e</sup>Calculated from data in NI Water (2014). PE = population equivalent.



## DISCUSSION

### Hot spots in energy demand

The benefit of an LCA is that it identifies hot spots, so that targeted improvements can be made in the system. The highest direct energy demand is in the harvest phase for drying chips; the heat and electricity used accounts for 92% of total direct energy, with the electric fans responsible for 25% and the heat for 68%. The willow chip in Hillsborough is dried in a large open air shed, where large electric fans force warm air (heated by combustion of willow chips) through the floor. The design of the drying shed might be partly responsible for the high energy demand. It has been observed that condensation forms on the peaked roof of the shed and water drips back onto the chips. An improved ventilation system could be investigated as a means of reducing the energy demand. Alternative low-energy drying methods, such as whole rod drying under a breathable membrane, are also possible, but require further research.

Electricity is the largest contributor to indirect energy demand in the establishment and harvesting phases (and overall). The energy in grid electricity production is 2.07 MJ/MJ final fuel (EU mix average (Edwards *et al.*, 2014)). The use of wind electricity could significantly reduce the indirect energy; electricity from offshore wind requires only 0.12 MJ/MJ final fuel (Edwards *et al.*, 2014). In the establishment phase, the highest indirect energy demand is for lime. The addition of lime is highly dependent on the site specifics, particularly on the pH of the site (Caslin *et al.*, 2010). Some sites may not need any lime, resulting in considerable indirect energy savings.

### Willow yield

The 4 ha irrigated willow site investigated in this paper forms part of a 6 ha plantation, the other 2 ha of which are not irrigated. The yield data used in this paper was an average for the 6 ha, but this may underestimate the yield of the irrigated plot, as the literature suggests higher relative yields on irrigated plantations (Larsson *et al.*, 2003; Perttu & Kowalik, 1997). In addition, the yield of 11.4 tDM/ha/yr (from the three year cycle) is from only one harvest, and is assumed to remain constant over the eight harvests; this may be a conservative approach. Trials in the UK suggest that yields of up to 15-18 tDM/ha/yr can be obtained, with higher yields expected after the first harvest (Wickham *et al.*, 2010). Better onsite yield data would allow a more thorough analysis of the system and a direct comparison of the effect of irrigation on yield.

### Potential for wastewater treatment

It is estimated that 1 ha of willow can treat 3884 m<sup>3</sup>/yr of domestic wastewater (Table 5). Each year 1.17 x 10<sup>8</sup> m<sup>3</sup> of wastewater are treated in N Ireland (NI Water, 2014). Ten per cent of this wastewater could be treated with about 3000 ha of willow, five times the area currently under the crop in N Ireland (DARDNI, 2013). Although there are energy benefits to the use of willow for wastewater treatment, there are also drawbacks. The wastewater must be transported from dwellings and/or the sewerage network to the willow plantation. This would likely require the installation of sewerage pipes, so the location of the plantation relative to the wastewater source is important due to associated capital/operational costs and construction requirements. The irrigation at the Hillsborough site is only licensed for six months of the year, though there are irrigated willow sites for wastewater management licensed for year-round irrigation.

## CONCLUSIONS

The energy balance of the SRC willow plantation in Hillsborough revealed the biggest energy demands to be associated with the drying of the willow chip. With regard to the associated direct energy, improvements to the ventilation system in the existing drying facility should be investigated as a means of reducing the energy demand. The indirect energy from electricity usage is substantial. The calculations were based on the average EU electricity mix; a switch to wind generated electricity would significantly reduce the indirect energy demand. As a means of treating wastewater effluent, willow could be an effective solution. The pumping demand for an irrigation system based on SRC willow was estimated as  $1.6 \text{ MJ/m}^3$ , which is approximately 60% of the energy required to treat wastewater in a conventional WWTW. The added benefit of using the willow plantation is that it is a net energy producer. When the additional demand for pumping wastewater effluent is taken into account, the net direct energy of the system is  $48 \text{ MJ/m}^3$  of wastewater effluent. Ten per cent of N Ireland's wastewater could be treated with around 3000 ha of SRC willow. Further research should be carried out to identify suitable sites.

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# Urbanization and Water insecurity in Nigeria: A Study of Abuja Metropolis, Nigeria

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## ABSTRACT

Nigeria is endowed with massive water resources, with the capacity to meet emergent requirements. This requires both resources and a robust plan of action, to be managed by competent and dedicated experts through a well devised institutional framework. Therefore, it is critical that attention is paid to the envisaged effects of urban sprawl on the physical, economic and social environments of urban centres. Because Nigeria's rate of urbanization (and consequently, urban sprawl) is among the fastest in the world, it is important to study the consequences of urban sprawl in the rapidly expanding Federal Capital Territory of Abuja, particularly with respect to water resource management and climate variability and change. A literature review and a conceptual framework emerging from the study are provided. The framework is envisaged as the platform for developing the recommendations from the emerging study and to provide directions for future research.

## Keywords

Environment, Physical, Urban Sprawl, Water Resource Management

## INTRODUCTION

The impact of urban development and ground-water represents one of the most important aspects of growing cities. The interaction between urban development and ground-water may be explained in relation to land use patterns and stage of city evolution and affects on ground-water quantity and quality. Quantity and quality changes are affected by increased ground-water abstraction and new sources of recharge (Putra, 2007). Previous studies of the effect of fast growing cities on ground-water include Foster *et al.* (1993), Morris *et al.* (1994) and Vasquez-Sune *et al.* (2005). The main issues concluded from these studies are: urbanized areas change ground-water recharge and cycling, with modification of the existing recharge and the introduction of new sources, discharging of new sources of recharge in urbanized areas causes extensive but essentially diffuse ground-water contamination, and fluctuations in ground-water levels affect engineering structures.

Informative and comprehensive reports of the problem of contaminated ground-water in urbanized areas of developed and developing countries include Morris *et al.* (1994), Lerner and Barrett (1996), Massone *et al.* (1998), Chilton (1999) and Wakida *et al.* (2005). However, it is clear that

human activities in urbanized areas pose multiple threats to ground-water, especially diffuse contaminant loading from urban recharge systems. This means that the different forms of land use, such as landfills, urban agriculture, industry and trade, as well as diverse residential types with their corresponding waste-water systems, influence the emission of pollutants in surface and ground-water, including ground-water recharge (Strohschön *et al.*, 2011).

In Abuja, a survey on sources of drinking water in the FCT revealed that most of the population depends on water vendors, sachet water and pond water (FCT Baseline Data, 2010). The public water utilities are challenged by the rapid development within the FCT. Thus, many residents and estate owners construct private boreholes to meet their water needs, resulting in ground-water depletion.

## SCOPE OF THE STUDY

This study explores inter-relationships between increasing urban population, exploration of ground-water sources to meet water needs and impacts on the sustainability of ground-water resources within the FCT. There is currently insufficient capacity within the utilities and other stakeholders, including the domestic private sector, to properly tackle the issue of lack of access to water services for the urban poor (WaterAid, 2006). Water supply is integral to slum improvement and urban environmental health, yet there is disconnect between water resource management and the housing and urban development sector in the FCT. Rapid urbanization and the proliferation of slums and urban poor settlements pose major challenges in Nigeria. It is therefore timely to undertake detailed studies and make concerted efforts toward the improvement and co-ordination in the urban development sector and integrate water resource management into urban development planning. There will be a review of existing literature, reports and publications and research on water resource management issues. This will be followed by geophysical investigations, water resource mapping exercises and ground-water monitoring at selected locations. Resultant data will be analysed and thus assist the formulation of recommendations.

The study will improve understanding of urbanization pattern impacts on the ground-water of the City of Abuja. Therefore, the study intends to develop viable strategies, such as reduction of high dependency on ground-water, conjunctive use of ground-water and surface-water, rainwater harvesting, preservation of wetlands in and around the City, artificial recharge and decreased waste. These may contribute to effective and sustainable utilization of ground-water resources.

The research programme will be coordinated on the basis of primary and secondary data sources. Desk review of existing literature will be conducted, and other baseline information on urbanization and ground-water abstraction will be collected from multiple sources (i.e. books, journals, NGOs, international and national reports and government data-bases).

Primary data on ground-water will be collected using ground-water monitoring loggers at selected observation wells, located 30 km apart within the FCT. Data will be collected and analysed using relevant tools and 'win-situ' (water mapper software).

## POPULATION GROWTH AND THE CHALLENGES OF PROVIDING WATER SERVICES IN ABUJA

The growing demand for the use of water resources, in particular from rapidly expanding urban centres, is posing serious threats to sustainable development, especially in Africa. Ground-water exploitation exceeds sustainable yield, with some projections forecasting total demand increasing to double the sustainable yield by 2020 (Allison *et al.*, 1998, Stephen *et al.*, 2008). Abuja is well planned, but, with the rapid population growth, services to ameliorate this population pressure may prove inadequate.

A Federal Government study between 2008-2010 showed that little progress had been made in providing safe drinking water through taps and boreholes to most communities within the FCT (FCT Baseline Data, 2010). Ameto (2012) found that only 7% of households in the FCT had access to safe drinking water from taps; while 43% depended on rivers and streams, and 27% depended on boreholes. With increasing influx of people from neighbouring states, the FCT water utility (Water Board), with a daily production of 192,000 m<sup>3</sup>, is struggling to satisfy water demands. The National Water Supply and Sanitation Policy (2000) stipulates 120 litres/per capita/day for urban water supply.

Access to safe water from the utility is sporadic, even in areas accommodating the FCT elite. Some inhabitants of Maitama District still struggle to store water regularly to meet daily requirements, as supply from the Water Board is irregular.

The Federal Capital Territory (FCT) was formed in 1976 from parts of former Nasarawa, Niger and Kogi states. It is the central region of the country on an area of 7,315 km<sup>2</sup>, of which the actual city (Abuja) occupies 275.3 km<sup>2</sup>. It has a population of 1,406,239 people (2006 Census). Within the last 10 years, the population living in the FCT has grown by 9.3% (2006, Census), and the projected population of FCT in 2014 is 3,028,807 (UNFPA Report, 2010), ranking it as the highest in Nigeria and far in excess of the initial city plans.

Admittedly, the planners of Abuja did not envisage that the population would grow suddenly, thereby exerting pressures on available government facilities, amenities and infrastructure. Most of the City does not have pipe reticulations for water supply from the only available surface source, Usuma Reservoir, which is fed by the River Usuma. The reservoir has a capacity of 120 million m<sup>3</sup> of raw water and is sited 26 km from Abuja City Centre, along the Dutse-Bwari road, and 10 km from Bwari. Thus, even new government buildings are difficult to connect, as the network distribution does not cover such areas in the original plan, let alone bringing water to individual homes. As a result, each household is forced to sink its own borehole, which in the long-term has negative implications for ground-water quality and quantity.

People who relocated to the FCT find it cheaper to settle in areas lacking potable and sustainable water sources. These include Lugbe, Karimu, Nyana, Deidei, Gwagwa, Idu, and Gwagwalada. These towns have fast become giant slums, with no public space where pipes can be run. The indiscriminate sinking of boreholes without proper surveillance is common and, consequently, many boreholes are close to pit latrines and garbage dumps.

When developers lose sight of the fact that people need to be at the centre of planning, there is

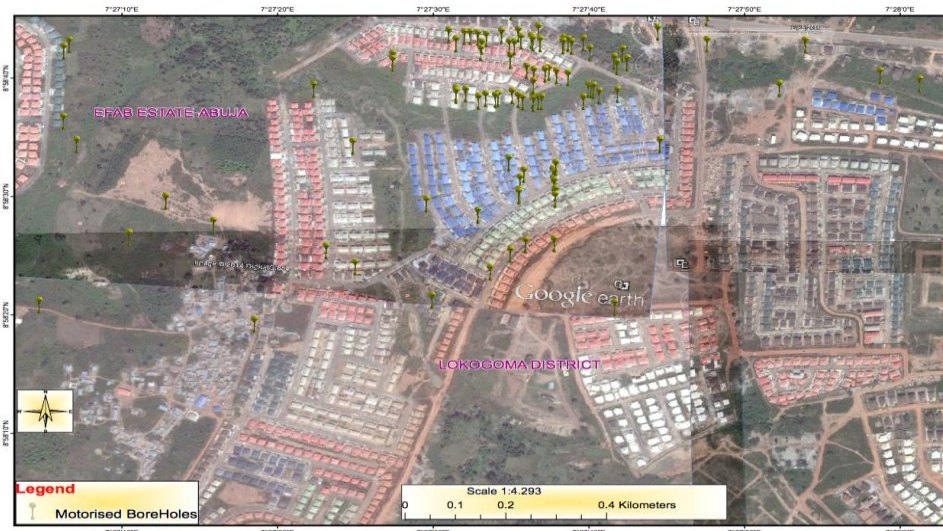


every chance of chaotic settlements, a phase FCT is gradually becoming if remedial actions are not taken. The United Nations Population Fund (UNFPA, 2010) stated that the sustainable development agenda to improve well being and preserve the quality of the environment cannot succeed without a core focus on population.

## MAPPING AND GROUND-WATER ANALYSIS OF SAMPLE HOUSEHOLDS IN EFAB CITY ESTATE, LOKOGOMA DISTRICT, ABUJA

Gathering information is key for adequately assessing both the ground-water pollution potential and safety of drinking-water sources. The establishment of an information inventory is therefore a central tool in developing a sound understanding of potential pollution sources and the likelihood that pollutants may reach ground-water in concentrations hazardous to human health (World Health Organisation, 2006).

A pilot phase study was conducted in Efab City Estate (Figure 1) to understand the extent to which water usage patterns, depth of boreholes and distance between boreholes and soak-aways is linked to the quality of water consumed by households.



*Figure 1: Map of Efab City Estate showing water and latrine facilities (source: Google Maps, accessed 11/02/2014).*

### Study materials and methods

The data required for assessing ground-water pollution potential (i.e. the likelihood that diseases, pathogens or chemicals reach ground-water) can be achieved through several methods. These include: (1) site and catchment inspections; (2) public consultation (i.e. communication with the local population); (3) collating ground-water data; (4) targeted hydro-geological field surveys (e.g. for aquifer vulnerability mapping), and (5) ground-water quality screening or monitoring programmes involving laboratory analyses (World Health Organisation, 2006).



The pilot study adopted the combination of quantitative and qualitative methodologies. The sampling technique used for the study was both systematic and simple random sampling techniques in selecting questionnaire respondents.

A total of 110 households were sampled through a stratified random sampling technique. Household questionnaires were administered to elicit information about people's views on water services within the Estate. Co-ordinates of water points and sanitation facilities within households were also captured using the Garmin III GPS device. Subsequently, the 'win-situ' instrument for ground-water data will be used to collect data on water levels at selected locations within the FCT. Loggers will be installed, retrieved, recalibrated and reinstalled at regular intervals for data collection.

### Study Area

Efab City Estate, Lokogoma is located at 8.97502°N and 7.46161°E. It occupies approximately 60 hectares with 800 housing units and is 5 km north from the City Centre. The local geology is underlain by Pre-Cambrian basement complex rocks, which include discontinuous and localized aquifers (Adakayi, 2000; Balogun, 2001). Mean annual rainfall is 1,631.7 mm. The mean annual temperature ranges between 25.8-30.2°C (Adakayi, 2000; Balogun, 2001). Local soils are alluvial soils and Luvisols.

## RESULTS

The survey captured the situation within the 110 households (HH) with respect to access to water supply, usage patterns, depth of boreholes, distance between boreholes and soak-away pits, and the mean depth of pits. Physico-chemical analyses were also conducted on water samples collected from 11 households, to determine the potability of water.

All 110 households have boreholes and a toilet facility, each located within the compound with mean land area of 450 m<sup>2</sup> (Figure 1). The location of boreholes and nearby soak-aways has implication for ground-water quality. Boreholes located within distances <50 m from sources of contamination (such as septic tanks and poorly drained areas, which receive contaminated run-off from slurry pits), are more likely to be polluted. Verheyen *et al.* (2009) found a significant positive correlation between viral contamination of a water source and at least one latrine within 50 m. Ground-water nitrate concentrations have also been correlated with proximity to pollution sources, including pit latrines, in Senegal and South Africa (Tandia *et al.* 1999; Vinger *et al.* 2012).

The estimated water consumed per household per day is 534 litres (Table 1) and water is pumped daily to meet this demand. This has consequent effects on the environment, especially when ground-water is removed from aquifers by excessive pumping. Thus, pore pressures in the aquifer drop and compression of the aquifer may occur. This compression may be partially recoverable if pressures rebound, but much of it is not. When the aquifer becomes compressed, it may cause land subsidence and associated infrastructure damage (Sophocleous, 2002).

**Table 1: Summary of borehole results from Efab City Estate ( $n = 110$ ,  $\pm$  SD)**

S/N	Parameters	Measures
1	Mean depth of borehole (m)	$31 \pm 0.79$
2	Mean distance between borehole and soak-away (m)	$8 \pm 0.50$
3	Mean depth of soak-away (m)	$3 \pm 0.08$
4	Estimated water consumed per Household per day (litres)	$534 \pm 0.04$
5	Mean number of people in household	$7 \pm 0.01$
6	% Households with water odour problem	$4 \pm 0.04$
7	% Households with water colour problem	$5 \pm 0.09$
8	% Households with water taste problem	$9 \pm 0.09$

Table 2 shows co-ordinates of sample HH water collected for water quality analysis. Some 11 water samples were collected and analysed for major physico-chemical parameters, including temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH),  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , as per the assessment of ground-water quality method described by APHA (1992). Water sample temperature, pH, electrical conductivity and TDS were determined at the point of sampling, using a Hach digital thermometer with a glass sensor. Total hardness and total alkalinity were estimated by standard methods of water and waste-water using the Hach DR2000 direct reading spectrophotometer.

**Table 2: Co-ordinates of sampled boreholes for Water Quality Analysis in Efab City Estate**

BOREHOLE (BH)	LATITUDE (°N)	LONGITUDE (°E)	ALTITUDE (M)
BH1	8.97252	7.45828	464
BH2	8.97726	7.45983	460
BH3	8.97722	7.45972	460
BH4	8.97472	7.45818	460
BH5	8.97720	7.46002	459
BH6	8.97721	7.46014	459
BH7	8.97716	7.46037	458
BH8	8.97868	7.45994	465
BH9	8.97577	7.45968	464
BH10	8.97329	7.45689	463
BH11	8.97560	7.46053	456

The membrane filter technique method was employed for all microbiological analyses. A 100 ml water sample was filtered through a membrane (pore size 0.45  $\mu\text{m}$ ), small enough to retain indicator bacteria to be counted. The membrane was incubated on the selective differential to allow bacteria to grow. Colonies were recognized by their colour, morphology and number.

There were considerable variations in the examined samples from different sources, with respect to their physiochemical characteristics (Table 3). Results indicated that intra-site water quality varies considerably. Some samples showed they possessed some perceived odour that was not quantified in this study. The occurrence of odour was probably associated with the presence of contaminants. Related to taste, water with a strong odour will obviously be rejected by consumers. Odours may be caused by dissolved volatile organic compounds, small concentrations of which may have considerable organoleptic effects.

Water points (BH3, BH4, BH5, BH6 and BH10) are generally weakly acidic; and the remaining five are within the permissible pH range of  $7.0 \pm 0.1$ . All underground water samples are characterized by either a weakly acidic or weakly basic pH, within the maximum permissible pH level (6.5-8.5) of the Nigerian Standard for Drinking Water Quality (2007).

**Table 3: Results of Water Quality Analysis conducted on sample boreholes in Efab City Estate, Lokogoma**

S/N	BOREHOLES	COLIFORM (CFU/100 mL)	ALKALINITY (as CaCO <sub>3</sub> ) mg/dm <sup>3</sup>	HARDNESS (as CaCO <sub>3</sub> ) mg/dm <sup>3</sup>	pH	TDS (mg/L)	INFERENCES	ADVICE
1	BH1	TNTC	49	49	6.59	63.9	Not Fit for consumption, except if treated	Install small portable water purification sytem
2	BH2	0	57	87	6.45	122.4	Good water source	
3	BH3	TNTC	21	21	6.03	33.8	Not Fit for consumption, except if treated	Install small portable water purification sytem
4	BH4	11	20	22	6.1	34.9	Good water source	
5	BH5	0	17	18	5.84	31.4	Excellent water source	
6	BH6	13	32	50	6.09	49.4	Good water source	
7	BH7	0	58	80	6.63	93.1	Good water source	
8	BH8	3	19	20	6.13	28.4	Good water source	
9	BH9	TNTC	72	96	6.74	120.9	Not Fit for consumption, except if treated	Install small portable water purification sytem
10	BH10	0	18	20	5.95	36.4	Excellent water source	
11	BH11	TNTC	65	94	6.61	133.6	Not Fit for consumption, except if treated	Install small portable water purification sytem

Conductance (total dissolved solids) is related to the ionic content of the water sample, which is in turn a function of dissolved (ionisable) solids. This property is related to water hardness, because the more dissolved ions (including  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{SO}_4^{2-}$ ) present in a water sample, the more its conductance and hardness (Istifanus *et al.*, 2013).

Coliform, ‘Too Numerous To Count’ (TNTC) was observed in 36% of water samples (Table 3), indicating that the water is unsafe for human consumption. Because samples from these households showed a large presence of *E. coli*, the inference is that heavy, recent pollution by humans or from soak-aways has occurred. *E. coli* is bacterium that causes gastroenteritis in humans, and is abundant in human and animal faeces (>1,000,000,000 *E. coli* per gram of fresh faeces). Human faeces harbour many microbes, including bacteria, archaea, microbial eukarya, viruses, and potentially protozoa and helminths (Feachem *et al.* 1983; Ley *et al.* 2006; Ramakrishna 2007). Areas characterized by shallow water-tables and fractured rock aquifers have high faecal coliforms concentrations in domestic wells located near pit latrines and septic tanks (Pujari *et al.* 2012). This was corroborated by a study on ground-water quality in an unplanned settlement in Zimbabwe,

which indicated detectable total and faecal coliforms in over two-thirds of study boreholes and existing domestic wells (Zingoni *et al.*, 2005).

## CONCLUSIONS

This study suggests that sewage systems (soak-aways), close to shallow wells and boreholes contribute to high levels of ground-water contamination. The presence of *E. coli* in water always indicates potentially dangerous contamination requires urgent attention. Immediate chlorination processes should be embarked upon to eliminate negative impacts of water contamination where found. Water supply is more critical for urban development intervention.

These findings revealed the urgent need for water service providers, national government and beneficiaries alike, to work together to achieve better management outcomes for the sustainable utilization, conservation, and remediation of ground-water resources within the FCT and its environs.

Essentially, further study is required to develop a composite framework for ensuring that estate developers and urban development practitioners comply with best practices for urban planning and development while emphasizing public orientation programmes for conjunctive use of water resource. A framework that will improve understanding of sustainability of ground-water and how it can be achieved. A guide to bring about the lasting changes which those in low-income settlement (slum areas) and the FCT need and demand. A regulatory outline for extending water supply services; increasing water storage capacity, reducing indiscriminate sinking of boreholes and water collection times, and ensuring sufficient quantities are available to meet multiple water needs using a multiple use service approach where appropriate. Protecting and improving water quality and ensuring better water management. Cited observations also suggest that a robust development framework for improvement and co-ordination in the urban sector and the integration of water resource management for effective urban development planning is essential for future progress.

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# **Reframing intervention: what does a collective approach to behaviour change look like?**

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## **ABSTRACT**

This paper draws on a qualitative research into the patterns of domestic water consumption and demand management in the South-east of England. We present an analysis of various paths that could be, and in some cases are being, taken to mobilise collective action in order to achieve sustainable domestic water consumption. Building on a growing body of critique that posits conventional approaches to water efficiency are founded on oversimplified models of consumer behaviour, this paper explores domestic water consumption as a collectively ordered activity and outlines how this understanding can be used to inform water efficiency initiatives in order to achieve sustainable domestic water consumption. First, we synthesise a range of social science literatures into four perspectives on demand as a collectively ordered activity, demonstrating the consequences of these various perspectives for the water efficiency agenda (Table 1). Second, drawing on focus group data we evaluate the evidence for each perspective and their potential to inform behaviour change initiatives. We reveal that while evidence for each set of collective drivers can be identified, some offer greater potential for intervention than others, highlighting different sites, scales and subjects to which campaigns might attend. Our discussion focusses on laundry as a specific example of domestic water use to demonstrate how taking an approach informed by this notion of ‘collective’ opens up new opportunities for intervention.

**KEYWORDS:** Everyday water, Domestic demand, Practice theory

## **INTRODUCTION**

Headway has been made in establishing and developing an agenda for demand management across the water industry of England and Wales to enhance the security and sustainability of water supplies now and into the future. Typically activities are characterised by two streams i) infrastructural development to enhance supply efficiency and ii) household water efficiency initiatives to reduce domestic consumption. There is uncertainty regarding how climate change, population growth and other social changes will shape future water demand and to address these emerging challenges the water industry is increasingly referring to approaches that are said to substantially shift everything; from efforts to reconfigure everyday water consuming practices right through to developing collective infrastructures (e.g. water grids). This push towards discourses of ‘collectives’, ‘collaboration’, and ‘cooperation’ raises important questions for policy makers and managers; how can we



understand water consumption as a collectively ordered activity? And how can we use the collective drivers of consumption to reduce household water demand? From an academic perspective it is important to critically consider the types of ‘collectives’ enacted through water efficiency campaigns, and whether or not these forms of interventions can create longitudinal change towards sustainable water management.

Thinking about consumption as a collectively ordered activity reflects the growing critique of conventional approaches to sustainable consumption which draw on simplified models of consumer behaviour and demand (Shove, 2010; Chappells & Medd, 2008; Strengers, 2011; Sofoulis, 2011). Such approaches fail to account for the complexity of demand; embedded in household technologies, social meanings, cultures, infrastructures and institutions that shape and maintain everyday water use (Shove, 2003, Hand et al., 2005). In recent years a number of alternative social science perspectives have emerged which celebrate the collective, relational nature of demand (e.g. Browne et al. 2014). However this is far from a consensual body of literature. The purpose of this paper is to present an analysis of various paths that could be, and are being, taken to mobilising collective action in order to achieve sustainable domestic water consumption in the UK.

The following section provides a critical analysis of literature from across the social sciences, synthesising these diverse and divergent works into four perspectives that reflect how demand might be understood as a collectively ordered activity and demonstrate the consequences of these for future demand (Table 1). The second section presents findings from focus group research evaluating the role of these collective drivers in shaping water use in the home, identifying the opportunity for, and efficacy of, different paths to sustainable domestic water consumption. Using these perspectives as the basis for analysis, the focus group data reveals that each perspective highlights different drivers of demand; different sites, scales and subjects to which water efficiency campaigns might attend; and different opportunities for intervention, some with greater potential to bring about sustainable domestic water consumption than others. The discussion focusses on laundry as a specific example of domestic water use to demonstrate how taking an approach informed by this notion of ‘collective’ opens up new opportunities for intervention.

### **What are the collective drivers of demand?**

This section critically analyses various social science literatures that provide insights into how everyday consumption can be understood as a collectively ordered activity. This represents a meso-scale enquiry that suggests consumption is shaped and maintained by shared and collective drivers that consumers have varying degrees control over, connected variously to different spatial-temporal sites and scales. The findings are synthesised into four perspectives that describe demand as a product of i) service provision; ii) individual decision making; iii) social norms and networks; and finally iv) socio-technical practices. The following paragraphs outline each perspective and Table 1 demonstrates the consequences of each perspective for the principles and practices of water efficiency.

**Table 1: Perspectives of collective drivers of consumption**

	<b>Service provision</b>	<b>Decision making</b>	<b>Social norms &amp; networks</b>	<b>Socio-technical practices</b>
<b>What are the collective drivers of demand?</b>	Industry activities; institutionalised understandings about water resources.	Price and other use variables commonly valued by consumers.	Socially defined standards of normal and acceptable use.	Collective conventions; everyday routines; technologies and infrastructures.
<b>Principles of water efficiency</b>	Demand must be managed on behalf of consumers <u>or</u> need to re-establish limits to supply security under uncertainty & extremes.	Given the right incentives and tools consumers are likely to make better decisions.	Consumers can be influenced through moral and normative reasoning to make better decisions.	Socio-technical drivers limit the extent of consumers ability to control water use in the home.
<b>Water efficiency activities</b>	<ul style="list-style-type: none"> <li>• Improving mains efficiency &amp; leakage.</li> <li>• Planning reform (e.g. making space for water).</li> <li>• Regulation (e.g. of construction and manufacture).</li> <li>• Re-connecting supply to natural conditions (e.g. seasonal tariffs).</li> </ul>	<ul style="list-style-type: none"> <li>• Communicating costs of inaction and designing incentives (e.g. billing &amp; smart metering).</li> <li>• Providing advice (e.g. water saving tips).</li> <li>• Offering products to ease change (e.g. water efficient devices).</li> </ul>	<ul style="list-style-type: none"> <li>• Engaging communities and social groups.</li> <li>• Communicating positive, normal practice (e.g. comparative billing, normative messaging)</li> <li>• Offering products to ease change (e.g. shower timers).</li> </ul>	<ul style="list-style-type: none"> <li>• Re-designing / diversifying systems of provisioning (e.g. rainwater harvesting).</li> <li>• Re-configuring water in the home (e.g. drought resistant gardens).</li> <li>• Changing routines (e.g. white uniforms in warehouse work).</li> </ul>

The first perspective conceptualises demand as product of *service provision*, driven by the activities of the water industry. Current demand is the result of ongoing and historical institutional and infrastructural development revolving around the public health and civility agenda throughout the twentieth century, and the post-war project to extend control over natural resources (Bakker 2010; Taylor and Trentmann 2011; Graham and Marvin 2002). Privatisation in 1989 may have shifted responsibility for service provision into the hands of water companies but the presiding strength of structural engineering logics and the modern regulatory structure both reinforces and rests upon this history. From this perspective demand is coordinated through the organisations responsible for the regulation and management of water. Intervention involves engineering supply to accommodate rising demand and unpredictable future conditions (e.g. through leakage reduction and network development); and/or transparently and ubiquitously communicating the limits to supply security (e.g. through planning, construction and manufacturing regulation, and through pricing structures). While this service provision model reflects a top-down approach to water management it could, if done in the spirit of true collaboration, reflect a strong adaptive effort to cultivate a resilient society (Brown et al., 2008), ensuring that we are prepared for unknowable and potentially disastrous events (Clarke, 2011).

The second perspective presents demand as result of individual *decision making*. Demand is the sum total of individual choices influenced by variables such as attitudes (e.g. towards conservation), situational factors (e.g. income, tenancy arrangement), and perceived ability to take action and have influence (Russell & Fielding, 2010). The emergence of this position within the water industry can be seen as a result of the move from ‘predict/provide’ to ‘supply/demand’ approaches introducing a new role for responsible household behaviour. From this perspective the collective drivers of demand are common values which influence large swathes of the population. From an economic perspective price is a

particularly important motivator of water conservation, particularly of hot-water, as a common-sense means to reduce household bills (Energy Saving Trust, 2013). Others include the ease by which an action can be altered and the perceived availability of technologies to reduce water consumption. Consequently intervention involves providing the consumers with simple, cost-effective solutions and complementary incentives to make better decisions in the home (Jackson, 2005). Such interventions can be effective however they are problematic; particularly as they do not address the socio-technical landscape in which consumption is situated or challenge accepted standards of supply and demand. Consequently, in the long term per capita demand is likely to continue to increase and rising populations are likely to offset any short term reductions with limited long term benefits to supply resilience (Hobson, 2013).

The third perspective emphasises *social norms and networks* as influences on individual decision making. Clark and Finley (2007) demonstrate that individual intentions are more likely to translate into action if they are supported by others around them. Furthermore individuals seen to be indirectly influenced by their understanding of what is normal and acceptable both in terms of everyday water use, and in behaviour change (e.g. Lam (2006) demonstrates that people are more likely to install dual-flush toilets if it is perceived to be common practice). More broadly consumer decisions are presumed to be informed by underlying beliefs or ecological world views; such as whether consumers perceive water to be a scarce resource or whether they believe their actions have any impact (Russell & Fielding, 2010; Corral-Verdugo et al., 2008; Schultz et al., 2004). From this perspective intervention involves working within social networks to provide social and moral justification for change. At a household level, as is the case above, these interventions are not likely to have long term or widespread benefits, however intervention may also be interpreted as building the political momentum within communities to support wider action and increasing the confidence and ability of communities to take action.

The fourth perspective presents demand as an effect of *socio-technical practices*, hereby departing from psychological perspectives, typically with vociferous criticism (e.g. Shove, 2010). From this perspective domestic water consumption is mundane and inconspicuous, entangled the continual achievement of everyday life (Jack, 2013; Shove & Pantzar, 2005). Rather than being guided by explicit values and beliefs consumption is guided by collective conventions; “shared, accepted ways of doing things” (Jack, 2013, p.4) which are coproduced with water provisioning infrastructures, and household technologies; intangible meanings around, for example, cleanliness and convenience; and tacit, experiential understanding and skills that reflects ways of doing. Furthermore domestic water demand is implicated in the organisation and coordination of everyday life for example parenting, work and leisure, each with their own associated collective conventions (Shove et al., 2012). From this perspective the collective drivers of demand are a diverse array of socio-technical relations which produce patterns of consumption, consequently intervention becomes de-centralised and must engage with areas as diverse as design, planning, workplace relations and industry standards (Browne et al., 2014). Interventions of this nature are problematic in terms of monitoring and measuring impact in any conventional sense, yet are likely to be conducive to achieving sustainable domestic water consumption.

The paragraphs above provide a condensed account of what is a voluminous and conflicting body of literature. The achievement of this section has been to align some of the most powerful perspectives in contemporary resource management and relate them to a common topic; collective action. This enables the transparent analysis of consumption and

intervention as they appear through various theoretical lenses, a generosity which could not be afforded by a single-discipline approach. Table 1 also highlights examples of where these perspectives find traction in specific water efficiency activities. Such analysis reveals the extent of investment across the water industry and highlight potential areas of opportunity not being addressed. The following section explores these perspectives through the everyday actions and experiences of consumers, through focus group data.

## **WHAT DO CONVERSATIONS ABOUT NORMAL CONSUMPTION REVEAL ABOUT THE COLLECTIVE DRIVERS OF DEMAND?**

The following section explores the evidence for these perspectives in the everyday experiences of water customers in the south-east of England. This reflects the first stage of a mixed methodology approach to studying collective drivers of consumption in one water company boundary. Three focus groups were held to explore everyday consumption and the impact of targeted intervention on domestic water consumption. In the first exercise, through semi-structured discussion participants reflected on their recognition of, and response to, various water efficiency initiatives in their area. For the second, participants were asked to select from a range of cards those which best represent everyday behaviour in a scenario where they were asked to reduce their everyday consumption to 130l/d (in line with industry targets). This required participants to work as a group to negotiate their way to an account of normal and acceptable use of water in the home. While the outputs were revealing the true purpose of this test was to provide a platform for discussion of mundane and trivial activities in everyday life to identify the drivers of demand. The findings demonstrate the role of different drivers from each of the perspectives outlined above and how they impact on the efficacy of actions taken to intervene in household water use.

### **Service provision**

Privatisation reframed the water industry as a customer-service based industry, redefining the public as paying customers with associated responsibility for their consumption (Taylor et al., 2009; Haughton, 1998; Bakker, 2003; Chappells & Medd, 2008). However discussions reveal that the consequences of privatisation for consumer expectations are complex. Our findings are consistent with Haughton's observation that following privatisation "the public still chose to view water as a public good, not a private commodity" (1998, p.421) with charges seen to justify consumption, authorising access to secure, high quality supply. These perceptions not only drive demand but inhibit consumer-targeted intervention.

*"You can't be told what water you can use, you're paying for it, you use how much you want to pay for" (Stuart, 41)*

Importantly the boundaries of ownership and responsibility appear defined through financial exchange with clear differentiation between responsibility for water in the home and water elsewhere. A recurring example was the paradox between supply maintenance (i.e. burst pipes) and consumer focused campaigns asking consumers to stop wasting water. This is problematic when considering emerging responses to management issues such as 'fat-burges'; a result of household activities that are realised in pipes and drains.

Disconcertingly when extreme events occur (e.g. drought or flood) consumers are quick to blame the water industry for mismanagement. Thus water companies are seen to inherit the responsibility for securing supplies, now and into the future, and for managing sustainable domestic water consumption as custodians of the natural system. Consequently the most appropriate forms of intervention were deemed those taken on behalf of consumers. In some cases there is acceptance that this may require challenging current standards of consumption (e.g. rationing) but more importantly requires transparent communication of the natural system with consumers.

*Graham: but see would it have gone dry if [the water company] sorted the leaks out? Phil: they killed the river! Graham: Going back to the last drought, they brought the hose-pipe ban in far too late, they knew there was a serious problem and they just left it!*

Evidence of support for the service provision perspective has profound implications for intervention. As long as the current service arrangement sustains ‘top-down’ activity is likely to be a fundamental part of achieving sustainable domestic water consumption. Strong regulation and supply development may play a part in this; however our data suggests the most valuable interventions may lie in the development of a positive relationship with consumers, creating a visible presence for the values that water companies are trying to promote (e.g. fixing leaks quickly, repairing landscape around maintenance sites), and building resilience through the customer-supplier relationship prioritising transparency, consistency and trust. In the face of increasing turbulence and significant uncertainty it may require re-evaluating the service arrangement to develop a more responsive system of supply and demand.

### **Decision making**

As anticipated, participants were quick to discuss the importance of reducing household overheads, in particular making connections between hot water and potential savings on energy bills. Correspondingly people were supportive of a recent water efficiency campaign sporting the slogan “Free savings, no catch” describing it as eye-catching, simple, clean and entertaining (it was accompanied by a picture of empty fishing tackle). However the relationship between price as motivating intent and a driver of action is complex. While participants demonstrated a clear understanding of pay-backs and trade-offs feeding into their considerations on household spending, the low price of water undermines the perceived potential value of technological investments. Even free water efficient devices were seen as too greater encroachment for too insignificant a reward.

*“It would have to be more than £20 a month, I’m not rich or anything but that’s one take-away for four and I’m thinking that I’d rather not have the take-away than worry.” (Vladi, 40)*

Further evidence indicates that ability to deliberate over water use and price is inhibited by the widespread use of direct debits and low-frequency billing. However, more importantly the findings highlight the inadequacy of the assumption that cost reflective pricing and adequate information will equate to reduced consumption, various intangible processes diminish the impact of price as a motivator. Firstly complexity results from the low level of consideration given to water consumption, instead water consuming behaviours show a high degree of automation and habit (Shove, 2003).

*“I don’t sit there thinking I’m going to have a ten minute shower, I just shower” (Sian, 32)*

Secondly water plays diverse and invaluable roles in everyday life, such as preparing for work, looking after children, keeping the house in order, and relaxing.

*“sometimes we can jump in muddy puddles three times a day which means often we need three significant washes or baths, two year olds are pretty messy!” (Hadi, 34)*

*“That’s my time out, shut the bathroom door and that’s nice quiet time, I have a bath too, so I’m probably really bad, but there is no way I could shower in four minutes.” (Helen, 34)*

As a result water use becomes automated and necessary, not open to reasoning or deliberation.

*“I do the washing when I need to do the washing. I put the dishwasher on when I need to put the dishwasher on.” (Val, 51)*

*“I mean a shower isn’t exactly wasting water if you ask me, it’s an essential, you know, you need to keep clean and if I’m going to be in there for a minute longer than I’m told to by a timer, then I’m going to be in there a minute longer.” (Phil, 51)*

The evidence from these discussions is unanimous, as much as people agreed that saving money was a common incentive for water saving, this does not translate to conscious water conservation, or even to intention to save water. These findings suggest that future price increases will disproportionately affect those on lower incomes while providing an insufficient incentive for the average consumer to alter consumption. Perhaps counterintuitively, for those who can afford it, increasing the price of water is likely to further legitimise everyday consumption making behaviour further resistant to water efficiency advice and information. This poses significant challenges to the water industry. Resource managers rapidly need to address the emphasis placed on price as an influence on decision making, and more broadly on decision making as a collective driver of behaviour as consumers are habitual, instinctive and diverse in their consumption.

### **Social norms and networks**

Throughout discussions there was evidence of social and moral influences on participants’ behaviour. There was some evidence of environmental values and beliefs, cited as key predictors of sustainable water consumption (Corral-Verdugo et al., 2008) but more importantly was evidence of social comparison delineating the boundaries of acceptable water use. Consumers reflected on the visible behaviours of friends and relatives, but also on their experiences abroad where scarcity is more visible (e.g. Turkey & Greece), the price is higher (e.g. Czech Republic), or different technologies are available (e.g. aeration in Germany).

Social networks play a particular role in learning about new technologies and behaviours (Hitchings, 2012). During the focus groups lengthy discussions revolved around sharing experiences of washing clothes in a fuller wash or on a different setting, and questioning technologies such as rainwater harvesting and water butts; how to obtain them and first-hand reviews of others’ experiences. These exchanges are more than information dissemination, posing an opportunity for consumers to share personal experiences; enabling challenge, reassurance and in some cases the acceptance of previously controversial alternatives, for example see how Phil’s attitude shifts in the following:

*Neil: Could we use water free cleaners [to wash the car]? Phil: Another bloody product! Does*

*it cost a lot of money? Neil: No, they're quite cheap! Phil: How do you get mud off? Neil: Just wipe it. Squirt it on, wipe it off and it just comes up. Zoe: Wipe it off with what? Neil: A cloth! Zoe: Any cloth? Neil: yeah, a micro cloth ideally. Phil: Bird poo? Neil: Yes! Val: So is everybody happy with water free cleaners? Bridget: No. Phil: Why, it sounds a good idea?!*

Current approaches using social norms and networks tend to focus on providing information about social norms (e.g. Icaro Consulting 2013), for instance participants had received comparative bills which compared their household usage with other similar households. Despite lack of recognition when prompted these were received with interest, however like the criticisms in the previous section, this did not reflect intention for action.

*“Without being to blasé I use the water that I use because that is how live. I think if you came and told me I was four or five times over what people in my situation should be, I might feel a little bit bad then, but I still probably wouldn't change.” (Stephen, 31)*

The problems with the comparative bill lie more in the critique of the previous model, the assumption that once given proper information and incentive (in this case, normative as well as financial) people will make better decisions. The discussions demonstrated that behaviours poorly connect to explicit processes of social comparison. Despite significant variation between people's everyday behaviours most differences were accepted by the groups without challenge, with only a few exceptions. One participant revealed that he had a Jacuzzi, despite being proud of efforts to conserve water in the home. The same person, along with the rest of the group responded with shock to another participant's revelation that she chose regular baths (at least one a day) over showers. While these reactions indicate some limits to the boundaries of acceptable, normal behaviour, consumers possessing these water intensive technologies and behaviours considered themselves to be normal.

From the evidence collected, more important was the experiential process of learning about alternatives that consumers gain throughout their lives, including interaction with places, people and objects throughout their life-course which informed an intangible sense for the acceptable ways of using water.

*I was brought up in Ireland in the fifties in the countryside and I had to walk a mile to a well for drinking water carrying a bucket, and then a mile home again. My grandparents washed their cloths in a stream by their house, so I've always respected water. (Bridget, 63)*

This perspective reveals both the importance of social networks and norms but also the complexity. Discussions reveal that to some extent practices of consumption are learnt through explicit discussion and reflection which can be simulated, revealing an opportunity for intervention by creating new spaces for people to interact and provoking conversations around alternative ways of doing (e.g. Thames Water's Fit to Drink campaign). However less tangible experiences of people, objects and places also shape consumption and without efforts to address broader cultural conventions governing consumption, interventions are unlikely to have the scale of impact required to bring about sustainable domestic consumption.

### **Socio-technical practice**

So far we have touched on the collective drivers of consumption as having socio-technical elements which prevent economic and normative drivers achieving their full potential. This section draws such elements into the limelight to see what opportunities are revealed. Most

importantly is the recognition that consumers are not entirely in control of their water use, rather it is entangled in the design and construction of homes and technologies.

*“In the morning, I turn the shower on and because its comes from the hot water cylinder maybe twenty feet away, its cold, and I have to wait for the water to warm up.” (Phil, 51)*

These are not only seen as things that are difficult for consumers to overcome, but in some cases things that consumers shouldn't overcome as designers and manufacturers are seen to be specialists in delivering water to the standards of everyday life.

*Phil: I don't want to put something up my tap, I don't, if it was supposed to be there then why didn't the tap manufacturers put it on there in the first place. Bridget: I agree with that if something goes on your tap it is going to make life worse for you?*

Thus domestic consumption is partially determined by infrastructure and technologies produced by designers, manufacturers and builders, they in turn producing technologies in-line with societal perceptions of normal and modern. People's perceptions of technologies as fitting with ideas about the modern home are made clear when discussing alternative technologies. Significantly, technologies are seen as acceptable if they do not disrupt existing configurations, with the most commonly cited reason for not installing a new technology relating to appearance, fit or involving “tearing up the bathroom. There is also a subtle distinction about ‘backward’ technologies, those which are seen to inconvenience, inhibiting access to standards of water use.

*“I'm thinking of having [a dual flush toilet] fitted anyway in our house, they're nice and modern” (Alison, 41)*

*“We're supposed to go forward with technology, not backward” (Kim, 52: rainwater harvesting)*

These observations show that practices are resistant to change; yet this does not mean impervious; twenty years ago it was common place to have only one bathroom and no shower (Hand et al., 2005). Practices are open-ended, many participants could recollect a time where they did things differently, whether it was an effect of location, personal circumstance. Furthermore practices were exposed to temporary interruption, either voluntarily (e.g. holidays and family visits) or technological/infrastructural failure (e.g. burst mains/ boiler problems).

*“we had a boiler problem lasting for six months and we very often didn't have hot water at all [...] It got to the point where I boiled kettles and washed my hair in the sink” (Vladi, 40)*

In some cases these interruptions would yield sustainable benefits however in pursuit of normality these were generally limited, short-lived and localised.

While creating interruptions is perhaps unethical, particularly in a service based industry, these observations highlight a role for the water industry in reconfiguring standards of ‘normal’ and acceptable use. In particular there is a role for the water industry in supporting and engaging with designers, manufacturers and retailers as well as working with the media that shapes consumer expectations and experiences. It is important that actions taken to design sustainable technologies and homes work with their users previous research demonstrates when this is not the case that technologies risk being appropriated by their users with unanticipated consequences (Kuijer, 2014; Gram-Hanssen, 2014; Vlasova & Gram-Hanssen, 2014).



The second finding from the discussions was the relational nature of practices which connect across different activities and spaces in everyday life. Rather than simply doing the laundry participants were washing uniforms ready for work the next day, cleaning bedding and baby cloths, or washing dirty sports kit. The context of these sub-practices is significant, for example one participant was a car-part manufacturer handling “parts coming from all over the world with all sorts of dust and stuff on them”, yet the company they supplied to require staff to wear white overalls, requiring daily washing to prevent them becoming “manky and horrible”. This had considerable bearing on laundry for workers at the warehouse particularly those, unlike himself, who only had one over-coat.

*I know loads of my associates they wash theirs regularly, luckily because I control the budget I've factored in extra uniform for myself so I've one for everyday” (Stephen, 31)*

Treating demand as the effect of socio-technical practices is complex, but it reveals invaluable opportunities for new forms of intervention. Collective conventions around home-making, convenience, and ‘modern life’ all bear considerable influence on water consumption which will not be shifted through information and messaging as they are subtle and diffuse processes experienced throughout everyday life. From this perspective achieving sustainable domestic water consumption about reconfiguring normal, not only at an individual and household level but how it is engrained in everyday practices such as parenting, working and relaxing. These findings suggest the most useful starting point is to explore behaviours such as showering and laundry as multiple, relational practices.

## **DISCUSSION: WHAT DOES THIS MEAN FOR HOW WE INTERVENE?**

The previous section summarises the strengths and weaknesses of the four perspectives on consumption as a collectively organised activity. The following paragraphs explore how this evidence might inform intervention, focussing on laundry, one of the most resource intensive water consuming activities in the home.

It is difficult to envisage actions that might be taken on behalf of consumers to intervene in the collective drivers of laundry. Actions could be taken to ration water use; limiting the timing, frequency or mode of laundry however our findings suggest this is unlikely to be supported by customers. A further option might be to shift towards technological efficiency by regulating manufacturing; making A+++ machines the industry standard and ‘eco’ the default setting. However this fails to engage with laundry practices, merely modifying technologies and consequently offers only short term (or unexpected) benefits. To progress we must engage with the behavioural element of demand.

The *decision making* and *social norms* perspectives offer two potential routes to intervene in the collective drivers of laundry. The former promoting water, energy and money savings to make reduced consumption common sense, the latter using social comparison through mechanism such as informed billing or normative messaging (e.g. “The majority of people wear their jeans at least 10 times before washing them” Icaro Consulting, 2013, p.55). However although information campaigns may positively influence the attitudes and intentions of consumers this poorly translates into action (Russell & Fielding, 2010). A further opportunity informed by the *social norms and networks* perspective is to target specific communities. There is precedence for such an approach, for example Thames

Water's fit to drink campaign worked with members of the Muslim women's collective to deliver campaign messages through sermons, community events and social media. This campaign demonstrated the benefits discussed above, improving the knowledge, confidence and skills of the wider community, however focus group discussion reveals water consumption to be habitual, irrational and constrained by technologies in the home which reduce the efficacy of such campaigns.

Hobson (2013) describes stronger forms of sustainable consumption as those that elicit more substantial reorganisations of social, infrastructural/technological, and economic systems. Using the fourth perspective laundry becomes a fragmented *socio-technical practice*. There is washing to clean (e.g. sports kit), washing to freshen (e.g. black leggings), washing for hygiene (e.g. bedding and towels) and washing for work (e.g. uniform) each posing different opportunities for intervention. In the example above, the stipulation of white overalls for employees of a car-part manufacturing warehouse generates several washes a week. Here is a highly resource intensive sub-practice to which intervention might be targeted, and there are numerous paths that may be taken. Firstly workers may be provided with extra uniforms to enable them, like Stephen, to reduce the number of washes required in a week. However this doesn't alter how regularly uniform requires washing, merely generates more of it to enable it to be less intensive. As an alternative, through collaboration with employers, dark coloured uniforms may be introduced, requiring less frequent washing. There is precedence for action of this nature; the CoolBiz campaign in Japan worked with employers and the fashion industry to establish less formal dress codes in the workplace, allowing employees to dress more suitably for the seasons. This was effective in reducing emissions from air-conditioning (Shove et al., 2012). In a further alternative we might shift uniform washing from being a household activity to a workplace activity, posing an opportunity for high volume efficient washing. Combined with dark coloured uniform this could significantly reduce the resource intensity of uniform washing. Interventions of this kind are ambitious but achievable, furthermore by interrupting routines in this way we potentially gain access to networks of practices, for instance workers getting changed at the end of the day may be more inclined to take up cycling as they are already changing out of their clothes leading to contributing toward other sustainability agendas.

## CONCLUSION

This paper began with two key questions: how can we understand water consumption as a collectively ordered activity? And how can we use the collective drivers of consumption to reduce household water demand? Through a critical analysis of the literature and focus group research we have demonstrated the value of a multi-perspective approach to unravel complex, entangled practices of everyday water consumption. The synopsis of developments across the social sciences enabled the side-by-side discussion of different perspectives which are traditionally distant. The focus groups material enabled assessment of the suitability and efficacy of these four perspectives to inform intervention and bring about sustainable domestic water consumption.

The nature of a multi-perspective approach is to favour breadth over depth in order to creatively explore potential solutions to complex problems. In taking such an approach we have identified useful starting points for further research and designing intervention. Firstly

domestic water consumption must be understood as relational; while taking place in the home, it connects to different spatial and temporal sites and scales, actors and activities. Secondly practices of domestic consumption are multiple; connecting variously to practices of parenting, working, cleaning and recreation, each with their own relational entanglement. There is a growing body of research that makes similar observations (most notably from theories of social practice) and further research may be usefully directed toward generating a more holistic understanding of household water consumption to guide intervention. Just as important is that interventions are designed to reflect these wider developments and that policy and regulation supports this. Domestic water consumption is messy, and achieving sustainability equally so. Diffuse interventions such as those discussed are likely to require experimentation, innovative systems of measurement and monitoring, and flexible timescales against which to chart savings.

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# UTILISING TIME OF USE SURVEYS TO PREDICT WATER DEMAND PROFILES OF RESIDENTIAL BUILDING STOCKS: IRISH CASE STUDY FOR DOMESTIC HOT WATER

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## ABSTRACT

The prediction of water consumption patterns is a challenge, especially when water metering is not available at scale. The paper focuses on the prediction of analytical domestic hot water (DHW) demand profiles for detailed building archetype models, using an occupant focused approach based on time-of-use survey (TUS) data.

Five dwelling types are considered over different construction periods, representative of the majority of the Irish residential stock, which is used here as a case study. They are modelled at room level using EnergyPlus and converted into archetype models. A bottom-up approach is utilised to develop the required operational data at high space and time resolution. That methodology applies Markov Chain Monte Carlo techniques to TUS activity data to develop activity-specific profiles for occupancy and domestic equipment electricity use. It is extended to DHW demand profiles by combining the probability distributions for particular TUS activities with average daily DHW consumptions, depending on the household size, day type and season.

The archetype models are found to be 90% accurate with the Irish standard dwelling energy assessment procedure in estimating the annual energy requirements for DHW heating. Moreover, they capture variations in DHW consumption, heat demand and energy usage for DHW heating, on a national scale and a fifteen-minute basis.

**KEYWORDS** <Building simulation; Demand side management; Domestic hot water; Residential buildings; Time-of-use survey

## INTRODUCTION

### EU policy and targets

Buildings are the largest energy using and CO<sub>2</sub> emitting sector in the EU at present, with residential buildings accounting for two-thirds of the sector's consumption (BPIE, 2011). The so-called "20-20-20" targets set by the EU challenge the building sector in terms of energy efficiency, greenhouse gas emissions and integration of renewable energy sources (RES). Furthermore, a series of EU directives has mandated each member state to improve the energy and environmental performance of

dwellings. Through the Energy Performance of Buildings Directive (EPBD) (European Commission, 2010) a series of reference buildings, representative of the national building stock, should be defined and a standard methodology developed for the calculation of their energy and environmental performances. Through Directive 2009/28/EC (European Commission, 2009) on the promotion of energy use from RES, 20% of total energy consumption from RES is targeted by 2020.

### **Response of the residential sector**

The direct response of each EU member state to the EPBD requirements is the development of national standard energy assessment procedures, such as the Irish Dwelling Energy Assessment Procedure (DEAP) (SEAI, 2012) or the UK Standard Assessment Procedure (SAP) (DECC, 2011). These methodologies enable the publication of building energy rating certificates and are key tools for policy makers to verify the implementation of current building regulations and to elaborate stricter ones in terms of fuel and energy conservation within dwellings.

As acknowledged by the US DoE (2011), the integration of RES requires more flexibility from the power system. This is due to the variable and uncertain nature of RES, particularly wind and solar generation. Utilisation of the flexibility offered by demand side management (DSM) is one possible strategy. However, for residential buildings in particular, it is challenging to quantify this potential due to the wide range of electricity usage patterns, variability of electrical loads and uncertainty regarding human behaviour. The integration of new load types, such as electric vehicles, and the electrification of space and water heating loads, as anticipated by the IEA (2011), further challenge the assessment of the associated flexible load resource capacity.

### **Modelling of residential sector**

Richardson *et al.* (2008) recognised that analysis of DSM in the domestic sector requires detailed and accurate knowledge of household consumer loads. By aggregating individual end-use loads, or groups of end-use loads, bottom-up approaches are capable of generating sufficient detail and are very useful for identifying the individual end-use contribution to the overall energy or electricity consumption of a national residential building stock (Swan & Ugursal, 2009). In the past decade, several bottom-up building energy or electricity demand models have been developed to study domestic loads with high time resolution (Richardson, *et al.*, 2010; Widén & Wäckelgård, 2010) and with high spatial resolution (Chiou, *et al.*, 2011). These models are usually based on time-of-use survey (TUS) data in order to extract the behavioural patterns of building residents, in terms of occupancy and use of electrical appliances. More recently, Neu *et al.* (2013) proposed an approach to develop operational data at high space and time resolution, based on TUS data, as input to building performance simulation (BPS) archetype models, with each model being representative of a group of dwellings and their loads. By integrating these operational data inputs, EPBD reference dwellings can be converted into BPS archetypes (Corgnati, *et al.*, 2013). This approach is in line with a power system perspective on the aggregated flexibility potential offered by smaller loads, such as residential ones, through the implementation of any DSM strategy (Ma, *et al.*, 2013). Water heating systems in particular, due to their thermal inertia characteristics, offer significant potential for flexibility. However, in detailed BPS archetype models, a prerequisite for the assessment of this potential is a knowledge of water consumption patterns at high time resolution (Neu, *et al.*, 2013). The prediction of these patterns is a challenge, especially when water metering is not available at scale.

### Contribution and approach

The paper deals with the development of analytical domestic hot water (DHW) demand profiles for detailed building archetype models, using an occupant focused approach based on TUS data. The Irish residential stock, whereby water metering is not available as yet, is used as a case study. The five EPBD Irish reference dwellings (DECLG & SEAI, 2013) are considered over different construction periods, representative of the majority of the national stock. They are converted into BPS archetypes by integrating high space and time resolution operational data. The bottom-up approach developed by Neu *et al.* (2013), which applies Markov Chain Monte Carlo techniques to TUS activity data, is used to develop activity-specific profiles for occupancy and domestic equipment electricity use. It is extended to DHW demand profiles by combining the probability distributions for particular TUS activities with average daily DHW consumptions, as estimated through the SAP procedure (DECC, 2011), depending on the household size, day type (weekday or weekend) and season. The archetypes capture variations in DHW consumption, heat demand and energy usage for DHW heating, on a fifteen-minute basis. Results are verified by comparing them with those estimated through the DEAP approach.

## METHODOLOGY

The set of EPBD Irish reference dwellings (DECLG & SEAI, 2013) is considered. They are modelled in detail through EnergyPlus and converted into a set of BPS archetypes by integrating the high space and time resolution operational data developed by Neu *et al.* (2013), and in particular occupancy profiles. Focus is placed on the prediction of analytical DHW demand profiles based on TUS activity data.

### Set of archetypes

Table 1 introduces the two building categories considered, namely single family and multi-family buildings, further divided into five dwelling types, such as flats or detached houses, as well as their total floor area (TFA) and the share of the Irish residential building stock represented, according to the results from the Irish 2011 Census (CSO, 2012). The set of reference dwellings is representative of approximately 82% of the Irish national dwelling stock. Each dwelling type is considered over different construction periods, namely existing and new dwellings, the latter being built in the last decade. The geometrical characteristics, construction types and materials, infiltration and ventilation levels, as well as the heating systems and control types, are in line with DECLG and SEAI (2013), and adapted from the Irish building regulations (DECLG, 2011) for both new and existing constructions.

**Table 1 – Set of EPBD Irish reference dwellings**

Building category	Dwelling type	Total floor area (m <sup>2</sup> )	Number of rooms	Share of national stock
Single family	Bungalow	104	8	43.2%
	Detached	160	13	
	Semi-detached	126	10	28.2%
Multi-family	Mid-floor flat	54	3	10.9%
	Top-floor flat	54	3	

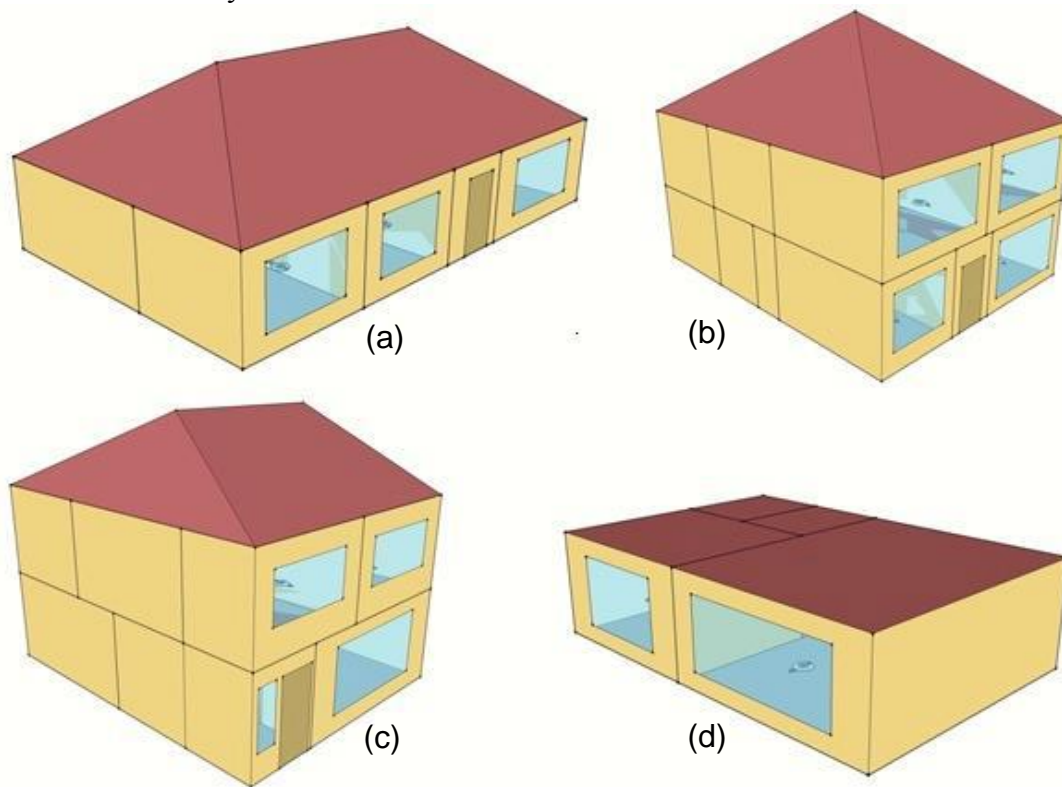


Table 2 introduces the main characteristics of the DHW heating systems and control types assumed for both the new and the existing dwelling archetypes modelled through EnergyPlus.

**Table 2 - Characteristics of the DHW heating systems and control types**

Dwelling construction period	New	Existing
Heating system fuel type	Natural gas boiler	Oil and coal boiler
Heating system combined efficiency (%)	91.3	76.0
DHW tank volume (m <sup>3</sup> )	0.278	
DHW tank outlet temperature set point and heating operation schedule	10 °C from 00:00 to 05:00 65 °C from 05:00 to 24:00	

The number of rooms, layouts and floor plans are adapted from representative dwellings defined by Brophy *et al.* (1999). Figure 1 shows a SketchUp drawing of each reference dwelling. The most representative reference dwelling of the Irish national stock, namely the detached house (i.e. dwelling (b) in Figure 1), is considered here as a case study.

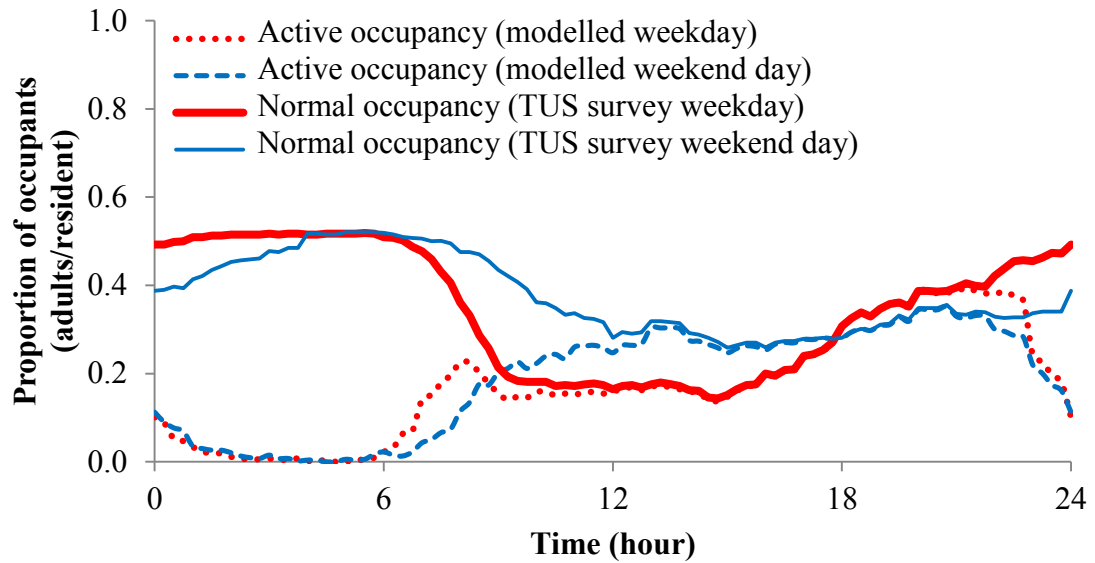


**Figure 1 - SketchUp drawings of reference dwellings: (a) bungalow, (b) detached, (c) semi-detached, and (d) flats**

#### **Operational data: occupancy**

The occupancy profiles were developed and validated by Neu *et al.* (2013), based on surveyed TUS data and varying with the household size (1, 2, 3 and “4 or more” residents) and the day type (weekend or weekday). Two types of occupancy profiles are considered, namely normal and active profiles, as shown in Figure 2. An active occupant is defined as a normal occupant who is not sleeping, and is thus willing to use any domestic equipment, such as DHW, or to perform any action to restore comfortable indoor conditions, such as the operation of natural ventilation, depending

on the active occupancy level and the performed activity type. Since only adult residents were surveyed in the Irish TUS data used (ESRI, 2005), there is a risk of underestimating the use of any domestic equipment.



**Figure 2 - Average daily modelled active occupancy and surveyed average daily normal occupancy: “4 or more” resident household**

As shown in Table 3, the chosen household sizes of archetypes are similar to the number of residents calculated by the DEAP procedure, which varies with the TFA of the building. The average household size for both the EnergyPlus and the DEAP archetypes, weighted by the share of each dwelling type within the Irish national stock, is identical but greater than the national average number of residents per household. While this might be a concern for the DEAP methodology, it is not for the household sizes considered in this work. Indeed, as shown in Table 3, the additional adult residents within the archetypes compensate for the missing national average number of children, namely 0.7 residents.

**Table 3 - Household sizes assumed for the archetypes**

Dwelling type	EnergyPlus household size	DEAP household size	National average household size	National average number of children
Bungalow	3	3.0	2.7	0.7
Detached	$\geq 4$	4.4		
Semi-detached	3	3.6		
Flats	2	1.7		
<b>Weighted average</b>	<b>3.4</b>	<b>3.4</b>		

#### **Operational data: DHW demand**

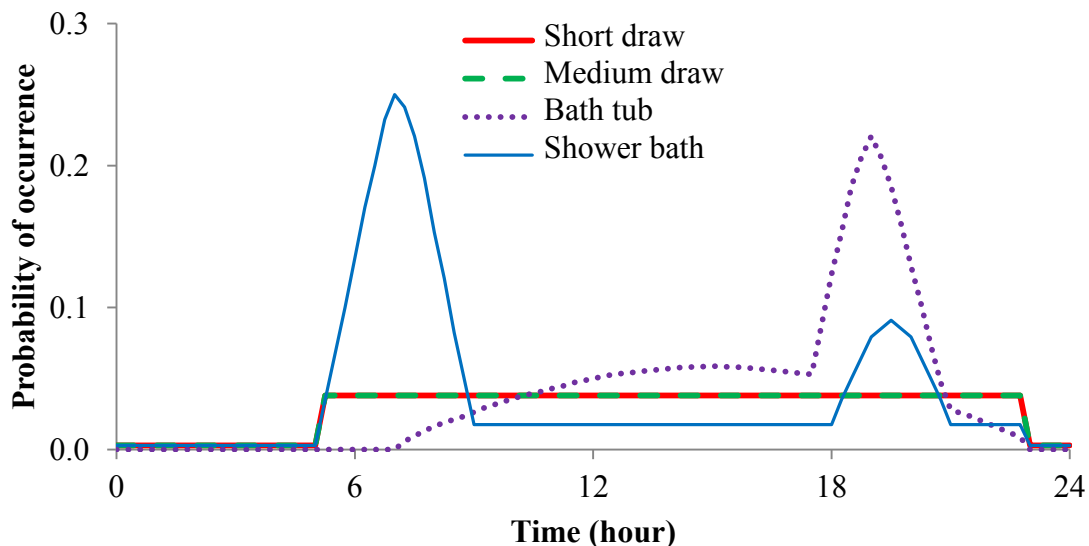
Without any water meter installed in Irish dwellings, insufficient data is available to support the development of DHW demand profiles. Instead, a national standard energy assessment procedure, compliant with the EU EPBD requirements, provides an estimation of the average daily DHW consumption per household. While the Irish

DEAP methodology (SEAI, 2012) is based on the assumed household size only, which in turn is based on the dwelling TFA, the UK SAP methodology (DECC, 2011) also takes into account the seasonal variation of the average daily DHW consumption and is believed to be a more accurate correlation. As a result, it is utilised to estimate the monthly and annual averages of daily DHW consumption for each archetype, as detailed in Table 4. Correcting for occupancy, using the household sizes set out in Table 3, a strong correlation is observed for each archetype across each methodology. The resulting monthly average daily DHW consumptions are the basis for developing activity-specific daily DHW consumption profiles at a fifteen-minute resolution, depending on the household size, season and day type.

**Table 4 - Average daily DHW consumption assumed for the archetypes**

Dwelling type	EnergyPlus DHW consumption		DEAP DHW consumption	
	(L/day)	(L/day-resident)	(L/day)	(L/day-resident)
Bungalow	111.0	37.0	107.1	35.2
Detached	159.6	32.3	141.3	32.4
Semi-detached	111.0	37.0	121.2	33.8
Flats	86.0	43.0	71.6	42.7

Four categories of DHW draw are considered: short draw (e.g. hand wash), medium draw (e.g. dishwashing), shower bath, and bath tub. Each category is assumed to be responsible for 14%, 36%, 40% and 10% of the total volume of water consumed per day, respectively, based on research studies conducted across European countries (Jordan & Vajen, 2011). Initially, the daily probability distribution functions developed by Jordan and Vajen (2011) for each category of DHW draw are considered, as presented in Figure 3.



**Figure 3 - Daily probability distribution of the DHW draw categories**

The probability distribution function of the TUS “washing” activity (ESRI, 2005), Figure 4, is found to be representative of the “bath tub” and “shower bath” probability distributions, in terms of load duration, peak times and peak amplitudes. Consequently, these two categories of DHW draw are substituted by the unique TUS

“washing” activity type of draw, assumed to be responsible for 50% of the total volume of water consumed per day.

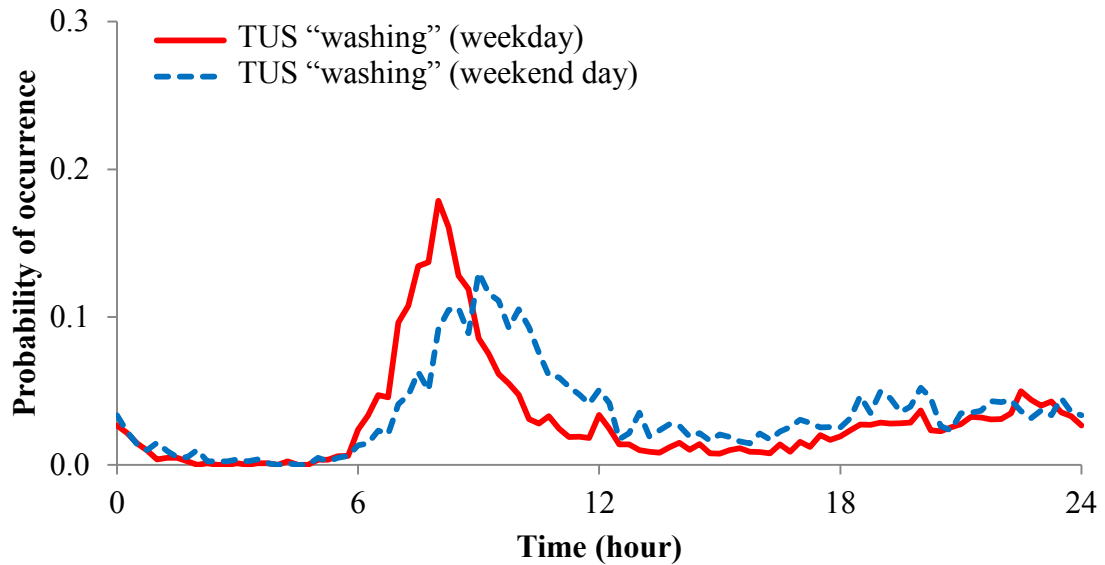


Figure 4 - Daily probability distribution of the TUS "washing" activity

## RESULTS AND DISCUSSION

The archetype models capture the variations of DHW demand, heat demand and energy usage for DHW heating, on a fifteen-minute basis. Results are verified by comparing them with those estimated through the DEAP approach.

### DHW daily consumption profiles

By fitting the average daily volumes of DHW (Table 4) within the final DHW draw probability distribution functions, the average daily DHW consumption rate profiles are generated at a fifteen-minute time resolution, as seen in Figure 5.

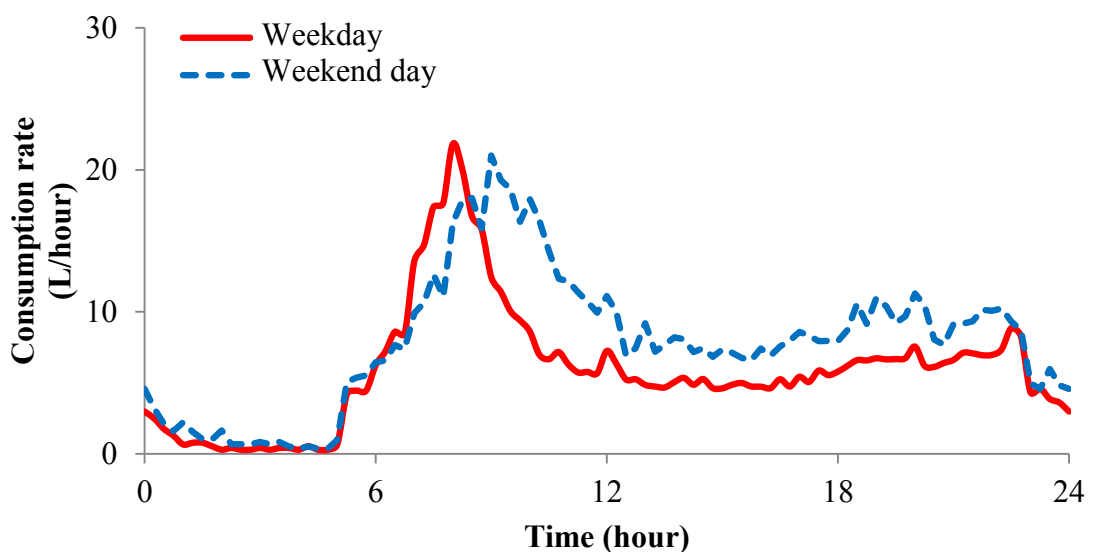
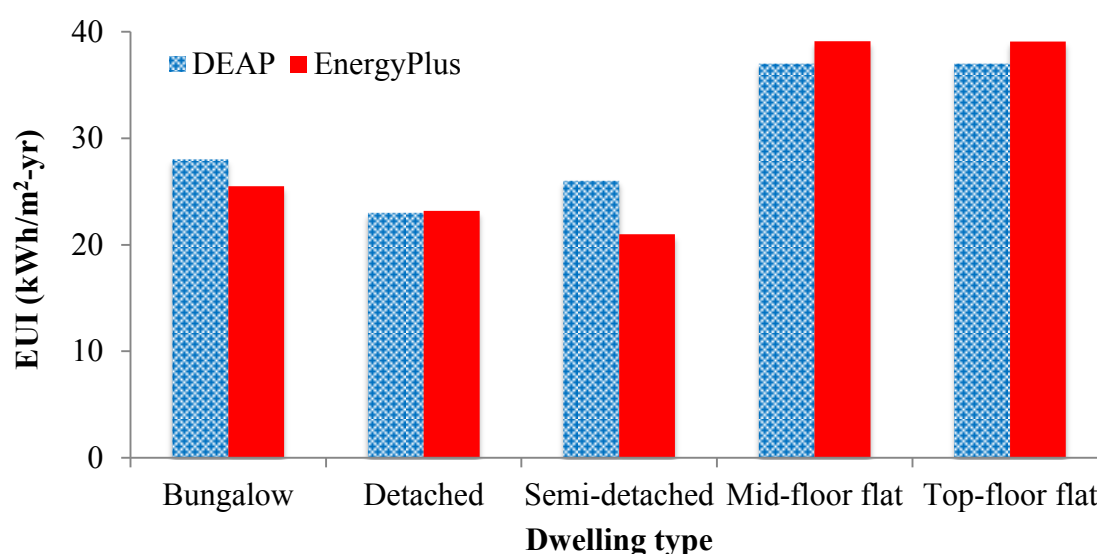


Figure 5 - Daily DHW consumption profiles: “4 or more” resident household

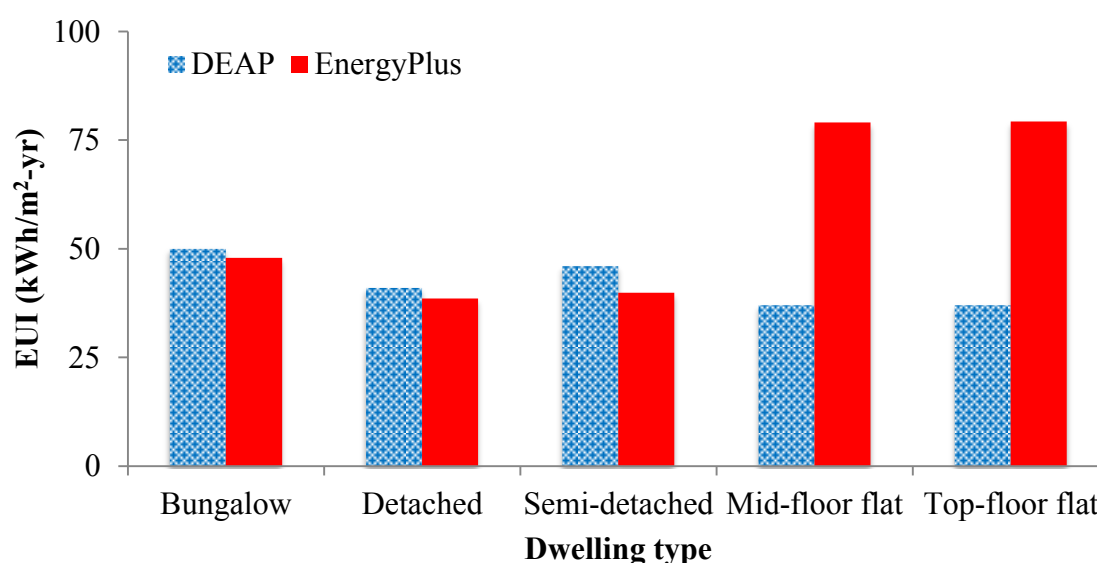
Considering Figure 5, the main peak of DHW daily consumption occurs in the morning, around 8 am for a weekday and 9 am for a weekend day. Another noticeable peak of consumption occurs in the evening, especially for weekend days. These peaks of DHW daily consumption match the peaks of probability of occurrence from the probability distribution function of the Irish TUS “washing” activity (ESRI, 2005), Figure 4. A greater resolution of the TUS data used, in terms of water consuming activities reflecting the short and medium draw categories, Figure 3, would allow the daily probability distributions, and the DHW daily consumption profiles, to be further tailored to the case study of interest. Furthermore, a similar approach could be adopted to extend the prediction of residential DHW demand to the total water demand.

### DHW annual energy use intensity

Figure 6 and Figure 7 show the annual DHW heating energy use intensity (EUI) for new and existing dwellings, respectively, as calculated by DEAP and EnergyPlus.



**Figure 6 - Annual DHW heating EUI: new dwelling archetypes**



**Figure 7 - Annual DHW heating EUI: existing dwelling archetypes**

Except for the semi-detached and the existing multi-family dwelling types, a strong correlation is seen between the DEAP and the EnergyPlus approaches, especially for existing dwellings. However, even with these outliers, a difference of 8% is observed on a national scale for new dwellings, as per Figure 6, and of 7.9% for existing dwellings, as per Figure 7. Sources of discrepancy include the differing approach for considering DHW consumption, which is standardised by DEAP while dynamically modelled within EnergyPlus based on occupant behaviour. Furthermore, the DEAP methodology accounts for distribution circuit heat losses but does not detail how they are calculated, while EnergyPlus assumes an adiabatic distribution pipe network, and heat losses are estimated by reducing the DHW tank insulation to compensate for this assumption.

Despite the difference in DHW heating EUI for the semi-detached dwelling type (Figure 6), strong correlations are observed for the other new dwelling types, and the EnergyPlus semi-detached model behaves consistently for each construction period, with a similar error observed for each of them. Considering the DEAP approach in Figure 7, there is a significant underestimation of the DHW heating EUI for the existing flats. This directly relates to the assumption made in DEAP that for flats, there is no difference in the DHW EUI between new and old construction periods, despite significant differences in heating system efficiency, whereas an increase by an average factor of 1.7 is estimated for all other dwelling types. EnergyPlus predicts an increase by an average factor of 1.8 for all dwelling types.

#### Daily DHW energy use profile

Table 5 quantifies the average daily heat demand corrected for the daily DHW consumption (kWh/L), Table 4, and the maximum heat demand over a fifteen-minute interval (kWh) of the new and existing dwelling archetypes, in winter (February) and summer (July) for DHW heating purposes.

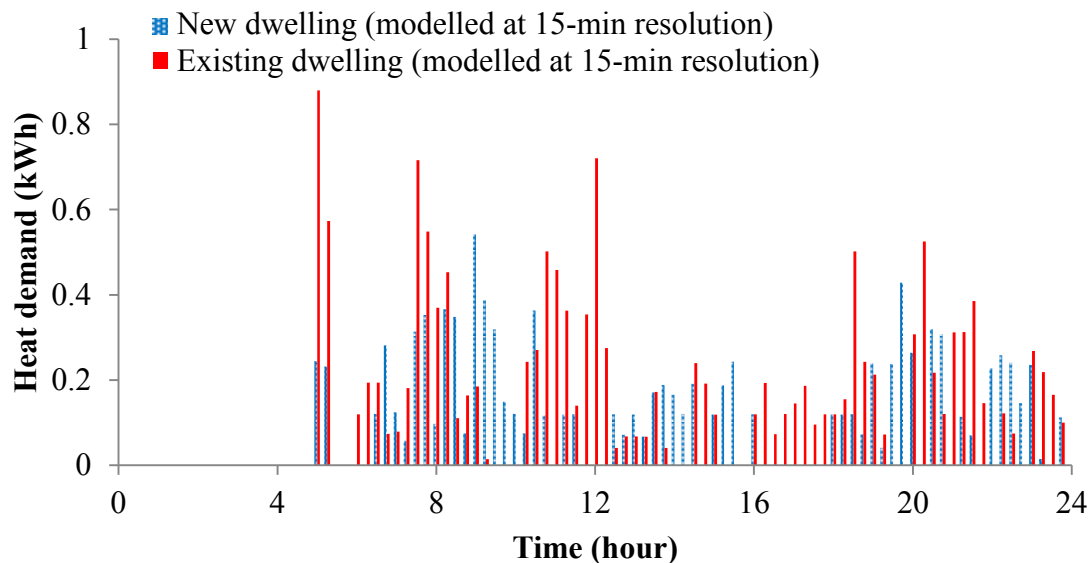
**Table 5 - Average daily and maximum heat demand for DHW heating**

Dwelling type, construction period	Average daily heat demand (kWh/L)		Maximum heat demand over a 15-min interval (kWh at “time”)	
	February	July	February	July
Bungalow, new	0.063	0.057	3.36 at 20:15	3.39 at 08:15
Detached, new	0.062	0.056	3.45 at 09:00	3.44 at 07:45
Semi-detached, new	0.062	0.057	3.45 at 05:00	3.40 at 08:30
Top-floor flat, new	0.064	0.058	3.35 at 10:00	3.36 at 08:45
Mid-floor flat, new	0.064	0.058	3.39 at 08:30	3.37 at 08:00
Bungalow, existing	0.100	0.094	3.78 at 05:00	3.70 at 05:00
Detached, existing	0.088	0.081	3.71 at 05:00	3.67 at 05:00
Semi-detached, existing	0.102	0.095	3.66 at 05:00	3.65 at 05:00
Top-floor flat, existing	0.108	0.103	3.72 at 05:00	3.62 at 05:00
Mid-floor flat, existing	0.108	0.106	3.67 at 05:00	3.47 at 05:00

The impact of building regulations on the average daily heat demand (kWh/L) for DHW heating is significant, with decreases, on a national scale, of approximately 36% and 38% for new dwellings, compared to existing buildings, in winter and in summer, respectively, Table 5. However, the impact on the maximum heat demand is much less significant, with a decrease of less than 10% for new constructions, compared to the existing ones, on a national scale, in both winter and summer, Table 5. Independent of

the season and dwelling type, the maximum heat demand for DHW heating of existing dwellings occurs in the early morning, around 5 am, at the beginning of the DHW heating operation schedule, Table 2. However, the maximum heat demand for DHW heating of new dwellings occurs later in the morning, from 8 am to 9 am, when the DHW consumption is at its highest, Figure 5. The seasonal variation of daily heat demand for DHW heating (kWh/L) is similar for both new and existing dwellings, Table 5: reductions ranging from 2% to 10% are observed, respectively, between December and July. For both new and existing dwellings, on a national scale, the seasonal variation of maximum heat demand for DHW heating is insignificant.

Figure 8 illustrates, on a fifteen-minute basis, the average daily heat demand profiles, for DHW heating purposes, of the detached dwelling archetype, during the winter season (February). The profiles for new and existing detached dwellings are uncorrelated, Figure 8, emphasizing that heat demand for DHW heating not only depends strongly on the DHW heating operation times but also on other external factors such as the DHW consumption profiles, Figure 5, or the building indoor and external conditions. As suggested in Table 5, the greatest peaks observed for existing detached houses are located at the beginning of the DHW heating operation schedule, around 5 am, Figure 8, while those for new dwellings are seen later in the morning, around 9 am, when the DHW consumption is at its highest, Figure 5. Further investigation is necessary to better understand the reasons of these observations.



**Figure 8 - Average daily heat demand profiles for DHW heating: “4 or more” resident household, February**

## CONCLUSIONS AND FURTHER WORK

A methodology based on TUS activity data is developed for predicting analytical DHW consumption profiles at a high time resolution, depending on the household size, day type and season. DHW consumption rate profiles are generated and successfully integrated within a set of BPS archetype models, representative of the majority of the Irish national dwelling stock. As a result, the archetype models capture the variations of DHW consumption, heat demand and energy usage for DHW heating, on a fifteen-minute basis. The Irish BPS archetype models are found to be

accurate to within 10% of the Irish standards, as exemplified using the DEAP methodology, for DHW heating annual energy requirements. Furthermore, the dwelling archetypes capture the seasonal variation, as well as the impact of building regulations, on both the average daily and maximum heat demand for DHW heating purposes, on a national scale. At a sub-hourly level, the maximum heat demand for DHW heating of existing dwellings is observed at the beginning of the DHW heating operation schedule, independent of the season and dwelling type. On the other hand, the maximum heat demand for DHW heating of new dwellings occurs at the peak period of DHW consumption.

A greater resolution of the TUS data used, in terms of water consuming activities reflecting each category of draw considered, would improve the accuracy of DHW daily consumption profiles for each case study of interest. Moreover, a similar approach could be adopted to predict not only DHW consumption but also total domestic water consumption. Further features of the archetype models will include the electrification of water heating systems, as well as the development of a methodology for the assessment of the demand response potential, embedded within residential BPS archetypes, through the implementation of load shifting strategies. Finally, the archetypes modelled are key to scaling up the potential flexibility resource from individual representative buildings to a national scale.

## ACKNOWLEDGEMENTS

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## **PROGRESS IN WATER CONSERVATION FROM 2010 TO 2013 IN ENGLAND**

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### **ADUVTCEV**

Water resources are increasingly under pressure due to climate change and demand from population growth as highlighted by the Government's Water White Paper. Short duration droughts (12-18 months) similar to the major drought of 1976 are predicted to become more common. Water conservation has been recognised as an essential element in managing the balance between water supply and demand. In the UK there is a duty on Government to encourage water conservation and to report to Parliament every three years on actions taken to promote it. Research for the latest report included a literature review, questionnaires to key organisations and follow-up interviews. This paper highlights findings on the progress in water conservation across household behaviour; home and communities; products; non-household water use; government estates; water supply and water industry; water sensitive urban design; and, climate change and innovation.

Keywords: Behaviour, Communities, Government, Products, Water efficiency

### **INTRODUCTION**

Climate change and population growth are placing increasing pressure on water resources. The drought in 2012 followed parts of England recording their lowest 18-month rainfall in at least 100 years and resulted in severely depleted groundwater levels and associated river flows. This led to implementation of Temporary Use Bans (watering restrictions) in 7 water company areas affecting around 20 million customers (Burton 2014). During the period 2010 to 2013 a 3% decrease in demand from public water supply was observed and linked to improved efficiency of appliances, reduced industrial use and water efficiency activities. A decrease of 6 litres per head per day was also observed for households (Defra 2014).

Under Section 81 of the Water Act 2003 the Secretary of State has a duty to encourage water conservation and also to report to Parliament every three years on actions taken to promote it and any steps proposed for the future. The first report was published in 2008 and encompassed the 2004-06 drought (Great Britain & Department for Environment 2008). This paper highlights some of the key projects identified within the latest report to Parliament that was published on 6 May 2014 (Defra 2014). Progress is compared with the previous report and the implications for future water efficiency discussed.

### **APPROACH**

A questionnaire template was developed to gather initial information for the report and to inform which stakeholders would be interviewed. The template included general information on the respondent's type of organisation and activities they were involved in. This was followed by a project specific template adapted from the UK

Water Efficiency Awards 2012. The questionnaire was emailed to stakeholders. Those organisations that responded provided a detailed update on the projects they were involved with and others highlighted their availability for interview.

Interviews were undertaken with those who indicated a willingness to participate in their questionnaire responses and were also targeted towards gaps in information in the questionnaire responses. Interviewers were held with representatives from the Environment Agency, WRAP, Department for Communities and Local Government, Defra, and Waterwise.

Information gaps identified in the questionnaire and interview responses were targeted in the review. A wider review of web pages and grey literature was undertaken for organisations including: DEFRA; Environment Agency; WRAP; Ofwat; Department for Communities and Local Government; Department of Energy and Climate Change; Crown Estate; and, Waterwise.

## RESULTS

### Household Behaviour

Household behaviours have been a major focus area for water efficiency between 2010 and 2013. This includes actions ranging from supporting academic research and networks to water company pilots and applying these approaches from a policy perspective. Future programmes will benefit from the insight gained into household water using behaviours and the most effective communications/ messaging approaches to reduce water use.

The Energy Saving Trust and Waterwise launched a project in January 2009 with the aim of highlighting the links between water and energy to householders in the UK, and promoting the benefits of adopting water and energy-efficient behaviour. The project took place in Cardiff, London and Edinburgh and ran until April 2011. It was funded by contributions from the LIFE+ financial instrument of the European Community, Department for Energy and Climate Change and the Scottish Government. The report in 2011 estimated the uptake of 18,000 water saving devices and/or behavioural measures resulted from the project covering 25,000 people and saving 523 tonnes CO<sub>2</sub> per year, 176,000 cubic meters of water, and £135,000 on water and energy bills. However, one of the key recommendations was around delivering personalised, in-home advice to enable the greatest water and energy savings (Energy Saving Trust 2011).

Plugin was another programme testing innovative approaches for achieving pro-environmental behaviours: working with intermediaries as facilitators of change to the way people live or consume (2010-2012). Funded by Defra, this project developed tools that will enable trusted intermediaries (plumbers, retail store assistants, etc.) to assist consumers in making water efficient choices as they are purchasing or sourcing new kitchen and bathroom fittings and white goods. This focussed on a 'moment of change' at which water efficient behaviour can be introduced or reinforced. Water-saving equipment was installed in 3,300 homes between April 2011 and April 2012. This saved almost 40,000 litres of water a day (equivalent to the water use of about 308 people) and approximately 250 Kg of CO<sub>2</sub> a day. During the project 737 residents were directly engaged with the EcoTeams behaviour change advice activities looking at ideas for sustainable living (Environment Agency 2013b).

A Defra project testing high level water efficiency messaging aimed to establish households' motivations and barriers in respect of water efficiency. This research sought to take a broader view of water using behaviours, incorporating psychological and sociological drivers associated with certain activities that take place in the home (e.g. laundry, showering). Results highlighted that the public retain a core belief that water is an abundant resource and the treatment of droughts as an exception to this reinforces this point. As with energy and appliances, householders may not know how to make the most efficient use of new water using appliances. High level messages on water efficiency need to be applied carefully and messages that contradict the belief rainfall is abundant are less successful than those linked to wider pressures. Finally, more specific messages are required that demonstrate how households can change and are targeted at specific behaviours and activities (Icaro Consulting 2013).

Herne Hill "Lost Effra" was a two year project co-funded by Defra under its Civil Society Advisory Board aimed at producing a strategy for both funders, and government, on how to transform a mixed district in London using water management strategies, as the basis for collaboration, and sustained consumer behavioural change. Water efficiency features in the strategy released in 2014 including householder awareness of their consumption, a reduction in water usage from 166l/h/d currently to 141 l/h/d by 2040, and schools in the area promoting water efficiency (London Wildlife Trust 2014).

Save Water Swindon (June 2010) was a campaign launched by Thames Water, Waterwise and the WWF, to help everyone in Swindon use less water in the home. Save Water Swindon aimed to reduce water use in Swindon to ensure that there is enough for people and the natural environment, now and in the future. It is the first project to take a 'whole-town' approach. In 2012, over 2,500 home retrofits had been completed. Between June 2010 and June 2011 alone it is estimated that 34,869 litres of water per day has been saved across all home retrofit properties (Jordan 2012).

Patterns of Water (published 2013) was funded by the ESRC/Defra/Scottish Government's Sustainable Practices Research Group. This report focuses on the research results of an 1,800 person survey across the south of England, and a number of qualitative interviews with survey participants. It covers household water use related to laundry, washing/bathing/showering, toilets, gardening, car washing, cleaning, food consumption, recycling, bottled water and kitchen use. The key outcome was understanding routines and behaviours of every life linked to domestic water consumption required consideration of practices rather than attitudes, behaviours or simply focussing on volume used (Sustainable Practices Research Group 2013).

### **Homes and Communities**

The Government commissioned an independent review of charging for household water and sewerage services - The Walker Review (published April 2011) - which examined the effectiveness and fairness of current and alternative methods of charging to ensure that England and Wales has a sustainable and fair system of charging in place (Walker Review 2009). The key recommendations from this including social tariffs were consulted on in 2011 (Defra 2011b).

The Building Regulations 2010 introduced new minimum water efficiency standards, requiring all new homes to be designed so that their calculated water use is not more than 125 litres per person per day. The Water Efficiency calculator for New Dwellings (2009) was developed in accordance with the Government's National Calculation Methodology for assessing water efficiency in new dwellings in support of The Code for Sustainable Homes, and the Building Regulations Approved Document Part G, the Water Calculator uses the method set out in the "Water Efficiency Calculator for New Dwellings". The Water Calculator contains information on water consumption for hundreds of products, enabling quick and easy specification, without the hassle of gathering data from several product manufacturers (Bathroom Manufacturers Association 2014).

This Environment Agency and Energy Efficiency Partnership for Homes report *The potential for combining household water and energy retrofitting (2011)* examined the policy and regulatory framework for both domestic energy and water efficiency retrofitting, along with incentives and funding programmes taking place in these areas. The opportunities for delivery of water and energy retrofit, through installation of measures and labelling schemes are set out, followed by a discussion on how these can also be linked with activities for retrofitting for flood resilience (Environment Agency & Energy Efficiency Partnership for Homes 2011).

The Waterwise Tap into Savings programme was launched to help residents in social housing and their neighbours save water, energy and money. During 2010 and 2011, projects were delivered in Merstham and Redhill (Surrey), Coventry (West Midlands) and the Braintree District (Essex). Over 4,500 home visits were carried out during which free water and energy efficiency devices were fitted and advice provided. The programme delivered average water savings (based on the devices installed) of 40 litres per day per home visited. Overall the programme saved more than 57 mega litres of water per year and reduced emissions of climate changing gases by more than 185 tonnes of CO<sub>2</sub>e annually. It was the first water efficiency programme to build in energy efficiency and recycling, and to place an equal emphasis on installing efficiency devices and influencing pro-environmental attitudes and behaviours (Waterwise 2014).

Defra co-funded the Construction Industry Research and Information Association (CIRIA) project and report 'Creating water sensitive places – scoping the potential for Water Sensitive Urban Design in the UK'. Water Sensitive Urban Design (WSUD) is an holistic approach to planning/retrofitting development within the limits of the water environment which has been developed in Australia and can help address current and future pressures in the UK. Water efficiency is a key consideration within WSUD and features in the ideas produced at a range of scales from household to city. The report identifies the need to consider both water efficiency and alternative supply options along with the wider benefits of rainwater and storm- water harvesting for reducing flood risk (CIRIA 2013).

## **Products**

The Water Label is a voluntary scheme providing comparative information on volumes of water use between similar products to help inform consumer purchase decisions in favour of more water efficient ones. The Water Using Products Group, facilitated by WRAP worked with major retailers and merchants to increase the sales

of water efficient bathroom products by DIY retailers and builders merchants, through a voluntary labelling approach (WRAP 2014d). The new labeling will start to appear across a wide range of products in summer 2014.

The Enhanced Capital Allowance (ECA) scheme and Water Technology List (2003 to present) offers a 100 per cent first-year allowance for investments in certain water efficient plant and machinery for companies paying tax in the UK. Launched in 2003, the aim of the Water Technology List is to improve the water efficiency of the non-domestic sector and encourage businesses to save money by investing in technology and products that reduce water use and improve water quality. Criteria of the scheme are reviewed annually so that they reflect any changes in Government policy, British Standards or European Standards. In addition, a number of new technologies which have the potential to be added to the scheme are reviewed each year. Views of stakeholders such as manufacturers and suppliers are taken into account throughout the process (Defra 2013).

A 2010 report presented the findings of a study into the energy and carbon implications of rainwater harvesting (RWH) and greywater recycling (GWR) systems. The Environment Agency (EA) commissioned the review jointly with the Energy Saving Trust (EST) and National House Building Council (NHBC) Foundation. The study quantifies: lifetime carbon footprints of RWH and GWR systems, consisting of embodied carbon and the carbon emitted from operational use; and the contribution of RWH and GWR systems to reducing carbon emissions associated with mains water demand and foul water volumes (Environment Agency 2010a).

### **Non-household water use**

Improved water efficiency in non-household water use has been led by several government-industry partnership projects and provision of support to businesses through procurement guidance.

In response to Defra's 2006 Food Industry Sustainability Strategy (FISS), the Federation House Commitment (FHC) was developed to help companies in the food and drink sector to reduce water use across their manufacturing sites. This voluntary agreement is managed in partnership with WRAP, Food and Drink Federation (FDF) and Dairy UK, with support from the Environment Agency. It is funded by Defra and the Scottish Government. All companies that sign up to the FHC agree to make a contribution to the food and drink industry water reduction target of 20% by the year 2020, against a 2007 baseline. By 2011 a 12.8% decrease in water use was reported and this rose to 16.1% by 2012 in the latest 2013 report (WRAP 2014b).

WRAP's Business Resource Efficiency (BRE) programme was launched in 2010 to help businesses identify and implement resource efficiency measures. From 2011 to 2013 WRAP's BRE work has engaged with the water industry to develop and deliver a partnership arrangement which aims to accelerate the implementation of water efficiency measures within water companies' non-household (commercial and industrial) customer base. Pilot projects were established with two major water companies (Anglian Water and Thames Water), to provide 'proof of concept' such that the approach could be rolled out more widely across the water industry in England in the future. In total over 430 organisations participated in the pilot projects resulting in over 390,000m<sup>3</sup> (1.08 Ml) /year of actual water savings with further

potential savings identified through on site water efficiency reviews of over 290,000m (0.81Ml)/year (WRAP 2014c).

The Food and Drink Manufacturing Water Demand Projections to 2050 project looked at how demand for water from food and drink manufacturing may change in the future. Outputs from the project will provide additional details on food and drink manufacturing to the Environment Agency's Case for Change. It will also help to deliver against the commitment in Defra's Water White Paper to 'develop demand scenarios in partnership with different sectors, and use the outputs to develop a common understanding of the future risks to both the abstractors and the environment and provide advice to Government' (Environment Agency 2013c).

In 2011 WRAP developed guidance and model clauses to help clients and developers ask for water-efficient buildings when procuring design, construction and facilities management services. The water efficiency through good procurement practice summary (WRAP 2014a) guidance is available for those involved in new build and management and refurbishment of existing buildings .

The Green Construction Board (GCB) was established in 2011 and the group includes representation from a broad range of construction industry bodies (e.g. CPA, UKCG) as well as government (Defra, BIS, CLG) and agencies (EA, WRAP). To date, the Water Subgroup has developed a methodology for establishing the 2008 baseline for water use, against which progress towards, and ultimately performance against, the 2012 target is being measured. The group prepares annual reports on progress to the target as well as progress against other actions detailed in the group's Action Plan. By 2012 a 20% reduction in water use was observed for the construction sector compared with 2008 (Strategic Forum for Construction 2011). Guidance was also developed on preparing a water efficiency strategy.

WRAP also wanted to develop robust primary data quantifying where water is wasted and the associated water using processes on construction sites. The final report summarises the findings from an evaluation of water use on construction sites and a subsequent water audit programme which comprised an audit of three construction sites over an extended period. The audits revealed water saving opportunities at all audited sites, with savings ranging from 13% - 24%, and as high as 40% - 83% where significant leaks were observed. Some of the main opportunities identified for improving water efficiency included: the domestic and welfare facilities on sites; improved monitoring and targeting to raise awareness of water consumption; investment in appropriate water saving equipment and devices particularly for use in dust suppression; and action on leaks (WRAP 2012).

### **Government estate**

The Government Estate includes around 9.2 million m<sup>2</sup> of office space and associated water use for domestic and specialist purposes. The Government have agreed the commitments for greening Government operations and procurement which includes reducing water usage. By 2015 the Government, including Defra have agreed to reduce water consumption from a 2009/10 baseline (Defra 2014b), and report on office water use against best practice benchmarks (i.e. ≤4m<sup>3</sup> per FTE best practice) .

The Cabinet Office leads on delivering sustainable procurement across Government. Government Buying Standards are designed to make it easier for Government buyers to buy sustainably (Defra 2014a). The standards are mandatory for all central Government departments, their executive agencies, Non Departmental Public Bodies (NDPBs) and Non-Ministerial Departments (NMDs). During 2010 a number of mandatory water efficiency products were specified such as water efficient taps, showers, toilets and urinals (Defra 2011a).

In early 2012, Defra implemented a range of measures to reduce water use in washrooms across its offices. Opportunities were identified for installing flow restrictors on taps and showers, as well as toilet flush restrictors and waterless or low flush urinals. Implementing these technologies represented easy and relatively cheap wins, taking three months to implement with minimum disruption to business. The biggest saving came from the waterless and low flush urinal devices which delivered an annual saving of 9,900m, with the flow and flush restrictors delivering an annual saving of 2,521m. The annual financial saving from this water saving was approximately £25,000. Altogether, these changes have contributed to a 23% reduction in water consumption across the estate, and office water use levels per head of staff very close to meeting demanding good practice standards.

The Environment Agency's corporate strategy sets out their aims for the period to 2015 and describes the role they will play in being part of the solution to the environmental challenges society faces. The Environment Agency has set a target of reducing water use by 25 per cent compared to the 2005 / 2006 baseline (Environment Agency 2010c). In 2012 / 2013 this target was exceeded and water use has been reduced by 29% (Environment Agency 2013a). The new Horizon House head office opened in 2010 and uses only a quarter of the water consumed at the previous two sites. The site's water conservation features include rainwater harvesting, waterless urinals, low flush toilets, infra-red activated spray taps and low flow showers. Rainwater from the roof is collected, filtered and stored, and used to flush the toilets.

### **Government Guidance and regulation**

The Environment Agency, Ofwat, Defra and the Welsh Government have developed the water resources planning guideline to advise water companies producing their 25 year water resource management plan (Environment Agency 2010b). A number of documents were published in 2012 and 2013, including: the guiding principles; the water resources planning guidance; supply-demand tables; technical methods and instructions for the supply-demand tables; and audit checklists. Where a company is in an area designated as water stressed, or where it has demand that is above the national average (147 litres per head per day), the guidance expected the demand trend to be significantly downwards. This includes considering all technically feasible demand side options together with other options to balance supply and demand. Metering approaches are also outlined based on areas of water stress and provision of support such as water audits and water efficiency advice to be provided when implementing metering programmes.

In October 2012 the Environment Agency consulted on a new methodology using up-to-date evidence, for determining the level of water stress for areas in both England and Wales. The project has produced a complete picture of where there is a recurrent in balance that arises from an overuse of water resources for a given area. The



designation resulting from the new methodology provides water stress data, which could be used for purposes other than metering. In particular, the stress designation could be used in encouraging or supporting higher water efficiency measures in new build, or to support retrofitting initiatives (Environment Agency & Natural Resources Wales 2013).

Ofwat published a document with proposals to amend elements of base water efficiency targets for 2012-13 to 2014-15 to improve the water savings that companies make by promoting water efficiency (Ofwat 2012). Changes to allow water companies to pay towards a collaborative research fund and receive an allowance against their water efficiency target. A financial contribution of £170,000 will be equivalent to 1 megalitre of the quantified base target. The maximum contribution companies can make is the equivalent of 15% of one year's base target.

The sustainable economic level of leakage (SELL) is the level of leakage at which it would cost more to make further reductions in leakage than to produce the water from another source. The SELL calculation should include all costs and benefits associated with different levels of leakage, including environmental and social ones. Defra, together with the Environment Agency and Ofwat, commissioned a study to review water companies' calculation of the Sustainable Economic Level of Leakage (Strategic Management Consultants 2012). This report recommended greater integration with Water Resources Management Plans and provided recommendations around external costs such as taking a catchment based approach to valuing environmental benefits of leakage reduction.

### **Developing the evidence base**

A 2010 Waterwise report summarised the water efficiency activities of the UK water industry over the past few years and detailing future projects (Waterwise 2010c). This has been expanded with the Waterwise Evidence Base, co-funded by Defra, Environment Agency and Ofwat. This provides resources to support water company decision making around water efficiency options within water resources management planning. The Phase II interim report in 2010 aimed to present robust, measured savings from trials and projects in the UK. This included uncertainty, establishing the Average Incremental Cost and Average Incremental Social Cost, compare measured water savings to theoretical water savings, estimate carbon emissions and energy savings from each trial; and, make recommendations for further work on the evidence base (Waterwise 2010a). The Phase II second report focussed on school retrofits with data from 600 school retrofits analysed (Waterwise 2010b). The Phase II final report included longevity of water savings from domestic water efficiency retrofitting trials (Waterwise 2011). To support water companies' decisions regarding demand management, the Environment Agency ran a project to provide an independent scrutiny and audit of the Waterwise evidence base and undertake a review of water efficiency demand management measures (Environment Agency 2012).

A research project in 2012 reported uptake in water efficiency home visit retrofit projects ranged from 6% to 60% in the projects included in the Evidence Base. This project sets out how to better understand factors behind uptake and reviews recruitment methods in previous programmes. The results covered use of letters, telephone calls, door-knocking, and combined recruitment methods. These need to be tailored to the scope and target audience of the project (Waterwise 2012a).

Investigating the impact of water efficiency educational programmes in schools: a scoping study (2012) was funded by Defra, Environment Agency and Ofwat as an evidence base project. Water efficiency education is provided to school pupils by water companies and a range of other organisations. Previous work for the water efficiency evidence base highlighted uncertainties, in particular around the interplay between school retrofit programmes and educational efforts. The scoping study brought together the range of evidence from schools programmes and made recommendations on evaluation programmes (Waterwise 2012b).

The Planning Effective Water Efficiency Initiatives guide, developed by Waterwise with WWF, draws on two major water efficiency retrofit programmes (Tap into Savings and Save Water Swindon), as well as projects included in the Waterwise Evidence Base, to provide direction for those designing a water efficiency retrofitting project. It aimed to help water companies put demand management at the heart of their Water Resources Management Plans and Price Review (PR14) plans (Waterwise & WWF 2012).

Water companies are considering opportunities for creating partnerships with Green Deal Providers to see a range of work being done in the property. Defra provided funding, along with others, towards an Energy Saving Trust and Waterwise publication providing guidance in 2012 on how to increase uptake of joint energy and water efficiency programmes, through partnership working between water companies and energy efficiency programme providers (Waterwise & Energy Saving Trust 2012).

## DISCUSSION

This research project collated and reported on a range of Government funded and supported water conservation activities between April 2010 and March 2013. A 3% drop in demand from public water supply and a 6 litre per head per day drop in household demand was observed over the period. The 2014 report covers 72 individual initiatives compared with 22 initiatives reported in 2008. Additionally, greater project and programme evaluation has been implemented along with water and energy saving figures reported.

The key insights into household behaviour include the benefits of personalised in-home advice to enable the greatest water and energy savings; utilising ‘moments of change’ to introduce or reinforce water efficient behaviours; the need to carefully apply any high level messaging on water efficiency; and, understanding water use practices rather than attitudes, behaviours or simply volume used. For homes and communities the major changes were to the building regulations and supporting higher standards of water efficiency with developments such as the water calculator. This is linked to product changes such as the voluntary Water Label and the Enhanced Capital Allowance scheme. Government programmes have resulted in significant water savings in the food and drink sector, construction and more widely through Rippleffect. Clear policy direction has resulted in improvements to the Government estate that can be exemplified for other sectors.

The evidence base has moved on significantly between 2010 and 2013. However, the collaborative water efficiency programme to meet Water Efficient Targets represents

an opportunity for larger-scale and more strategic research into water company water efficiency interventions. The Leaky Loos Phase 2 project is an example that will assess over 300 toilets for leakage and provide strategy and policy recommendations for the whole industry. A large scale showering project has also been proposed and both will benefit from large sample sizes to enable more statistically robust analysis. With the removal of water efficiency targets from 2015 the momentum behind this strategic approach to research needs to be maintained.

A major question raised in the Walker Review was around responsibility for delivering water efficiency and water conservation. This paper highlights the many partnerships between government, water companies and wider stakeholders that have been delivering water efficiency. Research on the impacts of messaging and temporary use bans/ watering restrictions during the 2012 drought suggest that pro-active communication around water efficiency is important and that messaging from water companies had the greatest impact (Burton 2014). Continued research is required to understand how to change water using behaviours over the long term and create new social norms.

Finally, Water Sensitive Urban Design provides an opportunity to address water conservation as part of resilience to both drought and flooding. This can be delivered through greater partnership working and this will enable funding for more innovative approaches. In considering alternative water sources and decentralised water and wastewater solutions we need to ensure that costs and benefits of these are adequately compared with traditional water efficiency measures. Programmes need to take an integrated approach to maximise the benefits of water companies being in homes and communities. The Water Efficiency in Buildings Network (WATEF) is already demonstrating moves towards this approach by holding events on water reuse and also considering sustainable drainage within their remit.

## CONCLUSION

There has clearly been an increase in Government funded and led water conservation activities in this report to parliament compared with the 2008 report. There is a need for continuing improvement to the water efficiency evidence base to support movement from pilot projects to large scale operational programme delivery. In order to address pressures from climate change on drought and flooding a multi-disciplinary and integrated approach is required from research to regulation and delivery of water efficiency.

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## **IS DECENTRALISATION OF WATER SUPPLY THE FUTURE FOR THE UK WATER INDUSTRY?**

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### **ABSTRACT**

Recent visioning work with the UK water industry repeatedly indicated that decentralisation of both water supply and wastewater treatment was an option for the future - by 2050. However, there are risks associated with the use of these systems in domestic and commercial properties and the water industry needs to establish whether or not the benefits outweigh the risks.

Rainwater harvesting and grey water recycling are regularly mooted as being the solution to reducing demand on potable water supplies, to reducing pumping and treatment costs and helping to prevent localised storm water flooding. Water companies have started to look at these benefits but as yet most of these have not been quantified. Up to this point the agenda has largely been driven by manufacturers, government, environmental campaigners and commercial organisations seeking business cost savings.

Working with five UK water companies, WRc has recently carried out a collaborative research project which explored the factors which impact on a water company through the installation of these systems by its customers. This paper discusses the major risks and opportunities, and provides a suggestion of whether we might see water companies evolving to be rainwater harvesting and grey water reuse system service providers in the future.

**Keywords:** Alternative Supplies, Greywater Recycling, Rainwater Harvesting, Water Reuse

## INTRODUCTION

There is an ever-growing need to conserve water and utilise the UK's natural resources in a more sustainable manner. Rainwater harvesting (RWH) and grey water recycling (GWR) are two solutions often proposed to help reduce demand on potable water supplies (Hassell, 2005). Other suggested benefits include a reduction in pumping and treatment costs and the ability to help the prevention of localised storm water flooding (Han and Mun, 2011)

A group of forward-thinking water companies worked with WRc to fully understand the true benefits, financial impact and risks to water companies and their customers of the growing market for RWH and GWR.

At their current rates of installation, the impact of RWH and GWR systems on water companies is small (Parsons, et al., 2010). However, the benefits to the water industry may suggest a significant change in the future promotion of such systems.

It is important that knowledge of the installation, maintenance and performance of these systems is sufficiently robust to ensure that there are no negative impacts on the water companies or their customers and, subject to the future strategy taken by water companies, that there is an opportunity to maximise the benefits. A thematic approach to reviewing the RWH / GWR evidence base has been used. The review identified that some themes have a strong body of evidence, some are lacking in validation of modelled impacts, and for some there is little or no existing information.

The positive impacts defined in this paper provide direction for water company involvement in the growing market for RWH and GWR systems. The results leave them well placed to assess their future strategy, and for some this may be to move to being a service oriented provider of such systems.

## OBJECTIVES

Based on the premise that customers (both domestic and commercial) will continue to install these systems for a variety of reasons, a water company will want to respond to this market need whilst also protecting their own business in terms of operation, regulatory obligations and income. Activities need to be prioritised by those of greatest importance to a water company and its customers and, even then, influence might be best achieved through engagement with other key stakeholders.

The objectives of the study were therefore to:

- Qualitatively assess the risks and benefits to a water company so that future planning is supported by a robust evidence base;
- Identify initiatives by key stakeholders to permit a water company to engage at the right level;
- Identify gaps in information needed to encompass RWH / GWR systems in business planning and / or mitigate risk to a water company; and



- Map out future actions to maximise the benefits and minimise the risks to a water company, recognising that these might be different for domestic and non-domestic applications.

## **RISKS AND BENEFITS OF RAINWATER HARVESTING AND GREY WATER RECYCLING**

There are competing motivations for encouraging or discouraging the growth in use of alternative water sources such as RWH or GWR. On the one hand, it is recognised that there is potential for a significant (negative) impact on public relations, environmental and social credentials should a water company oppose such systems. On the other, there is a suggestion that the use of RWH could help reduce surface water run-off and reduce the impact on flooding. There are conflicting reports over the real water savings and possible increases in carbon emissions, concerns over water quality and public health responsibilities.

The water industry still has an opportunity, whilst the market for RWH and GWR is developing, to influence the way in which these systems are introduced and, through doing so, can have a positive impact on a water company's business.

In collaboration with five UK water companies, WRc explored all perceived risks and benefits that could impact on a water company through the installation of RWH / GWR systems by domestic and commercial customers.

In practice, many of the perceived risks and benefits are linked to, and depend upon, selection, installation, use and maintenance of systems as to which are realised and which not. These can be classified into a number of key themes and are outlined in Table 1.

**Table 1 Themes identified through collation of perceived impacts on a water company**

<b>Theme Title</b>	<b>Description</b>
Customer contacts (with developers)	An increase in the number of RWH / GWR system installations will have an impact on contact and relationships between developers and the water company.
Customer contacts (with property owners/occupiers)	Domestic customers account for the majority of the water company customer-base. The number (and type) of contact these customers make with the water company is important as it has the potential to impact significantly on public image and company income.
Carbon footprint	The replacement of centrally distributed potable water with locally sourced non-potable supplies has the potential to impact on the carbon output associated with the production and distribution of drinking water and the carbon efficiency of the water company.

Theme Title	Description
Income	The introduction of water reuse systems has the potential to impact on a water company's income through reduced mains water supply.
Energy efficiency and energy use	The use of RWH / GWR systems would impact on the required capacity and the overall energy consumption for the water company.
Customers' bills	The installation of RWH / GWR systems has the potential to reduce customers' dependency on the supply of potable water from the water company. This reduction in potable water may lead to reductions in water bills received by customers.
Demand for drinking water	The use of water from RWH / GWR systems has the potential to impact on the amount of potable water used by both domestic and non-domestic customers.
Quality of supplied water	The use of water from RWH / GWR systems has the potential to impact on the quality of water within the distribution system up to consumers' tap.
Operation of wastewater systems	The reduction and replacement of potable water, as a result of water conservation actions, has the potential to impact on sewerage systems not designed or currently operated to account for such measures.
Operation of water supply systems	The use of RWH / GWR systems has the potential to impact on the design and operation of water companies' distribution systems including supply pipes.
Operation of stormwater systems	As sustainable drainage systems (SuDS), and the possibility of using SuDS to alleviate sewer overflows, have increased in prominence, it is necessary for the water company to understand the potential impact RWH may have on their asset performance.

The collection of evidence focussed on literature with transferable findings. The quality and availability of information varies widely across the identified themes.

### Themes Identified as Having a Strong Body of Evidence

- *Carbon footprint.* There has been detailed work on the carbon footprint of water supply operations through the carbon accounting workbook and TR61, a software package which enables estimates of costs and carbon emissions for constructing and operating facilities. The impact on water companies' carbon footprints can be modelled based on the assumption of water supply reduction (EA, 2010)
- *Energy efficiency and energy use.* There is good numerical evidence of the energy requirements for RWH / GWR systems documented by suppliers and the energy used to supply water through mains. Impact on a water company's

treatment and pumping energy requirements can be readily assessed using simple intensity indicators (EA, 2010).

- *Quality of supplied water.* There are a number of studies on the impact of cross-connections, the effects of stagnation in pipes and health impacts from use of non-potable water (DWI, 2010).
- *Operation of wastewater systems.* There is a good basis of modelled information including recent findings on the relationship between per capita consumption (pcc) and drain blockages. However, there is very little field testing and blockage investigation work (WRc, 2012).
- *Operation of stormwater systems.* There is a strong modelling and anecdotal evidence base on rainwater collection. Stormwater attenuation with storage tanks is well understood (HR Wallingford, 2012), whilst less is known of the on-site impact of RWH systems not designed with stormwater volumes in mind.

### **Themes Identified as Having a Weak Body of Evidence**

- *Customer contacts.* There is a lack of evidence to show the impact that existing RWH / GWR systems have on company-developer relationships and contacts, and little or no existing information that specifically considers how RWH / GWR impacts on customer contacts with the water company. Any evidence is largely centred on the negative impact of incidents of backflow or cross-connection between rainwater systems and drinking water.
- *Income.* The relative costs of providing a volume of water from mains or alternative sources are well defined. However, the only impact on a water company income is the reduction in volume of water supplied and wastewater collected. The potential savings made in their water bill by customers are well understood from modelling, although some discrepancies in assumptions exist, but the actual savings realised have not been tested.
- *Customers' bills.* There is minimal existing evidence relating to the relative consumption of water from water reuse sources against potable water and the frequency and degree of maintenance that such RWH / GWR systems will require to sustain supply.
- *Operation of water supply systems.* There is little or no direct evidence of the effect of using RWH / GWR systems on water supply networks, strongly linked to the fact that there is minimal evidence on the relative consumption of water from water reuse sources.

### **Identifying Gaps in Knowledge and Evidence**

From the review of available information, it is clear that there are a number of specific gaps in knowledge or evidence. Addressing the areas with weak bodies of knowledge, and other specific gaps, will strengthen the conclusions and support decisions on the best way of achieving a positive impact for a water company individually or the water industry collectively. However, it would not necessarily be economic for the water industry to address all of these gaps, or even appropriate for it to do so, in isolation from

other key stakeholders. An assessment of importance for each theme was therefore used to prioritise these activities.

## IMPACT ON WATER COMPANIES

A matrix was developed which considered the importance of each risk or benefit to water company business when scored against a number of factors. These factors and the scoring method are set out in Table 2.

**Table 2**      **Prioritising risks and benefits by importance**

<b>Factor</b>	<b>Score</b>
Benefit to the water company <i>How will the implementation of RWH / GWR recycling be of benefit to a water company in the context of the theme?</i>	None (1) 'Nice to have' (2) Critical to water company business (3)
Impact on customers <i>How will the implementation of RWH / GWR affect customer attitudes, customer relations or customer priorities?</i>	Minimal (1) Some (2) Critical to customer satisfaction (3)
Availability of evidence to evaluate impact	None (lots of talk, no facts) (1) Some (gap filling needed) (2) Lots of useful information (3)
Presence of regulation or policy driver <i>Are there any current regulations, codes of practice or government policies which influence the implementation of RWH / GWR?</i>	None (1) Guidance / codes of practice (2) Legislation / government policy (3)
Risk to water company <i>How will the implementation of RWH / GWR be of risk to the water company in the context of the theme when considering: (a) water quality; (b) reputation / corporate social responsibility; (c) financial; and (d) compliance with regulations?</i>	None / very little (1) Medium (2) High (3)

The importance of drinking water quality and wastewater operations to a water company's business, its statutory obligations under the Water Industry Act 1991 (for

England and Wales), the Water Industry (Scotland) Act 2002 and the Water and Sewerage Services (Northern Ireland) Order 2006 and the availability of evidence in these areas rank most highly. Any gaps in knowledge resulting from ‘quality of supplied water’ and ‘operation of wastewater systems’ are likely to be given high priority.

The impact of RWH / GWR on the water supply system ranks low – not because the water supply network is of low importance but because current evidence shows that it would not be possible to guarantee a reliable source of water from a water reuse system, so drinking water mains would have to be designed to the same standards (and capacity) as present and there would be no CAPEX savings for a water company. Therefore any gaps in knowledge resulting from ‘operation of water supply systems’ are likely to be given low priority.

The impact on ‘customer contacts’, ‘demand for treated water’ and ‘energy efficiency and energy use’ all directly relate to water company finances and are similarly ranked. It is important that knowledge is sufficiently robust to ensure that no negative impact results from the introduction of water reuse systems and, subject to the future strategy to become a responder or an influencer, an opportunity to maximise these benefits.

## RESPONDING TO FUTURE MARKET TRENDS

The evidence collection and analysis provided a sound understanding of the real risks and benefits to a water company resulting from the introduction of water reuse systems by their customers. Whether these systems will be introduced in sufficient numbers for the risks and benefits to be material will depend upon the growth of the market.

The Environment Agency’s (EA) paper “Water: Planning ahead for an uncertain future in the 2050s” (EA, 2009) notes that as pressure on water supply increases, access to clean reliable water supplies may not always be guaranteed. When thinking about future water quality and demand for water, assumptions are made about how people will live and work, systems of government, the technology that will be available, how people will use their leisure time and how they will value the environment. The EA has outlined scenarios to describe a set of possible futures which could be developed into a more detailed picture of water in the 2050s.

### Domestic Market

From the commentary on drivers for change in water use and the estimated values for pcc under each scenario, the reliance of the different scenarios on RWH or GWR was qualified. Using the Water Calculation Methodology for New Dwelling (HM Government, 2010), the extent to which RWH / GWR might reasonably be expected to contribute to the domestic demand was quantified. The results of this analysis are summarised in **Table 3**.

**Table 3 Reliance on RWH / GWR for each EA scenario for a new home**

<b>Scenario</b>	<b>Per Capita Consumption in 2050 (l/h/d)</b>	<b>Reliance on RWH / GWR (l/h/d)</b>
Baseline	155	0
Innovation	125	0
Uncontrolled demand	165	0
Sustainable behaviour	110	25 (all outdoor water use + all WC flushing)
Local resilience	140	5 (all outdoor water use)

Only under a ‘sustainable behaviour’ scenario would development of new technologies to effectively capture rainwater and grey water for toilet flushing be encouraged and needed to meet proposed targets. Even then, in the 36 years to 2050, only approximately 3% of current housing stock will have been replaced.

Under this scenario there would be more interest from householders for retrofit solutions. On average all bathrooms and kitchens in existing homes would have been replaced at least once and possible more during the same period. Should the water industry wish to promote the use of rainwater and grey water to reduce consumption of potable water, significant efforts would need to be made to build on this interest from householders and transform the market through the DIY / replacement market. An easier ‘win’ would be maximising the use of small scale RWH / GWR systems for outdoor water use and moving some way towards the ‘local resilience’ scenario.

### **Commercial Market**

The pressures on water supply in the future apply equally to commercial premises. The EA report (EA, 2011) provided detail for each of the water demand scenarios by considering the water demand by sector. Water use by different sectors was estimated and compared to the current baseline – this includes ‘total industrial and commercial use’. The EA does not, however, see these scenarios as having as much influence on commercial water use as in the domestic environment.

The greater influence for commercial mains water demand is likely to come from the changes to retail services for non-household customers already in place in Scotland, anticipated for England via the draft Water Bill, and possibly later for Wales through the same legislation. Key to the proposals is the removal of the current monopoly link between the wholesale part of a water company business and the retail business.

In addition to the most financial advantageous contract for supplied water and wastewater disposal, commercial customers will be looking for additional services from their supplier to manage their financial and environmental commitments, and therefore a water company would be seeking to maximise offerings to this customer-base in order to retain market share.

## DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

To map out the future water company actions in response to the growing market for RWH / GWR systems it is important to define the positive impact to be achieved from the selected company strategy.

As a minimum, actions to manage risks to a water company need to be taken. Key examples of these critical actions are (i) to ensure that the use of these systems does not lead to additional blockages in the drainage network, and (ii) to safeguard the quality of mains water through appropriate inspection for compliance with drinking water quality regulations / byelaws.

Currently, the available evidence suggests the main risk to water company operations arises from breaches of the water quality regulations from inadvertent cross-connections between the potable and non-potable supplies. This risk is hard to manage because water companies do not know where systems are being installed and cannot therefore distribute appropriate guidance or carry out adequate inspections.

It is important that knowledge is sufficiently robust to ensure that there are no negative impacts from the introduction of water reuse systems and, subject to the future strategy taken by a water company, that there is an opportunity to maximise the benefits. This review has shown that some themes (groups of risks or benefits) have a strong body of evidence, some are lacking in validation of modelled impacts, and for some there is little or no existing information (e.g. how increased interest in water reuse systems impacts on customer contacts with the water company).

Gathering evidence to fill knowledge gaps would be beneficial in terms of strengthening the foundation for business decisions, but could be time consuming. A structured prioritisation of risks and benefits suggests focusing on impacts on the quality of mains water supply; the operation of the wastewater system; and energy use / efficiency.

The positive impacts defined in the project provide direction for water company involvement in the growing market for RWH / GWR systems. Table 4 outlines how these positive impacts may be realised.

**Table 4      Achieving a positive impact through appropriate response**

<b>Area</b>	<b>Positive impact from water company response to introduction of rainwater harvesting and grey water recycling systems</b>
Compliance	Knowledge of where systems are installed to allow appropriate inspection to ensure there is no risk to consumer health from water reuse systems or indirectly through cross-connections.
Mains supply demand	Fit-for-purpose and correctly sized products providing a consistent supply of harvested / recycled water to allow mains supply demand to be estimated.
Mains supply quality	Correctly installed and functioning products to ensure a reliable supply of harvested / recycled water.
Customer relations	Good customer relationship by provision of accurate information presented for the target customer group.

Area	Positive impact from water company response to introduction of rainwater harvesting and grey water recycling systems
Customer services	Active engagement in response to demand for water reuse systems from customers.
Operations	No adverse effects of the current operational performance of water supply network and wastewater systems.

Experience from other countries provides some additional evidence on system reliability; however the differences in regulatory regimes and property development markets in these countries means that drivers and values for uptake of systems is not directly transferrable to the UK situation.

Many of the perceived risks and benefits are linked to the correct selection, installation, use and maintenance of systems. It is possible that some of these risks could be mitigated by appropriate actions such as good installation practice or guidance to property owners or developers. Using the EA future water use scenarios, it is suggested that *response* to the domestic market for inclusion of RWH / GWR systems in properties is a more appropriate response by a water company, rather than an *active drive* for market transformation.

For commercial and industrial customers, the greater influence for mains water demand is likely to come from the changes to retail services for non-household customers. This may provide the opportunity to provide more services to customers or product solutions to reduce demand. Unlike the domestic market, the anticipated change to the retail market suggests that water companies in England and Scotland (and later Wales) should be *actively* seeking a positive impact for their business.

The study suggests that the water industry should work together to:

- Support the RWH / GWR system manufacturers and installers to develop suitable guidelines and accreditation for installers and equipment;
- Identify and implement suitable methods for notification of new RWH / GWR systems by developers in new or renovated properties;
- Review and implement a suitable level of Water Supply (Water Fittings) Regulations inspections for properties with RWH / GWR systems; and
- Validate model predictions for the potential of such systems in storm water attenuation.

Individual water companies may decide to more actively promote or support the introduction of RWH / GWR systems at local or company levels to meet specific targets in their resource plans or to satisfy customer demand.

As now, there will be some element of voluntary take-up of RWH / GWR systems. Therefore it is proposed that filling any gaps in knowledge which ensures the quality of drinking water supplied is not compromised and that a good level of service to customers wishing to install these systems can be provided would be beneficial under all scenarios.



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## PROPELAIR® – THE TOILET REINVENTED

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### ABSTRACT

Water is a vital element for our society and economy. As water scarcity and prices increase, there's been a big push towards water efficiency within the commercial and domestic markets.

Toilets can account for a third of household water use and up to 90% for commercial outlets. Despite the vital role it plays in effective sanitation, there has been little innovation since the late 1800s. Recognising the need for an alternative solution inspired the development of Propelair®'s revolutionary new water saving toilet.

**Keywords:** Displaced air technology, High-performance flush, Innovation, Water efficiency

### INTRODUCTION

Britain and many other parts of the world have been using the same type of toilet for more than a century, with a handful of relatively small technical improvements – it was and largely remains a matter of storing water in a cistern and letting gravity flow into the WC pan remove the waste, where water conservation efforts has affected the efficiency of this process and resulted in increased frequency of double flushing. With UK toilets averaging 9 litres per flush, accounting for up to 30% of household water use and up to 90% for commercial buildings. It is easy to see why, in the drive to reduce water use, traditional toilet technologies have become relatively water inefficient and unsustainable in modern times.

Recognising the need for an alternative solution inspired the development of Propelair®'s 1.5 litre flush system. The British designed and manufactured toilet is a new form of technology using the power of displaced air and water. The simplicity of combining two elements produces a reliable, high -performance flush, reducing water consumption by an average 84%.

Launched last year, Propelair® is a result of five years' research and independent testing at numerous prestigious technical facilities; with WRAS, ISO 9001, BSI British Kitemark and Watermark approval.

## HOW IT WORKS

Propelair® has a two section cistern – one side a water reservoir and the other an air pump requiring a power supply provided by either battery or the mains. The energy consumption is less than 1,000 joules per flush (1,000 flushes costing less than 8p)

A simple innovation which works in three easy steps:

- Before flushing, the lid is closed to form a seal with the pan. To encourage putting the seat and lid down, the flush button is positioned behind the raised lid. The toilet will not flush if the lid is up.
- The flush button is then pressed, which first sends water into the pan to wash it, and then operates the air pump. Upon operation, the pump displaces air directly into the pan (which cannot escape because of the sealed lid) and pushes the entire contents of the pan into the existing drainage system, creating a powerful, reliable flush.
- The remaining water then flows from the container to refill the water trap in the bottom of the pan, thus complying with existing building regulations. In this way, water is not used for flushing and only 1.5 litres is required for cleaning and providing the water trap.

The process to the user is no different to using a normal toilet, and the whole flushing cycle is completed in three seconds with the toilet ready to be re-flushed in 30 seconds (subject to water supply pressure). This is particularly important in entertainment venues where ladies customarily experience long queues during intervals.

## PACKAGE OF USER BENEFITS

**Saves Water:** Propelair® reduces water consumption by a 84% compared to an average WC. This means less energy is required for water and waste processing, which in turn reduces the toilet's carbon footprint by an average 80%.

Benefits to customers:

- Improve resource efficiency and overall building performance.
- Advance sustainable business objectives and energy targets.
- Show leadership in water efficiency and enhance reputation.

**Saves Money:** Due to its significant water savings, Propelair® has the potential to reduce commercial water bills by up to 60%. When you consider that toilet flushing can account for up to 90 per cent of water usage in commercial buildings these savings are very significant.

**Case Study:** Propelair® monitored (litres of water used and flushes per day) a customer toilet in a well know retailer in Basildon which was being flushed between

90 and 100 times per day. The Propelair® toilet would save over 180,000 litres a year which represents a saving of between £360 (Thames Water area) and £940 (South West Water area) resulting in a payback of just over two years and less than one year respectively.

Water can be wasted with traditional gravity fed toilets due to leaks and double flushing. Propelair®'s revolutionary technology overcomes this problem meaning you pay for what you need, not what you waste.

Benefits to customers:

- See tangible results through lower water bills.
- Ease tight budgets with instant savings and allocate resources where it's needed.
- Achieve measurable savings, helping to anticipate incoming costs and plan for future budgets.

### **Improves Hygiene:**

Modern low flush toilets can leave 6% of the last user's contaminants behind after each flush. Propelair removes over 99.9% of contaminants. In addition, when flushing a toilet, particles of contaminated waste water are sent into the air, where they are drawn into ventilation systems and can settle on surrounding surfaces, where infections may be acquired through inhalation and ingestion. In an independent assessment carried out by Centre for Research into Environment and Health ("CREH"), Propelair® was found to suppress the generation of aerosolised contamination and, therefore, the associated health risks.

Propelair decreases the risk of cross-contamination, meaning the likeliness of office bugs spreading is lowered and overall workforce health improved.

**Improved Design:** The opportunity has been taken to redesign the lid, seat and pan. While the appearance is that of an existing high-end contemporary toilet, a new manufacturing process has been developed which allows the hinges to be positioned on the side and the pan and out of the way during use so they do not suffer from soiling, movement and corrosion (as with other WCs). A new "floating" pin design with snap-off side hinge covers means that that our hinges are very robust, yet released in seconds for easy lid cleaning and replacement. The pan is also rimless, which makes the unit much easier to clean.

- **Retrofitting:** Whether it is future developments or existing builds, Propelair is uniquely suited to both. A study by the Drainage Research Group at Heriot Watt University found that Propelair® can be retro-fitted to existing drainage systems as a like-for-like replacement for conventional toilets. Propelair® simply connects to existing pipes.

- **Drainage:** Unique design can be easily retrofitted to existing drainage systems but can also operate using small-bore flexible pipes in addition to the usual 100mm size. Small-bore drains can be run without gradients, unlike conventional toilets which rely on a fall in the plumbing. This is a significant advantage for refurbishments allowing total design freedom when deciding toilet positioning.

## **WATER EFFICIENCY - A GLOBAL CONCERN**

Of course saving water is not just a business opportunity – it's a crucial world problem. According to The UN's 2014 World Water Day Development Report, published in March: "Global water demand ... is projected to increase by some 55% by 2050, mainly because of growing demands from manufacturing (400%), thermal electricity generation (140%) and domestic use (130%). As a result, freshwater availability will be increasingly strained over this time period, and more than 40% of the global population is projected to be living in areas of severe water stress through 2050.

## **SUMMARY**

Conserving water is becoming more imperative within our society as water prices and water scarcity increase. The Propelair<sup>®</sup> toilet is one solution helping to improve water efficiency in the commercial washroom market, whilst contributing to the overall wider environmental goal of a more efficient, eco-friendly planet.

## THAMES WATER – SUPERSIZE MY WEFF!

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### ABSTRACT

There is an increasing focus on measurable water savings delivery and quality customer engagement within the UK water sector. It's quite a catalyst for change in both the scale of demand management activity, and how we engage with household and business customers. Thames Water has the largest customer base and water saving targets of any UK water company. These targets have already been met for the 2009-14 regulatory period, with our endeavours also building a vast evidence base along the way, including research, customer engagement and water savings programme delivery. This journey is now providing a platform for our next five years of water efficiency action – bigger water savings aims, more on-ground initiatives and far greater benefit for our customers.

**Keywords:** water efficiency, devices, behaviour change, AMP, customer engagement, TAP App, Water Energy Calculator, water metering, retrofitting, Local Authorities, Housing Associations, schools, water audits, portal, Multi-faith, Leaky Loos.

### INTRODUCTION

We're currently playing in some dynamic times, with even more interesting times ahead. Yes, this statement applies to the water sector in general, but specifically to the successful engagement of customers and the growing focus on measurable water efficiency delivery.

Regulatory water saving targets for AMP5 have been met, but Thames is still pushing hard on the water efficiency (WEFF) messaging and programmes, developed over the past few years. The remainder of AMP5 actually provides a unique opportunity to set-up and test new initiatives and platforms, all of which aim to deliver even greater water efficiency success in AMP6. Our customer base is the biggest, therefore so too are our water efficiency targets. For AMP6, we see this target effectively double! And, where possible, a move away from 'assumed' savings over measured reductions. A massive challenge! So within our water efficiency team, words and terms like bigger, better, streamlined, creative, and innovative and "let's aim big and get on with it", are becoming engrained throughout all our plans and discussions.

### AN EVOLUTION FROM 'TIPS' TO 'BESPOKE'

A greater focus on in-home delivery of water saving device retrofitting and the provision of household-specific advice, underpins much of the change about. We'll be focusing on installing, rather than just providing. We'll be in-homes more, in businesses more, greater partnership working, and making the process easier along the journey. Here's a quick look;

## SMARTER HOME VISITS:

In preparation of the Thames Water's Progressive Metering Programme (PMP), we are embedding intensive and very high-quality water efficiency delivery in parallel. The PMP will see meter installations rolled across our domestic customer base over a +10 year period, starting in a few London Boroughs. Environmental charity, Groundwork, is currently delivering an in-home water efficiency service – 'Smarter Home Visit' (SHV), as part of the PMP's testing phase. The SHV will install free water saving devices into each house, plus provide them with bespoke water audit and savings advice. SHVs are currently being offered to existing metered households in Bexley and Greenwich, before being rolled out to homes receiving a new smart meter in the future. Initial recruitment rates were about 1 in 4 homes taking up the SHV offer, but with some clever tweaks we are now successfully helping between 50-80% of all homes engaged with an SHV. The SHVs will help families understand their current water use practices, and identify their water and water-related energy bill savings potential. The nicest win-win of all.

## WATER & ENERGY BILL SAVINGS

We'll soon be incorporating the Energy Saving Trust's Water Energy Calculator (WEC) into our website, which will help all Thames household customers identify their water use and potential savings. And we're going a big step further. The WEC is now working as an app for tablets, so we're aiming for this tool to be our primary water efficiency engagement and education tool for Thames in-home programmes. We're currently testing a 'proof of concept'. Whether it's our staff, the Smarter Home Visits, or housing associations doing retrofitting and engagement work, we're hoping this new app will be the world's best tool for water efficiency engagement to domestic customers. Say hello to the Thames '**TAP App**' (*Talk & Products*). Apart from capturing the customers' water use, and associated water and energy bill savings, the TAP App will also capture all device installation and leakage data. These results will be automatically linked to our water efficiency and stock management databases.

**Online and oh so simple.** We now have a simple, but far more capable, online portal that enables all households, businesses and our trade partners, to order free water efficiency devices. Placing an order takes just seconds, and it's all linked to our stock management system, allowing us to automatically produce water saving results and reports. Reduces the burden of data analysis, and makes it easier for our customers. We love win-wins!!

**Local Authorities & Housing Associations.** Each social housing provider usually has a schedule of works dedicated to areas including general maintenance and energy efficiency improvement. Thames is working with Peabody and Southern Housing Group to embed water efficiency device installation and behaviour advice, into these routine customer visits. Housing Association maintenance and engagement staff will be provided with free water saving devices, and trained in delivering water efficiency education. The TAP App will be at the heart of this process (...we love the TAP). If it goes well, this process could help all housing providers across the Thames region.

**Existing operations.** Learnings from local authority and housing provider initiatives will also help our own routine operations. Identifying existing opportunities where Thames staff and contracted agents are already engaging with householders and companies, embedding water efficiency delivery into these mechanism, will become key. We're aiming to create more water saving opportunities through our existing operations, whilst improving the quality of engagement and education throughout. Helping customers understand their own water use and potential savings, becomes king.

**Schools.** We're starting a new round schools engagement programmes. This aims to not only increase the amount and creativity of water efficiency education, but coupling this advice with actual water consumption results, using Automated Meter Reads (AMR). These case studies will help schools across the supply area in years to come. Improving both awareness and device at the same time, will be something we hope to continue through AMP6.

**Businesses.** We all know that the deregulation of water services for commercial customers is underway, taking full-effect in 2017. For clean and waste water businesses, the split into a four-box model is both interesting and challenging – wholesale water and waste, retail household and non-household. But for water efficiency agendas, this regulatory and operation change introduces some great opportunities for businesses' CSR and the performance improvement of their buildings/sites.

A range of intensive water audits on commercial properties is currently underway to help establish some comprehensive water use benchmarks. These findings will help businesses identify priority demand reduction solutions for each of the commercial categories.

**Multi-Faith Water Efficiency Study:** To date, water efficiency messaging has been fairly generic. With greater emphasis being placed on metring and demand reduction, our engagement will need to suit the diverse range of cultural and community groups. Thames Water has commissioned London Sustainability Exchange & the University College of London to undertake a Multi-Faith Water Efficiency study. Tailoring the water saving messages and initiatives to better suit the needs and sensitivities of each major religious and community group, is becoming more important. LSx and UCL will be engaging with faith leaders and community groups to;

- establish specific faith/community water needs,
- develop faith/community specific water efficiency engagement materials
- and seek to faith/community support in delivering future water savings initiatives

**Leaky Loos Project:** Does your loo leak?? It is suspected that water lost through leaking WCs, is a bigger issue than we currently action. As part of the Water Industry Collaborative Research Fund, the **Leaky Loos Phase II** study aims to improve the understanding of the scale of the issue, as well as highlighting toilet or household types that may be more likely to have leaking WCs. It seeks to develop efficient methods of detecting wastage and to identify efficient ways to reduce water loss in homes. The study will include desktop and in-home investigative research phases,



where at least 300 leaking toilets will be analysed for leak causes and water volumes lost. Thames, Affinity, South East, United Utilities, South Staffs, Sutton & East Surrey are all involved.

The Leaky Loos Project follows an investigation carried out in 2010/11, which concluded that wastage from leaking toilets was in the region of 400 litres/toilet/day, and also that approximately 10% of toilets were found to be leaking.

Well that's a snap-shot of what's happening. Lots more fun to look forward to!

## **SUMMARY**

The increasing focus on water savings and customer engagement is a powerful catalyst for change within the water sector. Our demand reduction success is quite conditional on households and businesses becoming more aware of their own water use, and taking steps to reduce consumption. In the lead up to AMP6 (2015-19) we are setting up the platforms and programmes to help customers along this journey. Our focus is now changing to more effective and bespoke engagement; simpler processes for obtaining devices and reporting; greater number of higher quality in-home delivery programmes, and much more communication about what we do and how we can help.

# **Quantifying Flushes, Gushes and Slushes Or The challenges of Evidencing Water Savings Arising from Water Efficiency Interventions**

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## **ABSTRACT**

Gathering robust evidence of the effect of water efficiency interventions can be difficult, especially where the interventions have multiple elements and where a range of diverse water customers take part in a project. This presentation will examine three different approaches that can be used to evidence the impacts of interventions: macro (meta)-analysis, extracting added value from other data; and analysis of micro-components of demand. The work presented is case study based.

Keywords: analysis; domestic water use; interventions; micro-components; water efficiency.

## **INTRODUCTION**

Evidencing the impact of water efficiency intervention projects appears at first sight to be straightforward: measure water consumption (the “before”), then intervene, followed by measuring water consumption again (the “after”). Next take the “after” from the “before” and the difference is the water saving..... Simple!

Turns out in reality it is not Simple at all.

## **PRACTICAL DIFFICULTIES**

Firstly, consumers taking part in water efficiency projects undertaken by water companies are usually offered a range of devices (typically between 4 to 10 different device types). This is necessary: by widening the range of devices it encourages a wider customer participation. However, it makes it more difficult to assign savings to individual devices.

Secondly, different properties that participate in the project will have different numbers of devices fitted. In addition to the physical interventions, the educational element of the project – if successful – will have altered the water using behaviour of the occupants. So savings in each property taking part can vary widely.

Thirdly, the customers taking part are all distinct: they come into the project with own particular type of initial water use behaviours and practices, all of which are different; and this adds yet another layer of complexity.

The daily consumption at a property is usually very variable so relying on comparisons of short term consumption readings can be misleading. Day on day consumption at a property can often vary by 100 to 300 litres per property per day, while the water savings achieved from water efficiency interventions are typically of the order of 10 to 20 litres per property per day. So short term comparisons can be unreliable.

Comparisons of periods of unequal length bring even more uncertainty to the Water Efficiency Party. Suddenly, our simple “before” and “after” comparison becomes complex and difficult to understand.

## **ASSESSING THE EVIDENCE**

In assessing the effect of interventions a degree of scientific rigour is necessary. There are a range of approaches available to ensure this, and various statistical and analytical techniques can be applied to help reveal the underlying trends and impacts and to extract the insight and understanding from what on the surface can look like a sea of chaos.

The first approach is to go macro: this demonstrates what can be achieved when measurement and metrics recorded for individual studies are pooled and collated and analysed as a collective.

The second approach explores what value can be gained from attempting to make use of measurements that are already being routinely collected by water companies in support of managing their businesses.

The third approach is to go micro; this explores the benefits of measuring, recording and analysing data on micro-components of domestic water use - the information gathered from individual households that gives us insight to water use at appliance level in each property. By analysing the consumption patterns before and after interventions this approach can be very helpful in clarifying the detailed effects of interventions on individual behaviours and the effectiveness of each device on water consumption.

# REVIEW OF ATTITUDES AND PREFERENCES FOR WATER EFFICIENCY IN HOMES

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## ABSTRACT

Governments now recognise that climate change and its consequences need to be addressed by changing people's attitudes, behaviour and every day practises. Social factors such as occupancy numbers and demographics, age of inhabitants, occupation of inhabitants, personal habits, perceptions and attitudes, lifestyle and values of the water user influences how water is consumed in a building. Water efficiency strategies in buildings should therefore aim to understand what people care about, and preserve the things they consider important. Therefore it is necessary to understand the knowledge, views and priorities of water consumption within a property before deploying water efficiency interventions.

This paper presents findings from two studies designed to further understand water use in domestic properties, specifically looking at habits, lifestyles and attitudes towards water consumption. The aim is to establish the how these have changed since the first survey. The quantitative survey methodology was utilised and the data from the 503 respondents was analysed using statistical analysis packages. 66% of the respondents were from the South East region of the UK and only the findings from these groups are presented in this paper. The study found increased metering in the region since the first survey and that the metering program has resulted in changes in attitudes and awareness. The findings also draw on a change in barriers to the uptake of water efficient technologies. Further findings demonstrate that water Company practises appear to contribute to the environmental knowledge of respondents. Findings from this study will inform the next stages of a doctoral study which aims to propose a methodology for designing and implementing customised water efficiency interventions in homes.

**Keywords:** Awareness, Attitudes, Domestic water use, Water efficiency.

## INTRODUCTION

Water scarcity, aggravated by increasing water use, at more than twice the rate of population increase in the last century (Environment agency, 2011), affects all social and

economic sectors (UN-Water, 2007). Although there is no global water scarcity as such, an increasing number of regions are chronically short of water due to escalating demand and unpredictable environmental conditions.

The South East of England for instance has less water per capita than countries such as Egypt, which are considered to be the dry regions of the planet (Environment agency, 2008). The increasing frequency of drought has led to the Environment Agency (2008) to declare water resources under “considerable pressure”. Therefore, the UK is clearly part of the global water crisis rather than exempt from it. This ensures that water availability is a critical topic with all relevant agencies and companies.

Increases in water demand and climate change has moved many governments and public utilities to invest significantly in the development and the implementation of a range of water strategies (Correljé *et al.*, 2007; Stewart *et al.*, 2010; Chen *et al.*, 2005; Marsden and Pickering, 2006; Kenney *et al.*, 2008). Whilst water authorities attempt to secure future water supplies, they also recognise the need to manage water demand (Jorgensen 2009).

Clarke and Brown (2006) found that public water use awareness campaigns are often unsuccessful due to the fact that such campaigns fail to understand the factors that influence people’s water use, and what drives them to change or embrace new technology. This is because social factors such as occupancy numbers and demographics, age of inhabitants, occupation of inhabitants, personal habits, perceptions and attitudes, lifestyle and values of the water user influence how water is used in a building.

This study therefore sought to investigate and compare collective views on water consumption and efficiency in South East region of the United Kingdom.

## **STUDY CONTEXT**

The study compares the results of two surveys. The first survey was conducted nationally with about 1000 respondents which were sampled randomly from a market survey company’s database. 546 respondents started the survey, of which 393 fully completed it. Data from the South East respondents only are presented in this paper.

The second study was conducted more recently across the South East with participants primarily located in Surrey and Sussex. The survey was distributed at community events, local product merchants and water companies; there were a total of 243 respondents.

## **METHODOLOGY**

A quantitative approach using questionnaires was utilised for this study. This is due to the opportunity to include a wide range of participants.

Data from both surveys was inputted into a spreadsheet and analysed in MiniTab statistical analysis software. Although this study is an extension of a previous study comparing the rural and urban setting, the dataset is still limited to the South East region as well as the respondents that chose to participate.

## FINDINGS

There are 503 respondents, used in this research from both surveys. The age of the respondents was represented in 4 age bands: ages under 25 (8%), 25-45 (45%), 46-65 (37%) and over 65 (10%). In the initial survey, there were a higher number of responses in the 25-45 age group (54%) whilst in the latter survey, the highest responding group was 36-65 (48%). Results from both surveys were divided into 7 regions categorised geographically with the UK. Two thirds (66%) of respondents were seen to be from the South East region, 19% from the north of England, 11% from the Midlands, 2% from Wales and South West and the remaining 3% from the East of England and Scotland.

The majority (59%) of people in both surveys live in 1-2 people households, 35% in 3-4 people households and 6% in households with 5 or more occupants. 71% of the respondents owned the dwelling whilst 26% rented and 2% residents. 1% of respondents lived in maisonettes whilst 19% lived in detached houses, 23% apartments or flats, 25% in terraced houses and the largest group 31% in semi-detached houses.

### Metering

In both surveys, respondents were asked to identify if they had a water meter installed. In the previous study, more respondents did not have water meters, whilst this trend was reversed in the newer study. Data from both surveys indicate that the South East has higher meter penetration (53%) than north England (36%) and the Midlands (32%).

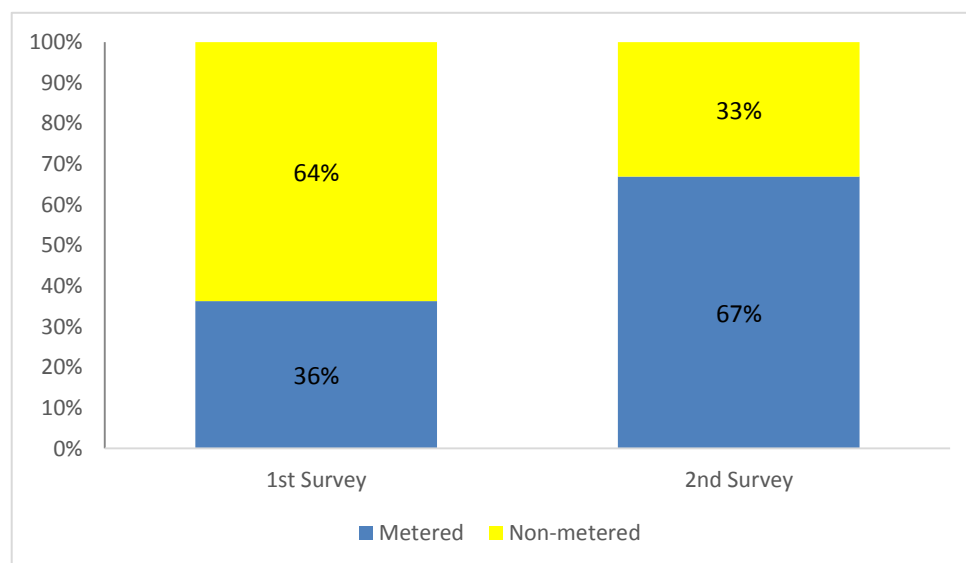


Figure 1 South East meter penetration

However, an interesting comparison of both surveys shown in

Figure 1 demonstrates a swing in meter penetration within the South East; the first survey found 36% of dwellings has water meters and this increased to 67% by the second survey.

Participants of the latter survey that have water meters were asked if this had an impact on their consumption. **Figure 2** shows that 54% of respondents stated that this influenced their water use and 30% do not agree; this was found to be higher in the South East with 57% and 26% respectively.

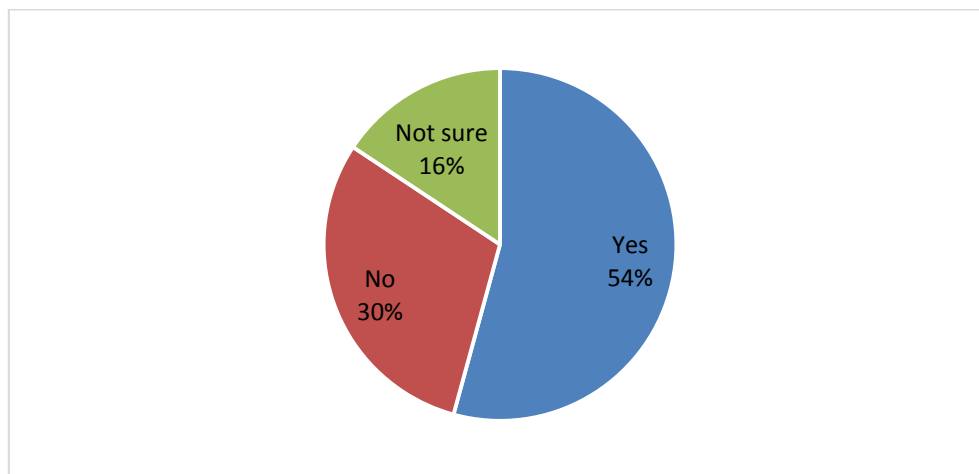


Figure 2 Influence of the water meter

### Attitudes

In both surveys, the participants were asked to select their attitude to water efficiency. The surveys had different wording but broadly had 5 options (Uzzell 2009), they want to save water but need to know more; they have little concern for efficiency, would save water but can't due to constraints, such as financial, cultural or lifestyle, save water, using the water saving technologies or save water without the water saving technologies.

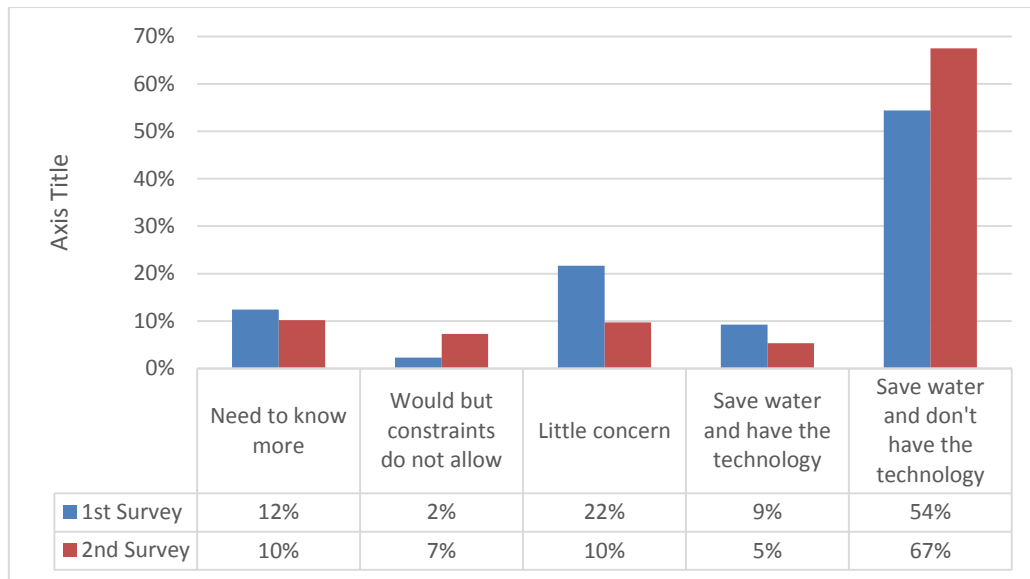


Figure 3 Comparison of attitudes

However, there was little statistical significance between the inclusion of a meter and the attitudinal responses ( $P=0.038$  for the initial survey and  $P=0.313$  for newer survey).

### Awareness

In both surveys, the participants were asked for their awareness of several factors including water efficiency and related environmental issues. The awareness of environmental concerns in both studies was typically average to high. Although, there appears to be an increase in respondents stating that they have low awareness of environmental issues.

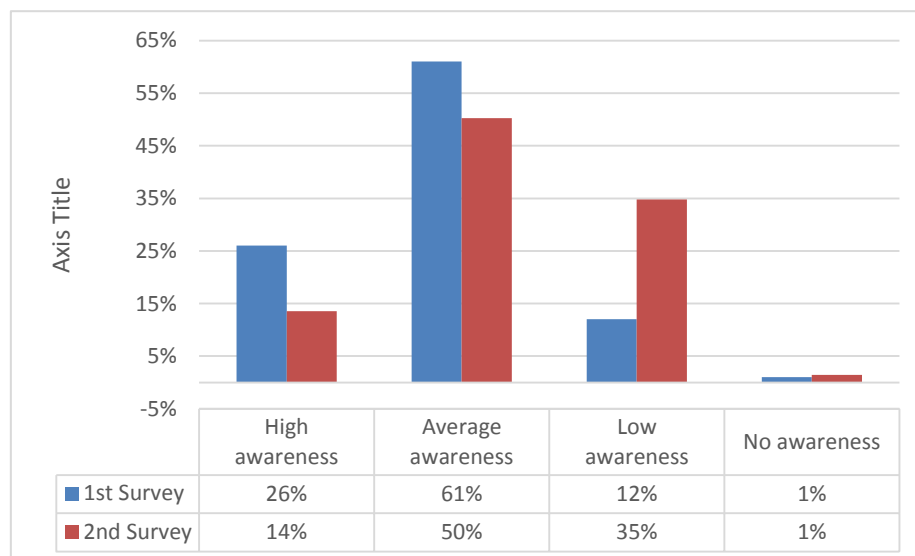


Figure 4 Awareness of environmental issues

**Figure 5** shows the awareness of water efficiency. Almost 20% in both cases (19%, first and 21% second survey) had high awareness, 57% (57% initial and 58% latter) had average awareness whilst on average 20% (23% and 21%) had low awareness.



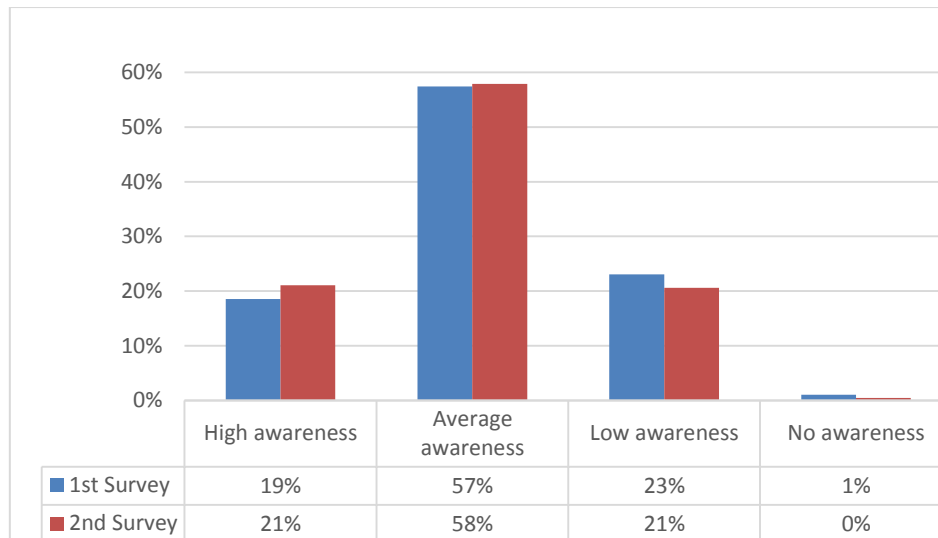


Figure 5 Awareness of water efficiency

### Barriers to the uptake of water efficient technologies

In both studies, participants were asked to define barriers to their adoption of water efficient technologies. The age of the property, cost of installation, disruption and level of responsibility were provided as possible barriers. **Figure 6** shows that the age of the property and cost of installation, 5% and 16% change respectively, stayed fairly similar in both studies. There was a significant change in the disruption and level of responsibility; 36% and 60% respectively.

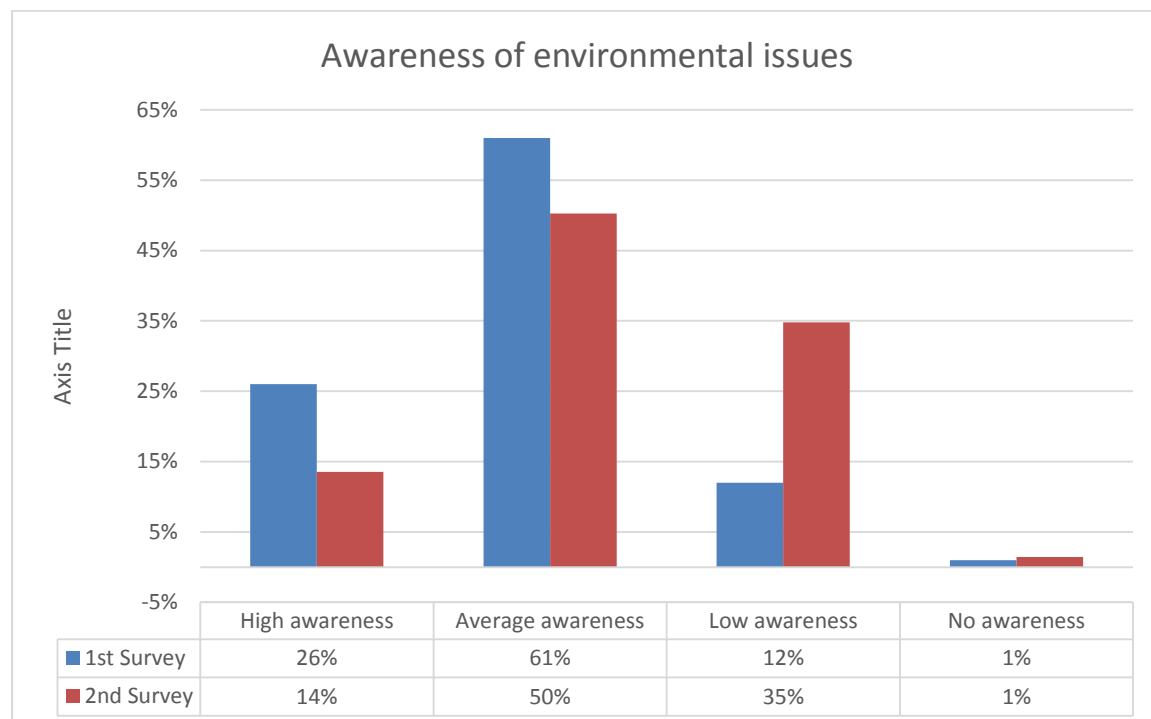


Figure 6 Barriers to the uptake of water efficient technologies

## DISCUSSION

Both surveys represent the combined views of 503 participants across various age groups with a similar spread of ages in both surveys. The majority of the participants were from the South East region of the UK and there is some regional bias in the data and findings. The survey also represents a mixture of different properties, occupancy levels with more responses from those in low occupancy housing (59% in 1-2 person households). However, this bias is statistically prevalent in the UK (ONS 2011).

During the period between the two surveys, there was an increase in the percentage of properties where water meters were installed. This is related to the large scale metering programme being implemented across the region (OFWAT 2013). Unfortunately, no statistical test could be conducted to confirm this due to the bias in the dataset to the South East region. This trend however is seen when results from the South East region are isolated as Figure 1 illustrates.

### **Metering**

The participants in the second study were also asked if they agreed that the installation of a meter had an impact on their consumption. There appears to be an overall trend to metering having an impact on consumption. This is probably because water meters are generally not installed in isolation, they are often supported with media campaigns and mail-outs occur at the same time.

### **Attitudes**

The analysis of attitudes to water efficiency generally shows that respondents are willing or perceive themselves to already be water efficient. Notably, an increase in the percentage of participants considering themselves to be efficient in their use of water despite not having the most efficient technologies was observed in the data. There was also a reduction in the percentage with little awareness or concern for water efficiency, or those that express constraints due to religious, lifestyle or financial reasons.

These observations suggest an attitudinal or perception shift or change in what is socially acceptable for efficient water consumption. This change can be attributed to a variety of factors including the media campaigns and mail-outs that supported the implementation of the compulsory metering program. Even though it was found that the presence of a meter in itself appears to have little significance to participant's attitudes. It can therefore be alluded that metering in itself may not change the attitudes and the resulting behaviour but combining this with other measures such as knowledge and awareness programme has better impact, particularly when considered with the downward trend in water consumption - in 2008 the average water consumption per person per day was 150 litres (Environment Agency, 2008), recent data however found that per capita reduction of water consumption per person in 2013 was 145 litres (Climate change committee, 2012).

## Awareness

In both surveys, there was an increase in awareness of environmental issues, whilst the awareness of water efficiency has maintained similar levels. This is probably related to media coverage of environmental issues or the changes in the commonly accepted meaning of environmental issues.

## Barriers to the uptake of water efficient technologies

Four barriers to water efficient technologies were analysed; the age of property, cost of installation and disruption and responsibility levels. The age of the property and cost of installation increased but not significantly. However, responses pertaining to the level of disruption lifestyle and the function of the home as well as the level of responsibility to make decisions and to adopt water saving technologies also increased significantly.

An increase in the level of disruption could indicate that efficient water use has led to increases in disruption to lifestyle and quality of life. With further exploration of the data and comparisons between attitudes and the barrier to being water efficient, it was found (**Figure 7**) that a large percentage of participants that identified disruption to their lifestyle and property as a barrier also stated that they already save water despite not having water efficient technologies. This could indicate a link between the attitudes of participants and the perception of the need have water efficient technologies in order to save water.

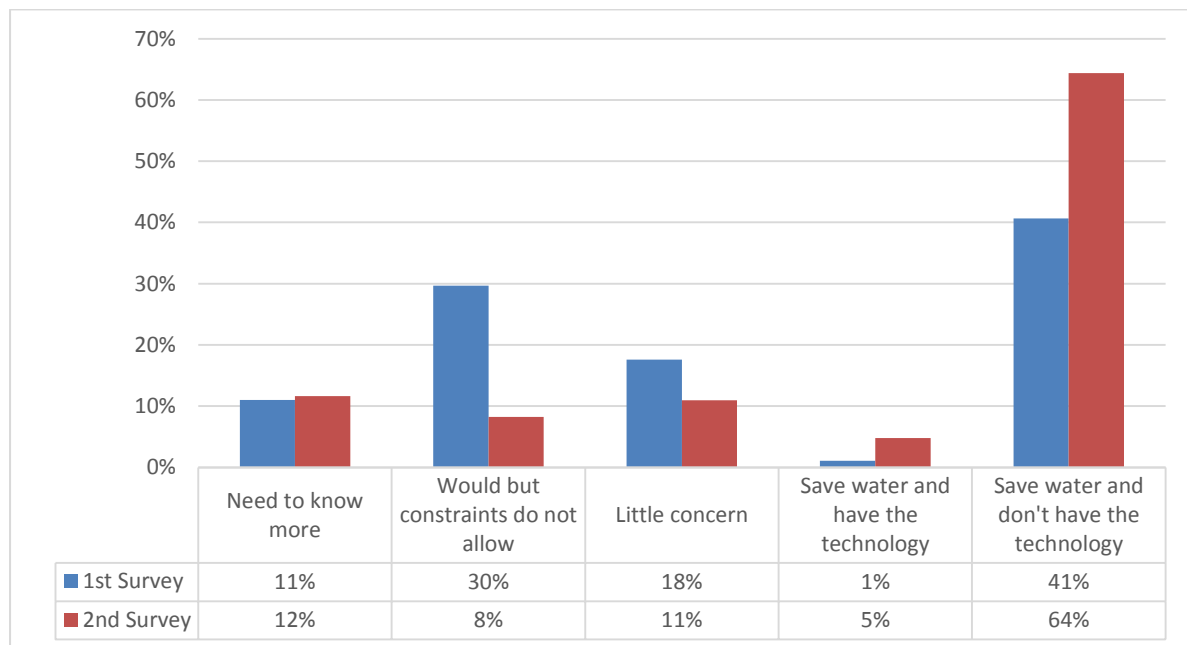


Figure 7 Cross-tabulation of awareness and perception of disruption in the implementation of water efficient technologies

Similarly, a change was observed in the perceived level of responsibility of the water user to use water efficiently. In the first survey, this was interpreted to be due to the

respondents being tenants and therefore not having the right or capacity to make changes to the building.

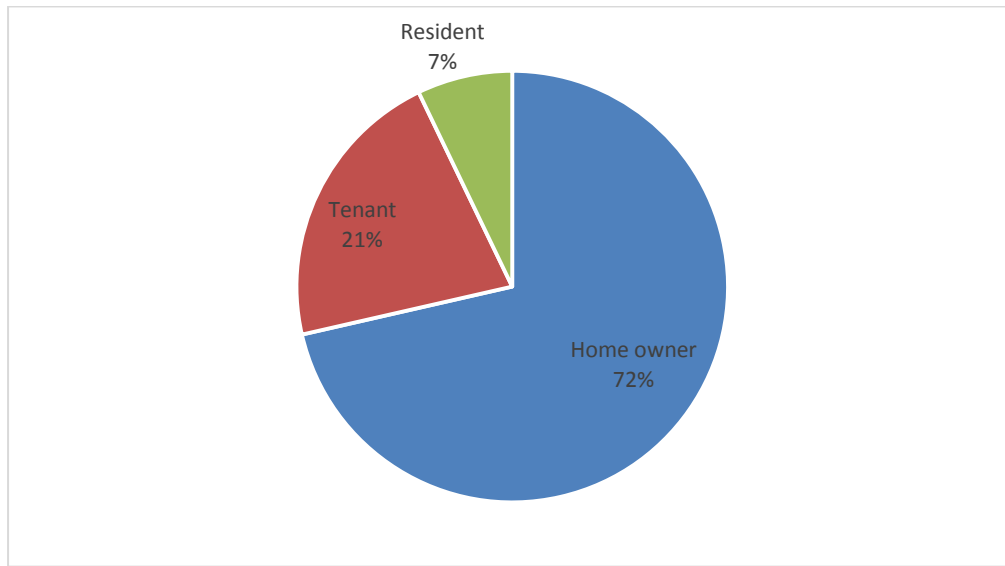


Figure 8 Breakdown of respondents who consider lack of responsibility to be a significant barrier

However, the latter survey had a higher percentage of tenants rather than owner-occupiers compared to the first survey, however, no correlation was found between tenants having reduced responsibility to make changes or adopt technology for water efficiency (Figure 8). Also, no significant relationship was found between ownership type and level of responsibility being a barrier  $P=0.026$ . Therefore, further studies is required into why some users consider it not their responsibility to make positive decisions, adopt technologies or make positive change when it comes to saving water.

## CONCLUSION

The findings from two surveys conducted a year apart were presented using only the data from respondents based in the South East region of England. It was not possible to present the detailed findings from these studies in the limited scope of this paper. Therefore, the paper discusses the comparative change between the two studies in the context of water user awareness, attitudes, effect of metering and barriers to the adoption of water efficient technologies.

The findings of both limited studies show that the attitudes and awareness of the public is changing particularly in the South East as compulsory metering is implemented and permeates the region. However, it cannot be concluded that metering alone has led to the decrease in water consumption. This changing trend, confirming findings from other recent studies, is more likely as a result of metering combined with awareness and attitudinal interventions. Therefore, it is likely that this combination of the various strategies and water efficiency interventions has contributed to the downward trend in

water consumption in South East UK (Environment agency 2008; Climate change committee, 2012). It also appears that in the participants of these studies at least, there appears to be correlation between metering and consumer attitudes, awareness and the barriers that delimits them from taking action or adopting water saving technologies. The ensuing study will investigate these findings in a lot more depth which will hopefully proffer further insights and practical methods or strategies for water efficiency in the home.

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## **‘WATERBLADE’ GREATER EFFICIENCY IN HAND WASHING**

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### **ABSTRACT**

The paper discusses the need for both water and energy efficiency and how reduced water usage can contribute in this case. How the idea for the Waterblade came about. What water saving devices are currently available in the field. How the idea has been developed to date, including some of the technical difficulties encountered. What the future plans are for the Waterblade, including the challenges presented and potential benefits to be realised.

### **KEYWORDS**

Water saving device, water saving device for taps, water saving device for cloakroom taps.

### **BACKGROUND**

Globally the demand for fresh water has never been greater. The demands of industry and agriculture combined with the effects of global warming are making fresh water an increasingly scarce resource. In their 2012 report the office of the US Director of National Intelligence identifies water scarcity as likely to

*‘increase the risk of instability and state failure’ and ‘hinder the ability of key countries to produce food and generate energy’*(ODNI 2012)

The ability to wash one’s hands with clean water is an essential part of good hygiene and health. It is also universal in that we all need to do it as part of going to the toilet. The question that occurred to the Author of this paper, when he was put on a water meter some 5 years ago, was how little an amount of water could he use to carry out this function?

Initially his emphasis was on the waste of heat energy supplied to his tap by his ‘Combi’ type boiler, which fired up every time he washed his hands. However the amount of pipe work between the boiler and tap meant that the hot water never reached his hands. The inefficiency represented by the heated water left cooling in the pipework after every wash really rankled.

Various devices were rigged up to use the water's energy to run a turbine to heat itself! The only trouble was that the amount of energy produced was so miniscule he had to find a way to reduce drastically the amount of water he had to heat. The Dyson Airblade had recently been launched, he had a split in his hose... the idea for the Waterblade came about. On telling his brother about his ideas, his brother suggested that the heating idea might not ever really work, rather like perpetual energy, but the Waterblade sounded promising.

It is entirely possible that if the author had not had undiagnosed advanced Neuro-Borrelliosis (Dr. Petra Hopf-Seidel 2012) at the time he would not have pursued such a mad idea in the first place!<sup>1</sup>

## **CURRENTLY AVAILABLE IN THE FIELD OF WATER SAVING DEVICES FOR TAPS**

All basically work by restricting the flow in some manner.

**Spray nozzles** Water is directed through a number of holes, rather like a traditional shower head. While this does reduce flow rates, at slow delivery speeds it can be ineffective, and at fast delivery speeds it can create excessive spray.

**Aerating nozzles** These work by using the Ventrouli effect to draw air into the flow, displacing water. They are probably the best option currently available, but lose effectiveness at low flow rates. Neoparl, a large manufacturer of aerating nozzles give typically 7 l/m for their aerating nozzles (Neoparl 2014). To put this in some context the author's cloakroom tap with an aerating nozzle operates at 6 l/m. His kitchen tap with no flow restrictor operates at 18 l/m. His water supply is delivered at approximately 3 bar of pressure.

Both the above nozzles are retro fittable to most types of tap found and sold in the UK.

**Infra-red triggers** are popular in commercial cloakrooms, ensuring that water is dispensed only when hands are under the tap.

## **DEVELOPMENT**

The initial idea was to produce a continuous veil of water, so that it would wet or rinse every part of the hands drawn through it. It seemed intuitively that this would be an efficient use of the water. Over a four year period hundreds of prototypes have been made and tested. They have been made from rubber, epoxy resin, metal, plastic and combinations of these.

Some of the factors/limitations encountered are as follows;



- 1) Speed of flow. If the veil is too fast it may clean your hands nicely but also wet your shirt because of excessive spray.
- 2) The current prototype that operates at 2.5 litres per minute (l/m) has aperture dimensions that are specified down to .05mm. For comparison a sheet of A4 printer paper has a thickness of little more at 0.07mm, and electrical insulating tape measures twice that at 0.1mm. Prototyping apertures with such small dimensions has been challenging. One methodology that was developed was to take a 'blank', cut it in half, then stick it back together using 0.1mm tape as spacers.
- 3) Working with such small apertures made it difficult to reproduce accurately any one prototype. As a result some work has been done on larger apertures then scaled down.....however not all results scale down well!
- 4) Standard water supplies will tend to overwhelm the Waterblade with the tap fully open. Best results are achieved by stopping down the flow on an isolator when retro fitting. New systems would require considerably smaller pipe work (and boilers/heating etc.)

## STATUS AND FUTURE DEVELOPMENT

The 'Waterblade' is 'patent pending'. The product is currently a fully functional prototype. It has been developed with help from a grant from the Technology Strategy Board at the University of Brighton.

Funding is currently being sought for future development in two areas, manufacture and evaluation.

**Manufacture** An injection moulded version is currently being made. The small dimensions and the importance of a high standard of finish that are required for the nozzle to function correctly are proving challenging.

**Evaluation** Some questions

-How effective at washing hands is the Waterblade at 3 l/m compared to an aerating nozzle and an unmodified flow at the same rate?

-Is the Waterblade just recommended for cloakrooms or could it be used in bathrooms? This is a question of usage. It may for example take too long to fill the basin if that is a function that is carried out in the bathroom.

-Can the Waterblade be used for other functions such as washing/rinsing of cars/ components/ dishes?

-How much energy could be saved by fitting the Waterblade. An interesting aspect of this question is that while heating less water uses less energy, is the temperature to which the water has to be heated to, less for lower levels of flow? Put another way, the

cooling effect on your hands of a flow rate of 6 l/m at 20°C may be similar to the cooling effect of a flow of 2 l/m at 7°C.

-Does the temperature of the water effect the performance of the veil, as surface tension is known to be affected by temperature?

- How thin is the 'blade' in the picture? (Width 200mm, flow volume 2 l/m, speed of flow? assume uniform thickness) How much thinner could it be?

The results of this evaluation, together with greater knowledge of the possibilities and limitations of manufacture, should inform any future development.

## PHOTO



VIDEO [https://www.dropbox.com/s/fxvtxm6pfi0nuv5/MVI\\_1126.avi](https://www.dropbox.com/s/fxvtxm6pfi0nuv5/MVI_1126.avi)

## References and Endnotes

<sup>1</sup>Neuro-Borreliosis is a bacterial infection of the spinal cerebral fluid, a less common form of Lyme disease. There is much that is not known about this infection, however what is known is that early aggressive treatment with antibiotics gives the best chances of avoiding a serious chronic condition, that is hard to treat.

Because of this it is important to be 'Lyme Aware'

- 1) Ticks which carry the disease are found in woodland and grassland. They may be as small as a poppy seed. If you find one attached remove it promptly in the correct manner.
- 2) If you suspect you have Lyme disease treat promptly and aggressively. The symptoms are an unusual rash, described as a 'Bulls eye' rash and flu like symptoms. Blood tests are unreliable, especially in the early stages. Less than half those infected ever report having had the rash.

Dr. Petra Hopf-Seidel 2012 *Chronic persistent Lyme Disease (LD) or chronic Borreliosis* Available at [http://www.dr-hopf-seidel.de/mediapool/87/874128/data/Chronic\\_persistent\\_Lyme\\_9-2012.pdf](http://www.dr-hopf-seidel.de/mediapool/87/874128/data/Chronic_persistent_Lyme_9-2012.pdf) Accessed 10/07/2014.

Neoparl 2014 *Basin: with a NEOPERL water saver consumption is reduced by up to 50%* Online. Available at <http://www.waterlimited.net/en/wl/savingwater/waterconservationproducts/basin.html> Accessed 10/07/2014

ODNI 2012 *Global Water Security Intelligence Community Assessment* Online. Available at <http://www.dni.gov/index.php/newsroom/press-releases/96-press-releases-2012/529-odni-releases-global-water-security-ica> Accessed 10/07/2014

## **Participation or “Exploitation”: How Can Concepts of Community and Privatisation Coalesce around Water Efficiency Approaches?**

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### **ABSTRACT**

The Water Framework Directive has as one of its central objectives stakeholder participation at the catchment scale. Accounts of water governance encourage water users outside of formal stakeholder relationships to become involved in resource stewardship, both inside and outside the home. In particular water conservation and increased water efficiency is presented as a community ‘issue’ which relies upon voluntary contributions of time and labour to support the stewardship of urban and rural water environments. This community participation is evidenced through fundraising to build community rain gardens, rain water harvesting within communal and municipal buildings and NGO, regulator and water company campaigns to promote lifestyle changes which augment household water efficiency through technology and personal use habits. Whilst there are good reasons to involve the community in water management, we need to ask some critical questions about the way in which this community participation is valued within a quasi-privatised water resource management regime. Does the drive to maximise water efficiency encourage participation or is it an “exploitation” of goodwill? Who derives the maximum utility from this approach; water stakeholders or water company shareholders? Exploring concepts of household revenue streams, monopoly, human economy and the Transition Town movement, this paper advocates an approach that repositions water governance at the catchment scale in such a way that ensures that community participation efforts are sufficiently rewarded.

**KEYWORDS:** Community Participation; Human Economy; Water Efficiency; Water Governance.

### **INTRODUCTION**

Water efficiency is embedded within the English water management regime. Since 1993 each water company has had a duty under section 93A of the 1991 Water Industry Act to promote water efficiency to its customers. Education campaigns supporting water efficiency have emphasised not only the importance of changing water consumption behaviours at home but also the consequences of how personal use impacts on the wider water environment, effectively transforming water users into water stakeholders. The role of the Water Framework Directive (WFD) in empowering local water stakeholders at the catchment level has been well documented (De Stefano 2010; Hammer et al 2011) and complements water efficiency initiatives. The formalisation of these working relationships between water companies, water regulators, NGOS and, increasingly, community action

groups, has created unique clusters of water stewardship along individual catchments (for example, the Internal Drainage Boards network work nationally but independently of each other). This framework of water governance can be located within the context of ‘the politics of community’. In recent years New Labour’s understanding of communitarianism and the present Coalition government’s tentative politics of the ‘big society’ can be seen as diverging ways of re-invigorating civil society involvement in the process of governance. Both had problematic relationships with the role of community participation in markets. Eschewing these policy initiatives this paper will explore an alternative approach to community participation – the ‘Human Economy’ model (Hart et al 2010). This offers participation in civic life which presents an approach which accepts the need to recognise the existence of a marketised environment. Put another way, participation comes not out of a moral coda of duty, but from a more dynamic, engaged approach of mutual self benefit which creates positive outcomes for a wider community. This difference is the central crux to the paper: mapping a new approach to water efficiency initiatives which harness a realistic model of participation and move away from the potential ‘exploitation’ of goodwill that volunteerism rests upon.

To understand these issues then, we need to go back to the structure of Integrated Water Resource Management (IWRM) agencies and actors, who have struggled to root water efficiency in the hearts and minds of English water users. Many studies have shown that water users have historically viewed potable water as a plentiful, cheap resource and a very different utility from that of gas or electricity (DEFRA 2009, Vugteveen et al 2010). Climate change arguments have helped to reposition the water efficiency thrust of ‘doing more with less’. It is clear that education campaigns regarding the water cycle and the process of water delivery have made consumers more aware of the pertinence of the water efficiency agenda. Whilst water remains unmetered for many consumers in England and Wales, the drive to reduce unnecessary use is to be applauded. Water efficiency plays a key role in community adaptation to increasingly water stressed environments.

Examples of water efficiency endeavours move from the personal to the social. From saving water in the home by changing personal use, toilet flushing, washing habits, to installing technologies such as rainwater butts for garden watering, the scale moves outwards. Community rain gardens are a relatively recent innovation in the UK that complement the Sustainable Urban Drainage (SUDs) approach to managing water in the urban environment. These are retrofitted shallow depressions of flowers, shrubs or trees that sit in the urban environment to absorb rainfall run off and attenuate flooding. They are often managed by partnerships between local authority and community groups, with installation often tax payer funded and maintenance through voluntary contributions. Other community water efficient activities include water recycling on community allotments, organising awareness events such as water cafes, fundraising for green roofs on community facilities such as schools and village halls, and the formation of community gardens.

Water efficiency issues raise a critical question. Can a developed economy rely on unpaid community participation in a sector as crucial as water? Water efficiency is a central

principle at the heart of water stewardship. Yet water supply is in the hands of private, profit-making companies. Surely if we use less water, water bills should decrease and water companies should make less profit? This is the logic of the market. Seyfang and Longhurst's work (2013) is pertinent here. They argue that the Coalition government's argument that a strong market economy underpins sustainable development is 'blind to the culturally embedded, social and psychological drivers of consumption behaviour'. Moreover, this faith in the market 'fails to see the social infrastructure and institutions which constrain choice' (2013,66). For Seyfang and Longhurst, patterns of consumption need to be addressed for sustainability to thrive. Asking consumers to reduce usage for an ethical principle only will not be enough. Moreover, decreasing volumes of water use do not necessarily reflect decreasing costs of water bills, partly due to the strictures of the regulatory system underpinning the water management regime, with 5 year planning cycles. Water efficiency has then to operate in a complex pricing system not clearly accessible to water users. How might forms of community involvement allow us to approach these issues? More importantly, how might the Human Economy approach offer a new way of encouraging community participation after the compromises and failures of New Labour communitarianism and the Big Society?

This theoretical scoping paper examines the delicate balance between 'participation' and 'exploitation' in the name of water stewardship. Previous research (Gearey & Jeffrey 2006) has explored the role of legitimacy in the relationships of water stakeholders under conditions of increasing water stress. This paper wishes to develop this line of argument further by suggesting that water efficiency initiatives could strengthen the trust between community groups and water management regimes but only through reframing the water efficiency agenda. In other words, water supply companies and regulators must galvanise support by recognising that the marketisation of water repositions community and consumer responses to saving water. There needs to be an element of profit sharing, albeit in an alternative form. The author hopes to use the ideas outlined in this paper to undertake some empirical fieldwork in the near future and would benefit from suggestions and critical feedback during the conference proceedings.

The first section of the argument outlines the relationships, and examines the present tensions, in the English water governance regime only. This is because the English IWRM model differs from those in Northern Ireland, Scotland and Wales as the only model that deploys private for-profit companies. The paper then turns to examine community participation and the tensions therein. The final section will offer some alternative approaches to rewarding the Human Economy of water stewardship at the catchment level, drawing on examples from the Transition Town movement.

### **Water Efficiency as Community Participation**

Water governance in England faces a number of challenges. Private companies, reliant on making profit, need to build legitimacy with their consumers. State regulatory structures go some of the way to define the terms of supply (Water Act 2014), but a legitimacy gap still remains (Gearey & Jeffrey, 2006 ). In part this is to do with the local nature of water and

the hydrological cycle: some parts of the country experience scarcity, whilst others do not. There are other factors. Water companies and other stakeholders attempt to involve consumers and water users through the perspective of water efficiency and conservation. The championing of water stewardship practices and the need to preserve a special resource are undoubtedly important in the governance 'mix'. However, in a period where public trust of private companies is being tested, it may prove difficult to persuade consumers that companies place the welfare of the commodity above its monetary role in creating profit. Rising bills and evidence of water wastage by the water companies themselves also make the governance regime vulnerable to the criticism that existing policies serve to present water companies as working solely in the interests of their shareholders and investors. Indeed, the role of neoliberal structures within water management systems has come under considerable criticism (Bakker, 2010). Without serious reconsideration of how the understanding of community operates in water governance, it may be that the idea that there is valid, reciprocal participation becomes completely discredited. We need to examine these themes in detail.

Within the dominant approaches water governance has been presented as a community issue. For domestic users, water regulators encourage this approach through campaigns to promote taking shorter showers, using water butts and being more mindful when using dishwashers and washing machines. For industrial users, water efficiency is depicted as part of a green agenda, whereby water resources are part of an environmentally friendly schema. For agricultural users the drive to become water efficient is linked to a more nuanced relationship with the natural environment. For public service or municipal work the adaptation is target driven, reducing use and therefore overheads: thus saving taxpayers' money. The global result is that behavioural change and adaptation to new water efficient technologies encourage a community 'buy in' and a more careful use of a localised resource

Before we can properly address what is at stake in community involvement with water governance, we need to clarify some key points. It is pertinent to restate the impact of the vagaries of the hydrologic cycle. Water efficiency initiatives, and community responses, are impacted by the perception, and the experience, of scarcity. The English and Welsh water management regime has to respond to disproportionate rainfall levels, where the North West, especially the Lake District, receives around 3200mm per annum compared to Eastern England which has on average 500mm per annum and the more densely populated part of the country, in particular London receives 514mm per annum as opposed to Cardiff at 1151mm per annum (MetOffice 2010). Changing water conditions indicate that more erratic rainfall events are likely to become more episodic (DEFRA 2010, Christensen et al 2007). The current water management regime has a tight national regulatory structure, super-imposed on regional areas with significant rainfall and population disparity. This creates a both in terms of water security and water supply, with regulatory bodies responsible for the former and privatised companies for the latter. Water efficiency straddles the two, pulled in two directions by the need to create social equity in relation to equal access to the resource although economic equity lies outside of the jurisdiction of any one institutional body. The submission of Water Resource Management (WRM) plans of

the water companies is a recent process lead by the Environment Agency. The WRMs enable long term planning for predictable supply and demand forecasts. The process of collecting all WRM plans is due for completion by the end of 2014. Innovative approaches such as reverse water auctions and water trading licences recommended in the 2009 Cave review of competition in the water industry have been incorporated into the new Water Act passed in May 2014. This has adjusted the landscape to the extent that increased options to widen competitiveness will drive efficiency in costs and resource deployment. The Water Act's most direct impact in terms of community water efficiency is its clarification that the building and maintenance of SUDS can be a function of sewerage undertaking. It effectively propels water efficient urban landscaping into the mainstream.

Yet the Act does not seem to have had the remit to address community participation in resource management endeavours. How can water efficiency hope to be more responsive to local environments and local consumers? We need to untangle some further themes. Water efficiency is not coterminous with water conservation, though the two have significant overlap, and both fit within the remit of water governance or 'stewardship'. The focus of water efficiency lies within behavioural change. It is a two step process that seeks to reduce the volume of the resource used and to do more with that water. Technological innovations which support water efficiency only work if the people and communities utilising them are prepared to adapt their behaviour. Water conservation can also include this type of behavioural and technological adaptivity, but its focus is shifted towards protection of the resource rather than a volumetric reduction of use. Water efficiency requires a step-change in water use which is both attitudinal and behavioural, and promotes active, mindful participation, which starts at the personal level to scale up to seek effects community wide. Taken from this perspective, water efficiency is the ultimate act of community participation, making personal acts communally significant.

Against the backdrop of water efficiency endeavours is a need to restate an obvious, though curious question – can we go beyond saving water to become more water efficient? If we use less water, we take less out of the environment. It appears a rational, logical causal link. Yet for critical geographers, such as Noel Castree (2009), and David Harvey (2005), there are far more large scale changes we could enact: Reducing our population size, changing our economy from industrial to knowledge based, reducing our carbon imprint, changing our diets. In short, and in line with Seyfang (2009), consuming less. Put differently, modern capitalist, neoliberal systems create the need for water usage on a vast scale. Through this lens community participation by necessity means addressing the political- the values that we hold and the way we choose to live our lives.

There is also a more prosaic concern. For householders and business users, a central water efficiency incentive is that using less water will save money. Both through less volumetric use of the resource, potable water, but also because water use is tied to energy use. The Energy Savings Trust state that 55% of water used in the home is heated water. Hence, less water means less gas or electricity use (Energy Saving Trust, 2013). Water efficiency initiatives have championed water meterage as a fundamental tool in reducing water use; enabling users to clearly see their volumetric consumption. Before 2004 approximately



20% of homes were metered. Since 2004 around 40% of homes, and 95% of businesses are now metered; a growth of 200% (Environment Agency, 2008). So have water users seen a reduction in their bills since they are more aware of their volumetric use? This question is pertinent since the Water Industry Act 1999 enables water companies to ‘universally meter households if the water company’s area has been determined to be in an area of serious water stress’ (South East Water, 2010). The issue is that increased metering has not witnessed a corresponding fall in water bills. The 2009 Cave review noted that in real terms domestic water bills rose by 42% in the 20 years since privatisation. The National Audit Office recorded domestic water bills as rising between 2002-2011 (NAO, 2013).

Water efficiency initiatives are all actively promoted by the water companies, but water bills do not see a corresponding fall in price. These initiatives seem ineffectual when we see that the leakage rates of the water companies remain at 25.6% for Thames, 16% for Southern and 26.7% for Severn Trent (OFWAT, 2010). For Thames, in a water stressed area, that is the equivalent of 665 million litres of water every day. These may be renamed as ‘returns to the system’ by the water companies, but as this is treated potable water, the Thames figure alone is the equivalent of 44 million toilets being unnecessarily flushed every day in the Thames water region.

More pertinent perhaps is the question of benefits to the consumer. If customers are being asked to change their behaviour around potable water then that drop in use should be reflected in a distinct savings in their water bills. Instead bills continue to rise; as do the profits of the water companies. As Pryke states (2013:426): ‘the operational side of the water business, indeed the actual cost of water itself and the amount used do not themselves seem to figure as part of the financial equation’. The actual volumes of water used by consumers seem almost an irrelevance. Indeed scaling up to include the involvement of the regulators, Helm and Tindall (2009) go on to argue that the volumes of water involved do not figure in the landscape of the five year planning cycle for water pricing. Allen and Pryke note: ‘Ofwat determines household water bills on the basis of how much the water companies invest, whether that is raised through equity or debt’ (2013:426). Ofwat state in their 2009 Price Review: ‘Promoting water efficiency will not affect company revenues. The revenue correction mechanism, which we will introduce from 2010-2011 will make sure that companies are not penalised if consumers use less water than we assume when we set price limits at PR09’ (Ofwat, 2009:31). Delinking water use from the make up of water bills resites water efficiency initiatives as a further exploitation of community participation in water stewardship.

It could be argued that there needs to be a directly corresponding initiative on behalf of the water companies and regulators to reinvest these ‘savings’ directly into long term investment projects to secure water resources for the future, outside of regulated investment funds. In other words, the companies need to make it clear that less water use may result in enhanced water resources even if it is not possible to demonstrate a corresponding drop in water bills that users receive. Instead, rising water profits appear to drive ‘the lifting out of investment opportunities’ (Allen & Pryke, 2013:423) out of the country. In other words, rising profits from the water sector fuel investment opportunities in other sectors, other

countries. There is a problem in squaring water efficiency, which, by its very definition, is locked into a distinct geographical scale, with the realities of shareholder capital ready to move with the next investment opportunity. Water may be utilised more efficiently in the home, in the catchment or in a region, yet the shareholders who help finance the water companies reside elsewhere geographically and are primarily interested in future revenue, not in protecting the original resource and its environment.

These problems are exacerbated because of the monopoly structure of the water market. The monopoly structure, based along water catchments, works in parallel with national regulatory bodies, such as the Environment Agency. Aside from large volumetric users at an industrial scale, water users cannot opt out from their service providers: for instance, customers in London can only buy their water from Thames water. As Thames water now use household revenue streams as a locked in, assured form of income, they use this as a guarantee against their wider corporate debt restructuring (Allen and Pryke, 2013). In other words, water customers finance the long term investment of their providers' other investment strategies. Macquarie Bank, which own Thames Water, use London water users' money to finance investments in other capital markets because that money is a predictable, guaranteed revenue stream income and so can be treated almost as an asset of the business. Guaranteed water use shores up the wider company investments.

### **Participation or “Exploitation”: A Dynamic Approach to Water Stewardship**

New Labour's main point of reference was to the 'third sector' (Etzioni, 1973). Critics of New Labour have stressed that the rhetoric of communitarianism was often far from the practice – and that the more radical of the stakeholding ideas were abandoned during Blair's second period in government. David Cameron's Big Society can be seen as a conservative communitarian approach- a response to the failures of New Labour. Outlined in the work of political philosopher Phillip Blond, the big society stresses the importance of community interventionism for a moral market economy. The idea has not fared well. Critics have shown that Blond's approach may downplay, if not entirely ignore, the savings that freely provided labour and expertise would otherwise cost central government (Davies & Pill, 2012; Harrow & Jung, 2011).

The Human Economy approach suggests an important way forward. Drawing on the work of Karl Polanyi and other economic anthropologists, human economy begins from the perspective that the commodification of water may be the source of the problem. However, it is important to stress that Human Economy of thought does not reject the market. Rather, it argues that for the market to work it needs to be embedded in social relationships. In short, markets need to work for people. Unlike the big society, Human Economy does not abandon the state. The power of the state is necessary to socially embed a market. Unlike New Labour communitarianism, Human Economy is much more concerned with decentring power in radical and participatory ways. Moreover, ideas of embedded economy are distinct from the present emphasis on formal regulatory regimes. New forms of social cooperation are necessary (Hulgard, 2010) to supplement such structures. We can elaborate these ideas with reference to the recent Waterwise response to a government white paper

(2010). Waterwise argue that the current regulatory framework has a supply sided bias: assurity of supply currently takes precedence over water efficiency. They also note that the regulatory system is muscle bound: unable to respond flexibly to changing scenarios both in terms of economic change but also environmental. The numerous planning cycles of various aspects of water provision and planning (CAMS, drought plans, flood risk management, pricing cycles, Town Planning Acts) reduce innovation and suffocates adaptation. From this meta-planning perspective, how can the privatised elements of water provision coalesce with the concept of community that the WFD is so keen to promote? The term that is reiterated by NGOs, local councils and water companies is 'partnership'. Using water efficiency as a focal point for partnership efforts, it may be possible to rebalance dialogue and action in favour of those community participants at the catchment level.

Human Economy thinking would further this approach. Garnering local catchment based support from a diverse range of community members, it may be possible for smaller stakeholders to reassert their expertise in crucial areas, to demonstrate that new partnership approaches may add in the missing flexibility and plug the gap between municipal, private and grassroots adaptation. Water efficiency may become a much more nuanced discourse, making use of local expertise and local knowledge outside of formal and privatised frameworks.

There is a second important theme. Human Economy approaches seek to recognise the value of unpaid work to the wider economy. The Human Economy perspective accords with Seyfang and Longhurst's work on community currencies. To move the debate on from 'exploitation' to 'participation', unrecognised work needs to be fully valued – and remunerated, even outside of standard market parameters. Their systematic review of community currencies identified those which generated momentum in 'green' communities (local exchange trading schemes) and those which appeared to demonstrate variety across different economic sectors (time banks) and those which offer sustainable consumption (Nu Spaarpas). Refocusing the agenda to recognise that the Human Economy is a resource, and therefore, like any resource, needs inputs and strategies to develop it, could provide one mechanism towards moving from exploitation to participation. What format might this take? One proposed method would be to utilise strategies that support both the local environment and the local economy. Numerous examples show that it is possible to engage communities in projects where an ethical long term outcome, using less water, can match with short term benefits.

The global 'Transition Town' movement can help concretise these ideas. The movement supports local entrepreneurs, consumers and businesses in mutually supportive networks that work at local levels. One of the practical manifestations of this approach is the idea of local currency – which is used in local businesses and exchanged for services, labour or products. This idea could be applied to water management. In return for water efficient endeavours the regulator, or the water company, depending on the input made and the water savings delivered, could reward local participants, whether shareholders or partners, with this local currency. The Bristol Pound and the Lewes Pound are two existing examples.

This currency drives local businesses, both chains and independents, and helps foster a sense of reward in return for participation. Other alternative forms of currency include time-banking and co-production; both new forms of rewarding participation. Local water stakeholders collaborating together may feel more empowered to demand a return for their endeavours, given the monetised environment that the quasi-privatised water sector embodies. Examples include vouchers for local shops, direct funding for community projects or apprenticeship schemes to promote youth employment. The nub is that participants gain something tangible as they give something very personal – their time, their expertise, their labour - but that something is idiosyncratic and rooted in the local community. This approach might go some way to highlight that a resource as geographically localised as water cannot be comfortably integrated into international capital markets. Human Economy moves the debate, and associated action, on from its current position.

## CONCLUSION

This scoping paper has aimed to go some way in addressing a very real issue in redressing the imbalance between asking water users to use less water whilst seeing no clear, corresponding drop in their water bills. Adaptation and innovation needs to assert itself from outside of the current IWRM regime. The large financial gains made by the water companies on international capital markets through the financialisation of household revenue streams, relationships of trusts between water companies and water users may be at risk of breaking down. Drawing on Human Economy thinking, this paper has argued that discourses on community involvement in water governance need to be re-thought. Human Economy thinking stresses the importance of decentred and local forms of stewardship and community involvement. Moreover, and perhaps most importantly, the Human Economy approach argues that any community work around resource stewardship should be recompensed in a way which supports the local economy at the catchment scale. Whilst much more work is necessary to articulate in detail how Human Economy thinking could reposition water governance, the Transition Town movement and the resources offered by local currencies, has the potential to move community partnership from “exploitation” to genuine forms of participation at the catchment level between regulator, water company and water user.

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## WATER EFFICIENCY INTERVENTIONS IN A NON-DOMESTIC BUILDING - TECHNICAL VERSUS BEHAVIOURAL CHANGE

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### ABSTRACT

The objective of this paper is to reiterate the need for the in-use evaluation of water efficiency interventions designed to reduce water demand in buildings. The paper reports on a research project which analysed water use data, during 30 weeks, from hot and cold wash hand basin taps in male and female toilets. During the 30 weeks the tap flow rate was reduced from 9.00 lpm, to 6.00 lpm and finally to 4.00 lpm. The consumptive water use data was logged each time a wash hand basin tap was used by office building occupants. Also during the 30 weeks, the tap flow rate was returned to 9.00 lpm and a behavioural change campaign enacted to challenge office users to reduce their water demand, from the wash hand basin taps and a kitchen tap by 25%. The research demonstrated a clear requirement for the evaluation of water efficiency interventions. During the study period the water demand decreased in the male toilet wash hand basins taps corresponding to the reduced flow rate in the taps. However, the water use increased in the female toilets per wash hand event; and overall the behavioural change campaign was overall more successful than the water efficiency intervention. The research concludes that although water efficiency is important and necessary, there should be greater emphasis on data collection and analysis. Such research should be undertaken before asserting buildings are water efficient based only on assumed data regarding frequency, duration and water-related user behaviour.

**Keywords:** Behavioural, Efficiency, Evaluation, Flow meter, Valve.

### INTRODUCTION

The requirement to encourage and promote the efficient use of water in buildings is supported by a multitude of organisations, and enforced by regulatory requirements. For example: the Office of Water Services (OFWAT) require water companies to report on proposed water efficiency plans in the annual resource management plans submitted to OFWAT (2014); Organisations require new buildings to achieve defined environmental credentials, and water efficiency contributes to this goal, see example: (Welsh Government, 2012; BREEAM, 2013); numerous consultancies assist organisations save money from water efficiency measures and Building Regulations in England and Wales require water efficiency is incorporated into new and refurbished buildings (HM

Government, 2010). The message for increased attention to improving water efficiency is reinforced by the long-term predication of ‘wetter winters and drier summers’ (Department of Environment Food and Rural Affairs, 2008) and regions of the UK are already classified, by the Environment Agency, as ‘Serious Stress’ Regions (2013). The message of water efficiency is growing stronger and louder; that the efficient use of water is an important consideration in the context of the built environment.

Water demand is much better understood in residential buildings versus non-domestic buildings (Tattersal, Ryan, & Allen, 2009). Historically research has focussed on residential water use, and because residential buildings typically comprise of small numbers of people, gathering and analysing data is less complicated in comparison to non-domestic buildings-which have larger numbers of building users, and thus uses of water. In addition, analysing smart water meter data using techniques such as flow trace analysis enables researchers to more easily understand patterns of water use, but is only effective if there are a limited number of water use outlets used by a small number of people (DeOreo, Heaney, & Mayers, 1996). In non-domestic buildings, flow analysis can be undertaken but requires a significant number of sub meters to compartmentalise the water network in the building. However most non-domestic buildings have only the mandatory singular water meter installed on a water supply to a non-domestic building (British Standards Institute, 2006) and which does not provide a sufficient granulation of data for the use of flow analysis.

Detailed data enables a much greater understanding of how water is used in a building by producing water use profiles which account for water usage at a minute-by-minute level. In non-domestic buildings, only low levels of detail, such as half-hourly volumetric water use data, is generally available from a single meter. The installation of sub water meters can provide a more detailed analysis of water use. Data for different types of non-domestic building is typically only available at a whole building level, see for example (Parkinson, 2003; Wagget & Arotzky, 2006; Market Transformation Programme, 2008). This means that when water efficiency interventions are installed, at building construction or as part of building refurbishment, the effectiveness of a water efficiency intervention is difficult to evaluate due to the type of data available. Instead, assumptions are used to predict a reduced water demand resulting from different types of water efficiency intervention.

The objective of this paper is to reiterate the necessity of evaluating the effectiveness of interventions, either technical or behavioural change, targeted at reducing water demand in buildings. The paper reiterates this need for post installation evaluation by reporting the research findings of the effectiveness of installing flow regulation valves. The valves were installed in isolation valves of the water supply pipes to hot and cold wash hand basin taps in the male and female toilets, located in the first floor of an office building. Data was gathered using flow meters and data logging equipment over a thirty week period. The use of flow reduction valves as a water efficiency measure was selected as they are marketed as a low cost, easy to install and high water saving intervention, often termed ‘low hanging fruit’ in corporate organisations. This type of ‘fruit’ is very attractive to facility managers and buildings owners. As this paper will show however, the interventions in this instance resulted in the unintended consequences of increased water demand.



## RESEARCH APPROACH

The research study was undertaken on the first floor of an office building. It was selected due to availability of as-constructed drawings, the ability to easily isolate the water supply to the first floor and a consistent building population. The study was carried out from the 6<sup>th</sup> December 2012 to 28<sup>th</sup> June 2013, 30 weeks in total excluding the Christmas holidays. The study consisted of six stages:

1. Establishing baseline water consumption,
2. Reducing flow rate from 9 lpm to 6 lpm,
3. Reducing flow rate from 6 lpm to 4 lpm,
4. Carrying out behavioural change campaign,
5. Data analysis,
6. Facilitation of focus groups.

The flow rate was regulated by the installation of a Flow Regulation Valve (FRV) into an existing water supply isolation valve. The water pressure to the taps was approximately 1.0 bar, as water is supplied from a roof mounted header tank. According to the technical specification of the FRV a 10% variance in delivered flow rate should be anticipated at this water pressure. The existing wash hand basin taps were pillar type taps, in good condition, with no detectable leakage. The flow rate of the water discharged from each tap was measured using installed flow meters.

In total nine flow meters were installed on the hot and cold water supply to the wash hand basin taps, and the kitchen sink tap. The flow meters were installed in-line with the water pipe, sometimes termed intrusive metering. A sensor wire was connected from the flow meter to a data logger located in a nearby plant room. This wired connection enabled the pulse emitted from the flow meter to be recorded every second by the data logger. The total water usage, per event, was derived from the total number of pulses emitted from the data logger. Prior to installation each flow meter was calibrated, under laboratory conditions, to record the number of pulses produced per litre of water. The flow meters were installed outside of normal working hours, and as far as possible building occupants were not told why they were installed.

Figure 1 shows the component parts of the water metering arrangement and the FRV, which is inserted into the isolation valve. It can be seen from Figure 1 that there is limited space available for placing metering equipment near the wash hand basin. The process of installing the research experiment was time consuming and costly, due to the capital cost of the equipment and the labour cost of the plumber. The labour cost was influenced by the need for out-of-office worker hours and the lack of working space. Furthermore, not shown in the photographs, is the considerable length of sensor cable required to connect the flow meters to the data loggers. The sensor cable had to be located behind a number of concealed panels, again this was a time consuming and costly process which also required agreement and cooperation by the facility manager. Overall, the installation and configuration of water meters required significant time and resources.



**Figure 1:** Left photo: Flow meter (circle with arrow) and isolation valve (circled) configuration on supply pipe to hand wash basin tap. Middle photo: Isolation valve and flow regulator valve. Right hand side photo: Plan view of isolation valve without a flow regulator valve installed. The valve is placed inside the isolation valve chamber and a cap screwed in place (not shown in photo).

The pulsed data output from the flow meters was analysed per event. The paper applied the following definition of an event: An Event is defined as using either or both of the wash hand basin taps either simultaneously or concurrently. For a concurrent event, it was assumed that an event constituted the taps being used concurrently within a one minute period; otherwise a separate event was recorded. For example, if the hot tap was used then the cold tap used five minutes later, the use of the cold tap would be treated as a separate event. After the data collection phase of the study the FRVs were removed and the baseline flow rate of 9.0 lpm was restored. The next phase of the research was to investigate how building occupants would respond to a challenge to reduce their water use per event as a result of a behavioural change campaign.

### Behavioural change campaign

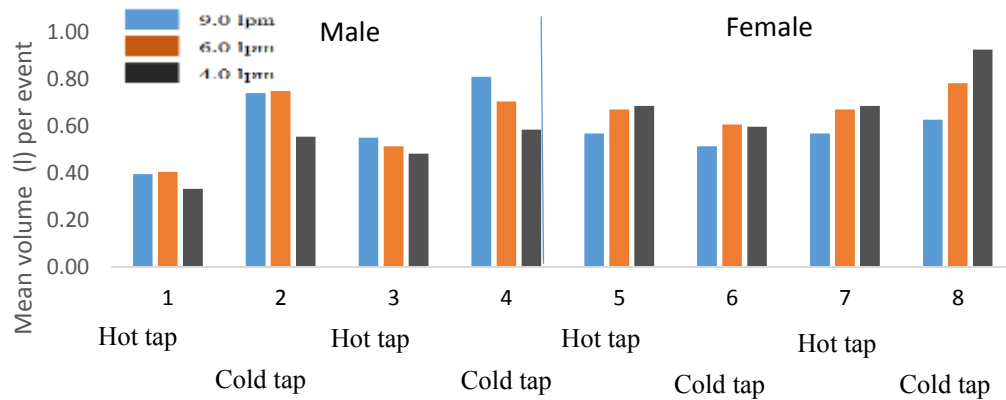
The objective of the Behavioural Change Campaign (BCC) was to challenge building occupants to reduce their water use at the wash hand basins taps and the kitchen tap, per event, by 25% without a FRV installed. During the BCC three week period water consumption for the male and female wash hand basins was graphically displayed on the entrance to the toilet cubicle door on an A4 sized graph. In addition to displaying the data results graphically, a number of posters were placed around the toilet area and the kitchenette, all of which promoted water efficiency. Finally, regular emails were sent to the building occupants to report on progress toward the 25% reduction in water use target.

## RESULTS

An important requirement of the analysis was to agree and define what constituted an Event. The definition stated previously was agreed by the research team as a reasonable and practicable approach. This definition of an Event enabled the results of water use where the tap was turned off and on in a short time to be analysed as one event. The water use Events, over the whole study period, were statistically compared using statistical software. Prior to generating results the data was cleaned to remove outlier data points, such as for example in a small number of instances the data showed a tap had been left flowing for a significant period of time. It was therefore decided to exclude such outliers

on the ground that it was unlikely that the duration of time was related to hand washing and thus did not constitute an event.

The results are discussed next, firstly the findings from the installation of the FRV are reported and which is followed by the BCC results.



**Figure 2:** Graph showing the water use per event, as a mean value, when the maximum flow rate was reduced from 9.0 lpm-4.0 lpm.

Figure 2 shows the hot and the cold water use per event, in litres, for wash hand basins in male and female toilets. The graph clearly shows a reduction in water use per event in the male cubicles. Conversely, water use per event actually increased from the wash hand basins taps in the female toilets. The percentage change is shown below in Table 1. A flow reduction from 9.0 lpm to 4.0 lpm theoretically should reduce water consumption by 56%, assuming the same duration of tap use and the tap was opened to full flow. The research results show that the assumed reduction in water use per event as a result of the FRV was not achieved.

**Table 1:** Percentage change in response to the installation of flow restrictor valves

Wash hand basin tap	Percentage change in volumetric use per event
Male-Hot	14% decrease
Male-Cold	26% decrease
Female-Hot	21% increase
Female-Cold	32% increase

**Table 2:** Percentage decrease in water use per event during the three week behavioural campaign. Note: Unless stated, all figures are a percentage reduction.

Behavioural change campaign	Male wash hand basin taps (combined)	Female wash hand basin taps (combined)	Kitchen tap
Week 1	0.51	0.67	1.02
Week 1 to Week 2	22%	19%	5%
Week 2 to Week 3	Increase 7%	Increase 17%	13%
Overall (Week 1 to Week 3)	19%	6%	21%

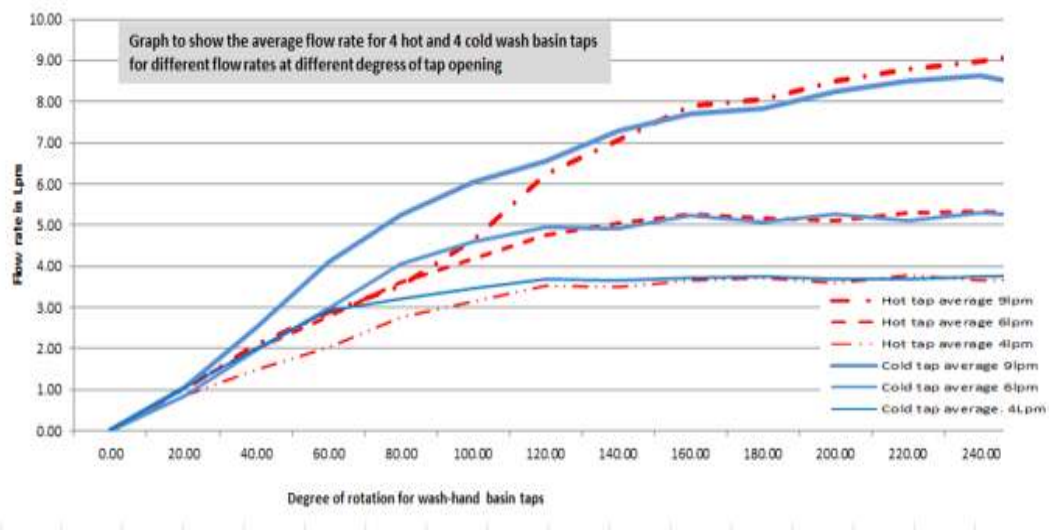
The results from the BCC, are shown above in Table 2 Overall the BCC achieved its intention of reducing water use, but did not achieve the 25% target reduction. Table 2 also shows that a consistent reduction in water use per event was observed from the kitchen tap. In comparison, this pattern is not seen in the wash hand basin taps, with water reducing by approximately 20% per event in the first week; but after this the BCC appears to provide a lesser effect with water consumption increasing again between week two to three.

**Table 3:** A comparison of overall change in water use achieved from the behavioural change campaign with that of the technical intervention. Note: Unless stated, all figures are a percentage reduction.

Overall percentage change	Male wash hand basin taps (combined)	Female wash hand basin taps (combined)
Baseline (Litres per event)	0.63	0.57
Flow reduction 6 l/p/m	4%	Increase 20%
Flow reduction 4 l/p/m	22%	Increase 27%
Behavioural change campaign (BCC)	19%	6%

The final set of results, in Table 3 above, compares the effectiveness of the FRV versus the BCC. The research results show that the FRV was almost as effective as the BCC with regard to reducing use of water per event with the male wash hand basins, but was much less effective with the female wash hand basins, resulting in an increase rather than a decrease of water use. Further research was carried to investigate this finding. Using the same equipment and operating conditions each tap was incrementally opened from no-flow to full-flow and the flow rate data logged. This additional research enabled an average performance curve for the hot and cold taps be plotted, and is shown below in

Figure 3.

**Figure 3:** Performance curves of wash hand basin taps

The flow rate is affected by how far the tap is opened. As would be expected, the more the tap is open the greater the flow. It is interesting to note that the FRVs had a very limited effect on regulating the flow from the tap when the tap was opened less than 30 Degrees. In addition, the flow rate was only fully restricted when the taps were turned to 120-160 Degrees. However, this finding is relevant to both male and female users, and did not explain why in the male toilets the water consumption decreased and increased in the female toilets, as shown in Table 1.

A focus group was carried with building occupants to discuss the research findings. The objective of the focus group was to better understand the research findings and to establish if users had noticed a difference in flow rates and how they responded to the BCC.

The focus group was attended by 9 members of staff, 5 males and 4 females. This represented 17% of the building occupants on the first floor, where the research was carried out. The focus group was facilitated by an Occupational Psychologist following a semi-structured topic guide and the proceedings were audio recorded and later transcribed, with the consent of the participants. The majority of the focus group participants stated that they did not notice the change in flow rate over the research period. However, they were all aware of the behavioural change campaign and some reported that they had taken steps to modify their behaviour as a result. After the findings were presented the facilitator asked for their suggestions as to why there was a difference in the research results between male and female wash hand basins and between the kitchen tap and the wash hand basin taps. A summary list of suggested explanations from the group is shown below.

- Females could be turning the tap more, to increase the flow rate, than males.
- Due to the lower flow rates, females could be spending longer washing hands resulting in the increase in water use.
- The liquid soap in the toilet required a certain amount of water to effectively rinse, and females might use more soap when washing their hands.
- A widely held view was that females are more likely to wash their hands more thoroughly (and therefore for longer) than males.

- Males might turn the tap further than females but for a shorter time, meaning that the reduced flow rate has more of an impact.
- With respect to the behavioural campaign, males were perhaps more likely to choose competitiveness over the thoroughness of washing their hands.
- It was easier to change water using habits in the kitchen versus hand washing, as there were more opportunities to change behaviour.

## DISCUSSION

Although, the research did not provide a definitive explanation to the research findings, the combination of a quantitative and qualitative research approach helped to formulate possible explanations for the findings. The most likely explanation for why the FRV and the BCC was overall more successful for the male wash hand basins users is that they turned on the tap much more open than female users. This meant for the male users the FRV were effective at reducing flow, as shown in the performance curves, when the taps were opened greater than 120 degrees. Additionally, because the use per event decreased it is hypothesised that males open taps more fully but for a shorter period of time—a short, sharp discharge of water. Conversely, the research findings suggest that female users opened the tap much less than males. However, due to slightly reduced flow rate (attributable to the FRV), females increased the duration the tap was left flowing. One possible explanation is that females could be using a similar amount of soap each time, but required a certain amount of water to remove the soap and hence requiring the tap to be on for longer. This helped to highlight that this type of research had an extensive number of variables, such as type of soap, outside temperature etc., which could influence the results.

The research has clearly demonstrated that the user and the type of tap have an impact on the effectiveness of a FRV when installed in water supply pipes to wash hand basin taps. The reason this finding is important is that it reinforces and demonstrates the need for a much greater understanding of water use in non-domestic buildings and especially a wider uptake of the installation of metering and monitoring equipment. As the need for increasing water efficiency strengthens so must the requirement for verifying assumptions of both how much water is being used and in what ways water is being used by building occupants at a more detailed level of data resolution.

In the case of the FRV, the assumption is that such interventions are cheap, easy to install and reduce water demand. However the research has challenged this assumption and shown, in this instance, the assumption to be incorrect. Furthermore, in the case of the female toilets the FRV had opposite of the desired effect by increasing the water use per event. It has been shown that although a FRV has a limiting effect on the flow rate of water, the complete effectiveness of the FRV is only realised when the tap is full flow rate.

As stated in the introduction, the objective of the paper is to highlight the necessity of monitoring the effectiveness of any type of intervention, either technical or behavioural change, aimed at reducing water demand. The research showed that monitoring water usage at high level of data resolution was very time consuming and resource intensive, as previously described. Accordingly, undertaking this type of research would require a

good relationship with the building owner or operator before being replicated on other buildings in addition to financial support for the project.

## CONCLUSION

The objective of the paper was to provide evidence which reiterates the message that water efficiency interventions, either technical or behavioural, should be more carefully monitored before claiming buildings are water efficient. This is especially important in retrofitting situations, such as this research, where a low cost and easy to install approach is taken to increase the efficient use of water. The results have shown the installation of FRVs, inserted in the isolation valves, located on the supply pipe to 4 sets of wash hand taps did not provide the anticipated water efficiency savings which corresponded to FRV flow rate, 6.0 lpm and 4.0 lpm. The effectiveness of installing FRV to reduce water use from male and female wash hand basin tap use has been demonstrated to produce mixed results. In the male toilets the volume of water decreased per event, by approximately 22% when the flow was restricted from 9.0 lpm to 4.0 lpm. Whereas it is potentially assumed, by facility managers and such like, that the flow rate should be reduced by 56%. Conversely the water use per event in the female toilets increased, by between 27% when the flow rate was restricted to 4.0 lpm.

The BCC demonstrated that a targeted awareness campaign can be a very effective tool to reduce water demand and in this instance was more effective, than FRVs, at reducing water use per event. The focus group findings suggested that the reason the BCC was effective in the kitchen could be attributable to a wider range of water uses, from cleaning a cup to washing fruit, and which presented more opportunities for changes to behaviour which were more water efficient. However the long term effectiveness of a BCC was not tested as part of this research, and the 'bounce back effect' might be applicable.

The findings from the focus group in addition to the research results indicate that the difference in effectiveness of the FRV could be attributable to the gender of the user and how they wash their hands. Females appear to open the tap less than males, thus resulting in a lower flow rate but run the tap for longer. Conversely, males open the tap wider but for a shorter duration. This may be attributable the amount of soap, if any, used in the hand washing process and the user's requirement for a defined volume of water required to clean off the soap. Furthermore, the type of tap is likely to have a significant impact but equally it is believed that this consideration is likely to be ignored when installing FRVs.

It is very unlikely that the level of water monitoring in non-domestic buildings as undertaken in this research will be widely adopted by facility managers and such like. This is predominately due to the extensive time and cost implication as demonstrated by the research. There is, however, opportunities for further research in this area and the results disseminated to industry. The research has clearly highlighted the need for a sharper focus on verifying the effectiveness, in operation, of technologies and behavioural change campaigns designed and claimed to improve water efficiency. The study has also shown, in this case, the potential for unintended consequences of installing FRVs as water usage increases in the female toilets. The research also recognises the challenges and costs associated with monitoring water use at a high level of data resolution. As we move

towards an uncertain future with respect to water use, it is important to ensure we are moving in the correct direction by checking assumptions and claims regarding the effectiveness of water efficiency interventions.

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