Water Frontiers:

Strategies for 2020 and beyond

BOOK OF ABSTRACTS

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Preface

This volume contains the papers presented at WatefCon 2016: Water Efficiency Conference 2016 held on September 7-9, 2016 in Coventry, UK.

There were 62 submissions in total. Each submission was reviewed by at least 2 scientific committee members. The committee decided to accept 35 papers. The program also includes 3 invited keynote speakers. The conference was managed via the EasyChair online conference management system.

This conference is organised annually or bi-annually by the Water Efficiency Network. The network is a global group of academics, industry practitioners, NGOs, interest groups and members of the public who share a common interest in promoting water resource efficiency and resilience, progressive water policy, useful and usable codes and standards as well as general best practice. The network was established in 2011 and is still going strong thanks to its many dedicated members and technical committees.

Thank you to all contributing authors and presenters, the keynote speakers, sponsors, this year's conference chair, Prof Sue Charlesworth, and her colleagues at Coventry University. Thank you to all network members; we hope you will continue to participate and support the network for the next 5 years. A very special thank you to Suzy Armsden, the network's administrator for her time and effort in organising another successful WATEF conference.

I wish everyone an enjoyable and productive conference.

July 25, 2016
University of Bath

Kemi Adeyeye
Lead, Water Efficiency Network

Program Committee

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EDITORIAL

This volume presents a collection of papers selected for presentation at the 4th Water Efficiency International Conference organised by the Water Efficiency Network. The network aims to facilitate the promotion of water efficiency and sustainable management of urban water by bringing together academics, stakeholders and practitioners. This fairly unique combination enables the dissemination of research and innovation in the water sector at a time of increasing populations in cities around the world combined with changes to the climate leading to water scarcity and flooding. The conference headline is: *Water Frontiers: Strategies for 2020 and beyond* and the selected papers have been grouped into seven categories:

1. Surface water management
2. Customer behaviour, water awareness and engagement
3. Water, Energy, Food nexus
4. Resilient communities
5. Water Reuse and Harvesting Systems
6. International water efficiency
7. Water Sensitive Cities

The selection of papers was via a peer review process; we would like to take this opportunity of thanking the scientific committee and network members for their hard work and constructive feedback to the authors of the papers. We have actively encouraged young researchers and industry to present their work, product developments and innovations in a constructive and encouraging environment.

We would also like to extend our thanks to the conference sponsors, the organising committee and in particular Suzanne Armsden for all her hard work and good humour in making this conference happen. We very much hope that the presented papers and discussions at the conference will help to cross fertilise research ideas with industrial advances in order to identify the challenges and opportunities to address global water issues to 2020 and beyond.

Conference chair:
Prof. Sue Charlesworth
Coventry University

MARTIN SHOULER

Martin is Associate Director and the Global Environmental Services Skills Leader at the international engineering consultancy Arup. Martin works on water and related projects across Building Engineering and Infrastructure.

Martin has extensive experience in the field of water system engineering having been involved in a wide range of major projects, in design, research and consultancy across the world. Particular expertise includes water supply, sanitation, sewerage, water conservation and efficiency, water quality, water treatment, wastewater engineering, and infrastructure services. In addition, he has a keen interest in sustainability particularly related to minimising water use and the energy associated with its use. He was a member of the Expert Group advising the UK government on technical standards for water systems for Building Engineering and Infrastructure. Martin takes a keen interest in accelerating innovation and has recently served on the Innovation Panel for the water regulator, Water Industry Commissioner for Scotland (WICS). He is jointly responsible for the water innovation showcase event, Wet Networks, held in London three times a year which brings together innovators, the investment community and technical experts. In addition, together with the UK's WRc, Martin is responsible for the recent innovation portal for the water sector – Venturi (venturiportal.com).

Martin is a member of British Standards Institution (BSi) committees responsible for a number of water and wastewater sector standards and has been involved in the development many British, European and ISO standards.

Martin is past chairman of the Society of Public Health Engineers (SoPHE).

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.

PROF DAVID BUTLER

David Butler is Professor of Water Engineering at the University of Exeter and a Director of the Centre for Water Systems. He was elected a Fellow of the Royal Academy of Engineering in 2015. He specialises in urban water management, has authored/co-authored over 250 technical papers, in addition to 12 books, published reports and edited conference proceedings, and is co-editor-in-chief of the Urban Water Journal. He has been funded without interruption by the UK Engineering & Physical Sciences Research Council since 1995 and is an EPSRC established career research fellow (2013-2018).

Keynote: **Resilience: Hype or Hope?**

The presentation will briefly consider resilience in terms of why, what and how. The background to the debate on the need for resilience is discussed, including Ofwat's legal duty to 'secure the long-term resilience of water supply and sewerage systems'. The theoretical basis for resilience is presented including definitions from a number of perspectives. The assumed properties or characteristics of resilient systems are highlighted and an example is given of measuring and improving the resilience of a water system. The issue of conflicting objectives is raised. The presentation is set in the context of the Safe & SuRe framework which aims to assess and quantify reliable, resilient and sustainable interventions. The conclusions emphasise that there is not one approach that is suitable for all situations and advocates a 'safe to fail' philosophy.

PROF LIAN LUNDY

Lian Lundy is a Professor of Environmental Science at the Urban Pollution Research centre at Middlesex University. Her research to-date has focused on sustainable stormwater management, the transport and behaviour of urban pollutants and the development of on-line decision-support systems at a national and international level.

This has resulted in the publication of a series of peer-reviewed papers and the award of over £2 million in European, UK Research Council, industry and University funding. Lian is currently co-ordinator of the EU TEMPUS I-WEB project, supporting three universities in Kazakhstan to develop Bologna-compliant integrated water cycle management MSc and PhD programmes, and is co-chair of the Risk Assessment and Policy Development working group of the wastewater re-use COST action NEREUS. She is co-PI on an RC-UK NEWTON fund research grant exploring linkages between environmental quality and community resilience in the UK and Brazil, and has recently completed research grants for Defra and the Scottish Government focussed on supporting policymakers to implement an ecosystem approach. Lian has recently been appointed the UK representative on the Joint Committee on Urban Drainage (a global body with a central remit of advancing scientific knowledge in the field of urban drainage).

Keynote: **Water scarcity: technology is not the problem – its decision making**

There is enough freshwater on the planet to meet all needs - why then are 2.8 billion people currently living in regions of physical or economic water scarcity? The UN defines water scarcity as the point at which the aggregate impact of all users impinges on the supply or quality of water under prevailing institutional arrangements to the extent that the demand cannot be satisfied fully. This paper commences by reviewing current and future predictions of water scarcity at a global scale, before beginning to unpick some of the key factors underlying the term ‘aggregate impacts’ through an assessment of water scarcity drivers in the UK, Kazakhstan and Brazil. Drawing on examples from three continents currently experiencing differing climatic and socio-economic conditions reveals both diversities and commonalities in the complexity of natural and socio-technical factors underpinning identified water scarcity trends. Clearly, addressing such 'wicked problems' requires the development and implementation of interdisciplinary approaches and it is within this context that the roles of wastewater reuse and sustainable urban drainage systems are considered as water management components that have the potential to contribute to strategies to address water scarcity in several contexts - if the decision-makers and public are open to and supportive of doing things differently.

Water Efficiency Conference 2016

The retention and *in-situ* treatment of contaminated sediments in laboratory highway filter drain models.

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ABSTRACT

This paper reports on the *in-situ* biological decontamination processes of organic pollutants that have been deposited in Highway Filter Drains (HFD). HFD are stone-filled roadside drainage trenches of approximately 1 metre depth and 1 metre width that run parallel to approximately 7,000 kilometres of motorways and main roads in the UK. This paper builds upon earlier results from a research programme into the treatment of contaminated road runoff by HFD at Coventry University. Results from previous work had demonstrated the removal of particulates from simulated road runoff, a statistically significant improvement in some water quality variables, in particular total suspended sediments released from the structure and no observed reduction in drain permeability, despite sediment accumulation on a filter fabric known as a geotextile (Coupe *et al*. 2015). The added particulate matter in simulated road runoff of <2 mm, was largely retained in the drain models as was >99 % of added waste mineral oil.

As it was found that the added contaminants were largely retained, it was important to determine where the immobilised hydrocarbons and organic matter (such as plant residues) were located in the structures and to what degree contaminants remained unaltered. This was important to determine the level of risk of discharge of stored material in drains that may over time, that produce greenhouse gases such as methane, but also to get an estimate of the persistence of organics between scheduled drain maintenance.

Another property of filter drains when dealing with sediments was the location of material deposited at different depth in the drains. Results showed an overwhelming majority of the sediment was accumulated in the top 10 cm of the drain, accounting for a minimum of 72.4 % located here. Total organic carbon was approximately half in the middle part of lab models compared with the top.

Microbial populations of $1.5x10^6$ bacteria, $2.0x10^4$ fungi and $1.5x10^3$ protists per millilitre of drain effluent had shown a positive biological growth response to the presence of organic contaminants, compared with much lower counts in non-contaminated controls. Results in this study could not confirm the impact of the microbial treatment on sediment composition, as the difference in sediment quality could be explained by partitioning at varying depths. However, a long-term field study, currently being constructed will continue the examination of the properties of this sometimes overlooked drainage asset.

Keywords: Biodegradation, Filter drains, Highway drainage, Microbial treatment, Sediment quality, Sustainable Drainage Systems, Water management.

1. INTRODUCTION

Highway Filter Drains (HFD) are a significant national asset in the UK, draining around 7,000 kilometres of the UK high-speed road network. Their importance in the normal functioning of the UK economy should not be underestimated, with the road network being the largest publicly held asset in the UK (Ellis and Rowlands, 2007) [1]. HFD are stone-filled roadside drainage trenches of approximately 1 metre depth and 1 metre width and run parallel to significant parts of the UK high-speed road network. Three major contributions that HFD make to the operation of highways are outlined below:

- Road user safety (by removal of water from the carriageway), contributing to roads more resilient to flooding issues.
- Pavement longevity (by efficiently eliminating standing water adjacent to the highway sub-base, keeping the water level to a secure distance below the pavement structure and preventing the structure from sudden structural collapse).
- Runoff water quality (by the filtering of sediments, hydrocarbons and other road surface contaminants through the 1 metre deep stone filter drain, purifying the water before discharge to the receiving waters downstream through a porous pipe at their base).

Frequently, the chief focus of the managers and contractors who are responsible for the Strategic Road Network (SRN) is safety and the other considerations can be seen as a lower priority. This has led to the description of the management of the SRN as an iceberg, with significant features and properties effectively obscured after meeting the most high profile objective, the minimisation of accidents.

Fig. 1. The highway drainage iceberg, concept by E.G. Rowlands

The Highways Agency (HA) became Highways England (HE), a government-owned strategic highways company in 2014, after a period of consultation. One of the stated aims of the new company was to "*improve the day-to-day operations of the network and over time transform the quality of the service that is delivered to road users, the long-term condition of our strategic road infrastructure and its environmental impact*" (Department for transport, 2013) [2]. This mission statement justifies the approach of the research programme in embracing all 3 points of the drainage iceberg. In addition to the assumed water quality benefits of HFD, the volume and rate of flow of water from the road is regulated by infiltration through the stone, with the high storage volume in the drain allowing extra capacity in the case of extreme rainfall events. The research in this paper is designed to give an overview of projects to investigate the potential drainage and water quality improvement properties of HFD and suggest opportunities for optimisation, for instance by the use of a geotextile material to improve purification and water management. HFD, when working correctly, ensure the safety of road users by infiltrating road runoff hence reducing the depth of standing water on the carriageway. The risk of accidents due to reduced traction between the road surface and tyres is the chief safety concern that is dealt with by HFD. The protection of the road running surface and the sub-base is also a function of the HFD; damage to the road is possible where they are not draining efficiently. Horizontal rather than vertical movement of water may undermine the road by washing out fines from the Type 1 road sub-base (Jacobs, 2011) [3]. HFD are thought to contribute to the environmental protection of downstream environments via the deposition of particles from the road surface in the top surface of the drain, although there is minimal direct published evidence for this. These particles include materials coming from the abrasion and wear of the road surface, hydrocarbons from engine oils, wind blown materials, embankments and other land next to the carriageway (known as the estate), silt on vehicle wheels and material in rainfall.

In order to examine some of the properties of filter drains that may have been given less attention previously, Carnell Support Services Ltd commissioned Coventry University, through the research centre CAWR, to construct a laboratory testing system for filter drains which would measure the retention, biological treatment and environmental performance of these systems. The key discriminating feature between treatment was the presence of a geotextile, and whether the geotextile was located near to the top of the drain profile or close to the base.

Data acquired during a 6-month period of laboratory testing and reported in Coupe *et al*, 2015 [4], demonstrated that the hydraulic function of filter drains was not adversely affected by the presence or absence of a geotextile and that the retention of silt by the drain did not significantly delay the discharge rate of water, with or without a geotextile. Key results, that will soon be published, showed that:

- The inclusion of a geotextile within the structure of a HFD did not produce a failure in their hydraulic performance, with a load of 2 years worth of silt, at 1 kg of silt per linear metre per year and used mineral oil at 17.8 g/m^2/week.
- The position of the geotextile within the HFD structure affects the attenuation properties of a lab based filter drain for water quality and quantity performance (attenuation defined as time needed to get the first discharge under a storm event).
- Biological activity and microbial numbers indicated a vigorous response to contamination and show that the retained contaminants were being degraded.

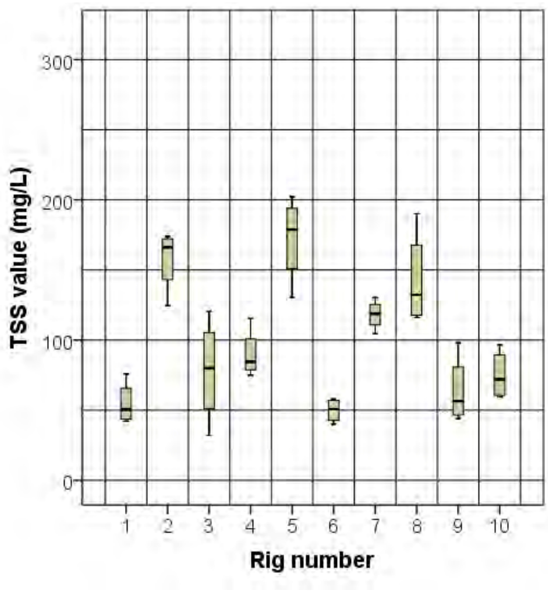

Fig. 2. The total suspended sediment released from filter drain lab simulation models. Models 2,5 and 8 had no geotextile and were found to release the most sediment (from Coupe *et al*, 2015).

The data recorded in the laboratory study demonstrated the capacity for HFD to act as water filtration and bioremediation platforms in addition to functioning as efficient drainage infrastructure (see figure 2). However, the stone used in the above study was clean, washed and graded ideal, 20-40 mm Type B material (DMRB, 2004) [5] and it is likely that most HFDs are far less free of fine material, fine material coming from either outside the drain through runoff, or the initial installation that may have used less well washed or graded material.

2. MATERIALS AND METHODS

Following the research into the retention of oils and sediment in the lab models, the material remaining in each of the models was extracted in order to determine the position of the added sediment after the runoff experiment was complete. The sediment was assigned a position in the model, (top, middle or bottom) and weighed and bagged to be sent for chemical testing at an independent laboratory.

3. RESULTS AND DISCUSSION

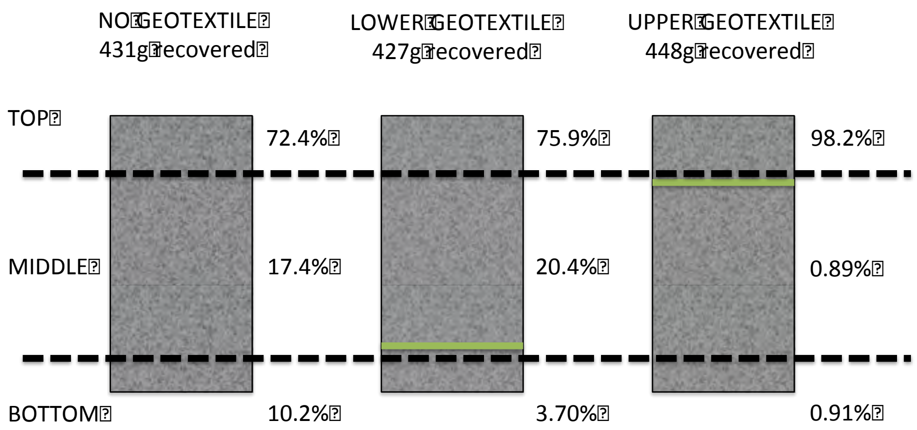

Fig. 3. The distribution of sediment in the three laboratory model types, down through the profile of the simulated filter drain.

As shown in figure 3, the overwhelming majority of the sediment recovered was accounted for in the top 10 cm of the models, irrespective of the presence of a geotextile. However, where a geotextile was located close to the surface, the tendency was to retain the sediment close by. This filtering mechanism had impacts on the quantity of material recorded lower down the drain profile, close to the point of discharge, and could suggest a benefit from a high level filter fabric. Previous hydraulic results (Coupe *et al*, 2015) had suggested no impact on surface infiltration from the sediment addition rates and the accumulation of sediment at the drain top.

The microbial load in the simulation models pointed to a significant processing of oils and the organics in sediment, with a considerable number of bacteria, fungi and protists recorded in the effluent released from the models. The concentration of pollutant remaining in the sediment and the position of the contaminants (e.g. metals, oils and nitrogen phosphorus and potassium from dead organic material) was performed to determine the ongoing environmental risks from deposition of road sediment, when immobilised in a filter drain.
The sediment analysis was done by Nicholls-Colton laboratories, Leicester, UK. Gas chromatography mass spectrometry was used to determine oil concentrations.

The results demonstrated a higher concentration of total petroleum hydrocarbons (TPH) in the top 10 cm relative to the middle and bottom layers of the models with 48 g/kg in the middle

layer compared with 170 g/kg in the surface. This reflected the deposition of oils and adsorption onto sediment and stone. Total organic carbon was also at a lower percentage in the deeper parts of the models, with around half the concentration as in the surface (middle of a model 10.75 % TOC, top of the models typically around 20 %). This indicated that the organic material was also concentrated in the oils and sediments near the drain top and not penetrating into the rig interior.
The results from lab analysis support the observation that sediment and the other pollutants tend to stay closer to the surface and that the proportion being moved down the drain profile is relatively small. The difference between the top and middle parts of the rigs in terms of TPH and TOC is most likely to be due to low mobility of sediment and associated oil rather than differential biodegradation. This suggests a reduced risk of pollutant discharge at the drain base and a longer residence and treatment time close to the drain surface, particularly where a geotextile is located close to the surface.

4. CONCLUSIONS

The results from this study suggest a good performance of filter drains in the retention of added sediment by highway filter drains and the prevention of sediment with discharge into possible receiving systems. Caution should be taken not to overlook the possibility of a long-term infiltration reduction at the drain surface after sediment build-up, thereby risking the loss of the primary function of the drain. The same need for caution relates to the position of a geotextile, where a reduced sediment penetration rate into the drain may improve the efficiency of sediment removal in maintenance and protect receiving systems, but could increase the risk of blockages.
Taken together, the results from discharged sediments in effluent and the location of the stored sediments in the profile show that highway filter drains operate very well from an environmental protection perspective and do provide a good treatment and retention capacity. A field trial on the UK road network is currently being constructed in partnership with Carnell, meaning that the larger scale picture of field operation of filter drains for both drainage and pollution removal function will start to become more apparent.

COMPETING INTERESTS

The authors declare no competing interest.

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Water Efficiency Conference 2016

Impact of Slow-Release Fertilizer and Struvite in Enhancement of Biodegradation of Hydrocarbon in Filter Drains to Prevent Groundwater Pollution

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ABSTRACT

Filter drains are usually laid along the margins of highways and highway runoffs are polluted with hydrocarbons and high levels of total dissolved solids. Hence, effective pollution removal mechanism is necessary in order to avoid contamination of surrounding soils and groundwater. Biodegradation is amongst pollution removal mechanism in filter drains, but is a relatively slow process which is dependent on wide range of factors including the type of pollutant and availability of nutrients. This paper reports on a study conducted to investigate the performance of slow-release fertilizer and struvite in enhancement of biodegradation of hydrocarbon in filter drains. French drain models incorporated with geotextile were challenged with cumulative oil loading of 17.8mg/m^2/week with a view to comparing the efficiency of these two nutrient sources under high oil pollution loading and realistic rainfall conditions of 13mm/week. Nutrients and street dust were applied at one - off rate of 17g/m^2 and 1.55g/rig respectively. The impact of the nutrients was studied by monitoring bacterial and fungal growth using Nutrient Agar, Rose Bengal Agar media and CO2 evolution. EC, pH, Heavy metals, TPH, elemental analysis, SAR were used to investigate water quality of effluent of filter drains for potential application as irrigation fluid. The results show that nutrient application encouraged microbial activities and enhanced biodegradation rates with differences in type of nutrient applied. Furthermore, it was observed that incorporation of geotextiles in filter drains enhanced pollution retention and there is a potential opportunity for utilization of Struvite in SUDS systems as sustainable nutrient source.

Keywords: Filter drains, Biodegradation, Stormwater, Pollution Prevention, Struvite.

1. INTRODUCTION

French or Filter drains are a type of sustainable permeable conveyance system that is mainly used to control runoff from road and car park surfaces via filtration and attenuation mechanisms or pipe conveyance system. The pollution removal capabilities of filter drains are dependent on some factors such as sorption, precipitation, filtration and biodegradation. Gravel filter media based systems that are reliant on attenuation mechanisms are prone to failure under high pollution loading particularly oil, and some studies have reported impact of clogging on the efficiency of such systems. In the case of attenuation based systems, the pollution carried by runoff is retained in the system for biodegradation and the extent of

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retention is affected by factors such as the type of pollution, rainfall intensity, design of drains and age of drains; and pollution retention failure could lead to groundwater pollution. In the case of piped systems, the residues and oil could be conveyed through the pipes to receiving waters (especially during high rainfall events) with serious impact on their ecosystem. Newman et al. (2015) reported a significant release of dissolved and dispersed oil from piped systems during simulated rainfall events. This is a disturbing observation considering the increasing incorporation of overflow pipes in filter drain designs for overflow runoff in high intensity rainfall and oil spillage incidents on the roads in addition to leakages from vehicles. Also, Newman et al. (2015) observed the ability of a specially designed geotextile known as Permafilter to contain most of the oil when wrapped around the overflow pipes. One of the important conditions for biodegradation efficiency in SUDS systems is that pollutants are retained long enough for biodegradation process; another is that there is availability of required nutrients to kick start and maintain the process without impacting the water quality. Slow release fertilizers have the capacity to releases nutrients at the required dose for optimal biodegradation. Struvite has emerged as a sustainable source of nutrient with the advantages of ease of application, low cost, low impurities, odour and pathogen free and efficiency in wide range of soils and pH levels (Tao et al 2016). Hence, struvite granules have the potential application in biodegradation reliant systems such as SUDS devices as a source of nutrients necessary for optimization of the process. Furthermore, the active ingredient in struvite, phosphorus is one of the limiting factors in biodegradation process (Newman et al, 2011). Whilst there are reports of application of struvite in areas such as agriculture, there is no known study of potential application of struvite in sustainable drainage devices. The main aim of this research was to investigate the performance of slow-release fertilizer and struvite in enhancement of biodegradation of hydrocarbon in filter (French drains) drains which were incorporated with Permafilter geotextile and challenged with cumulative oil loading with a view to comparing the efficiency of these two nutrient sources under high pollution loading and realistic rainfall conditions. Furthermore, the study offered an opportunity to study the impact of permafilter geotextile in comparison with previously studied geotextile under more realistic conditions. It was considered that the resultant effluent from drains could be utilized as irrigation fluid on landscaped plants on streets and roads; hence the effluent quality was assessed in order to determine whether it meets irrigation standards (Nnadi et al. 2015).

2. MATERIAL AND METHODS

A set of nine experimental test models designed to simulate filter drains were employed for this study. Two holes were created on the model rig covers for gas sampling and aeration after sampling and were closed with the aid of a Suba seal. Replicated experiments with three model filter drains per treatment and control incorporated with permafilter geotextile (which was used Newman et al. 2015) in-between 20mm gravel and 10mm gravel (Figure 1) were challenged with oil loading. Oil loading was simulated at the rate of 17.8mg/m^2/Week by adding diesel to each rig. Nutrients (struvite and slow release fertilizer) were applied at one - off rate of 17g/m^2 by administering granules were on the surface of the model rigs. Similarly, 1.55g of Coventry street dust which was sieved and characterized was added to the rigs to replicate a real life scenario in such a way that the environment is contaminated with dust particles. An equivalent of 13mm of rain was used for the experiment and applied weekly. The impact of the application of slow release fertilizer and Struvite on biofilm formation and biodegradation of hydrocarbon was studied by monitoring microbial growth (bacteria and fungi colonies enumeration using Nutrient Agar and Rose Bengal Agar (RBA) respectively) through microbial analysis and activity through CO2 evolution. EC, pH, Heavy metals, TPH, elemental analysis, SAR were used to investigate water quality of effluent of filter drains during experimental study.

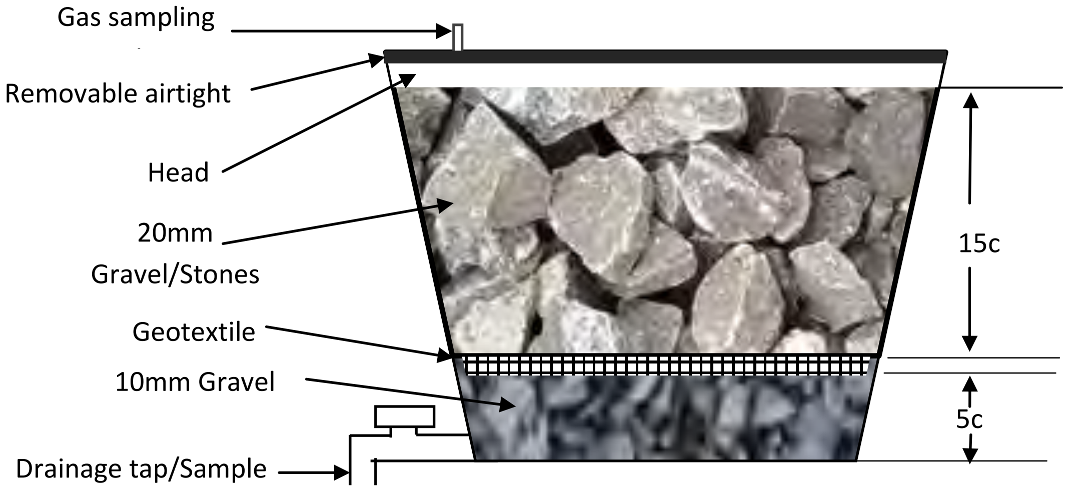

Figure 1: Schematic diagram of test models used

3. RESULTS AND DISCUSSION

The results obtained from this study showed that the population of microbes and fungal present in filter drains increased with the application of nutrients with a relatively higher increase in colonies of bacteria and fungi in test rigs applied with slow release fertilizer than others. Test models applied with struvite showed higher microbial activity than the test models without nutrient addition. Similar trends were observed in fungi growth after initial slow –down in growth which could be attributed to immediate response of microbes to toxicity of hydrocarbon. Unlike bacteria, Fungi population decreased at baseline stage but responded to the introduction of hydrocarbon and street dust with elevated growth. The rigs containing Osmocote fertilizer showed a higher bacterial and fungal growth compared to that containing Struvite. This is because Osmocote fertilizer is rich in nutrient and thus has the potential of stimulating higher microbial growth. TPH levels were very low in test rigs incorporated with permafilter relative to the ones without geotextile. Effluents from geotextile and nutrient incorporated models presented better quality than the controls and are suitable for irrigation.

4. CONCLUSION

Nutrient application increased microbial activities with high nutrient rich environment showing best potential for rapid degradation of pollutants in systems such as filter drains. This shows the need for incorporation of permafilter geotextile and nutrients in filter drains to improve pollutant removal of such systems and such improvement offers the potential for reuse of highway runoff treated in filter for landscape irrigation. This study shows the potential for utilization of struvite in SUDS devices for enhancement of biodegradation and improvement of efficiency of such systems.

ACKNOWLEDGEMENTS

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Assessing Barriers and Potential Drivers to Adoption of Water Re-use in the UK

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ABSTRACT

Feedback from delegates at a Water Efficiency Network workshop in 2014 suggested conflicting requirements in standards and codes presented a barrier to the take up of water re-use systems in the UK. They also prevented some white goods in the UK from using alternative sources of water (i.e. rainwater or greywater). The same white goods were approved for such use in Germany.

No conflicting requirement within standards or codes that would present barriers to take up of re-use systems was identified. However the Building Regulations, whilst encouraging water efficiency, provide a disincentive to adopt water re-use systems through an additional and complex water efficiency calculation.

With little information on the cost benefits of such systems and the relatively low cost of potable water in the UK, there is no financial driver for buyers to require water re-use systems in new homes. This contrasts with some other European countries where uptake of re-use systems is much greater. There is therefore a need for other, regulatory incentives to promote take-up, either through revised Building Regulations, or some financial 'discount' on new property taxes, or a combination.

There is also a real issue around maintenance of single-property systems and the consequent risk of cross contamination of the potable supply. Community based systems could reduce this risk. The paper makes recommendations to provide a more in-depth understanding of the issues around water re-use, including identifying actual cost benefits or impacts from both water and energy use and reviewing the advantages and acceptability of community based systems. For the longer term the paper recommends five regulatory changes that could help incentivise take-up of water re-use systems.

Water Re-use, Rainwater harvesting, Greywater, Alternative water systems.

1. INTRODUCTION

Feedback from delegates at the Water Efficiency Network workshop in 2014 identified the following barriers to take up of water re-use:

- Information on installation costs, potential savings and hence payback was not available and/or not robust.
- Conflicting requirements in different standards and codes. An example given by delegates was a BSI standard that prohibited greywater use for some white goods, whereas those same goods are approved for greywater use in Germany.

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This paper reports on a short project undertaken to identify those barriers, or perceived barriers, to the take up of water re-use in the UK, focusing on any conflicting requirements in standards and codes.

The scope and the desired outcomes for the project were agreed with stakeholders as:

1. Carry out a mapping exercise identifying all standards for rainwater harvesting and greywater re-use and the organisations responsible for them.

2. Explain the rationale behind the standards and how they work in practice to affect water re-use. Explain the logic for any change to remove conflicts to facilitate re-use.

3. Make headline recommendations for rationalising / simplifying relevant standards, e.g. on an industry basis. The key is to identify both light-touch changes that could be made without any regulatory interventions, plus more radical options that could be pursued.

4. Deliver an easy to understand guide to the subject, logically set out, identifying the big issues clearly, and assume an uninitiated policy maker without knowledge of the issues as the target audience. Avoid overly technical content.

2. METHODOLOGY

The initial desktop mapping exercise identified twelve standards, codes or guidance documents related to, or with references to rainwater harvesting or grey water use, including four British Standards (BS). These are listed in the References section.

Individuals, organisations and associations active or knowledgeable in the water re-use sector were then contacted to gain a clear understanding of the application and impact of standards on water re-use and other relevant issues. This included members of the British Standards (BS) committee on Water Re-use CB/506, responsible for developing and maintaining the standards.

The project timescale and funding necessitated a desk based approach supported by telephone interviews using predefined questions with identified individuals. However a number of face-to-face discussions with delegates at a Water Efficiency Network meeting and at a Waterwise Rainwater and Greywater Systems seminar were used to further explore the emerging issues.

To ascertain the difference in approach to water re-use with white goods in Germany and the UK, the white goods manufacturers' association AMDEA and the manufacturer Miele were also interviewed by telephone.

3. DISCUSSION AND FINDINGS

According to BS committee members the fundamental basis of the British Standards on water re-use is to define the water quality requirements to ensure public health.

The applications for water re-use are set out in the Building Regulations Part G1 and in the Standards.

The Building Regulations define 'wholesome water' as 'water supplied by a statutory undertaker or licensed supplier through an installation complying with the Water Supply (Water Fittings) Regulations'. It includes under 'alternative sources of water' both harvested rainwater and reclaimed greywater, together with water from wells and boreholes.

The Building Regulations state:

‘Water from alternative sources may be used in dwellings for sanitary conveniences, washing machines and irrigation, provided the appropriate risk assessment has been carried out. A risk assessment should ensure that the supply is appropriate to the situation in respect of the source of the water and the treatment of it, and not likely to cause waste, misuse, undue consumption or contamination of wholesome water.

A risk assessment should include consideration of the effect on water quality of system failure and failure to carry out necessary maintenance’.

Thus Part G1 allows water re-use within buildings but does not promote it. It does however refer to guidance on technical and economic feasibility, specifications and guidelines in relation to water quality standards set out in three MTP (Market Transformation Programme) reports from 2007. None of these reports appear to be available anymore as web searches for any of the three simply return the 2010 EA publication ‘Harvesting rainwater for domestic uses: an information guide’ [12]. The respondent from the Centre for Water Systems suggested this report was now very out-dated.

Part G2 of the Building Regulations covers water efficiency of new dwellings. Again this mentions water re-use – ‘*in some case rainwater harvesting and greywater recycling may be used as a means of reducing water consumption to achieve higher water efficiency performance levels’*, though without encouraging it. However, where water re-use is proposed for a new dwelling then the full and complex water efficiency calculation methodology as set out in Appendix A of Approved Document G must be followed. Where no water re-use is proposed then the designer/specifier simply has to confirm that the water fittings and any dishwasher or washing machine installed will have maximum consumptions less than the values set out in Table 2.1 in the Guidance. Whilst not a barrier to including water re-use in a new dwelling, this procedure provides a significant dis-incentive for designers and/or specifiers to include water re-use in the building’s design.

There are multiple British Standards applicable to water re-use and a further one in development. Without being a barrier, this does make the potential application of water re-use more complex.

British Standard BS 8525-1 prescribes where non-potable water may be used and what is included within ‘domestic use’.
‘Potable domestic use includes water for the kitchen sink, wash and hand basins, bath, shower and dishwasher. Non-potable domestic use includes water for WC flushing, domestic washing machines and garden watering.
In commercial, industrial or public premises, “domestic use” is limited to water used for those applications/appliances described above and excludes, for example, water used for fire fighting, central heating or irrigation systems’.

The latest Standard BS 8595 specifies the scope of re-use systems covered and also domestic water uses that do not require potable water quality, such as laundry, toilet flushing and garden watering. The standard does not cover systems supplying potable water for drinking, food preparation and cooking, dishwashing and personal hygiene. In the domestic context therefore, water re-use systems may be used to supply alternative water for toilet flushing, garden watering and clothes washing machines. One respondent reported a conflict with the Water Industry Act [13] since its interpretation of ‘domestic purposes’ includes references to the drinking, washing, cooking, central heating and sanitary purposes for which water supplied to those premises may be used. It was suggested there is therefore an implication that wholesome water is required for toilet flushing.

BS Committee members reported that use of recycled rainwater and greywater does vary by region and country and that a new European standard on water re-use is being developed, based on the more detailed German Zulassung standard. However this appears to have been delayed by failure to agree on which water quality requirements to include.

In the Alternative Water Systems Information Leaflet and Guide [9] published by the Water Regulations Advisory Scheme (WRAS) on behalf of water companies and the Water industry Approved Plumbers Scheme (WIAPS), it states that all alternative water supplies must be considered a fluid category 5 risk, i.e. they pose a serious health hazard. Rainwater will contain atmospheric pollution and due to the nature of the surfaces from which rain is collected, it is also likely to contain faecal, biological or pathogenic contaminants. Similarly, greywater and collected wastewater from washing etc. is also likely to contain faecal and pathogenic organisms. To comply with the Water Supply (Water Fittings) Regulations [7] any re-use system in a building also supplied with potable water will therefore require fluid category 5 protection that can only be achieved through the installation of a specified air gap, or through the use of a pipe interrupter (a device which incorporates an air gap), to separate the mains water supply and the alternative water system. WRAS advises that no mechanical device is capable of protecting against this level of risk. Therefore no direct or removable cross-connections are allowed. Where dual systems exist in a building, i.e. with pipes supplying mains water and separate pipes supplying alternative water there is a risk of misconnection or cross connection either during installation or in any subsequent rebuilding or repair work. The regulations therefore also require that pipe systems and any taps supplying alternative water within buildings are properly identified as such through labeling. Colour coding of alternative water pipework is also recommended.

3.1 Other factors that are barriers to take up

Whilst people contacted referred to differences in approaches and the relevant Standards across Europe and the delay in developing a new EN Standard, no one confirmed, or suggested, there was any conflict in current UK Standards that act as a barrier or perceived barrier to water re-use.

The British Standards focus more on the re-use systems themselves, their selection, design, installation, water quality requirements, performance and maintenance, rather than the applications and end uses for alternative water. There are however four separate Standards that have been developed over time. It could be argued that this in itself is confusing. The new EN Standard on ‘Systems for the on-site use of rainwater, greywater and domestic wastewater’ under development, but delayed, may overcome this. However, currently only development of Part 1: Rainwater has been approved with work underway. BSI also note that conformity with this standard, once published, would ‘not exempt from compliance of the obligations arising from local or national regulations’.

One commentator from the UK Rainwater Management Association (UKRMA) suggested any conflicts between Standards across Europe are more likely to exist in the context of Water Regulations, rather then system standards or codes of practice. He added – “The regulatory requirements in the UK (relating to the use of harvested rainwater) may not apply across the whole of Europe; they certainly do not worldwide”.

The other ‘non-Standards’ issues that were raised as barriers or potential blockers were

- A lack of understanding of greywater and rainwater harvesting systems and the uncertainty that generates.
- Ensuring that systems are safe to use, now and in the future. Mention was made of the Upton Eco-Housing Development, near Northampton, and the cross connections between rainwater harvesting systems and the mains supply found on multiple properties. WRAS reported subsequent, but smaller scale findings by water companies elsewhere.
- Other system issues around reliability, pump failures and maintenance.
- New homebuyers not requesting such systems.
- House builders and the Home Builders Federation not therefore seeing any benefit in providing such systems.

- The scarcity of information on benefits - i.e. costs saved and payback period.
- The need for education and awareness raising with consultants, designers, installers and developers.
- The requirement for a cultural shift amongst the public.
- The lower cost of water in the UK compared to some other countries where there is a much higher take-up of water re-use.

3.2 Washing machines and water re-use

One suggestion put forward for the lack of take up was that a BSI Standard prohibited greywater use for some white goods, whereas those same white goods are approved for greywater use in Germany. To get a clearer understanding the Association of Manufacturers of Domestic Appliances (AMDEA) and Miele, a German based manufacturer of higher-end domestic appliances, were contacted.

AMDEA suggested there was no barrier from Standards in the UK to the use of alternative supplies, i.e. greywater or harvested rainwater. However they advised that manufacturers require a 'standard' water for testing and to compare performance across products and in different countries. With potable water, manufacturers have a standard (including hardness) to work with. However greywater and rainwater can be highly variable and no standard applies. So manufacturers cannot define the quality of alternative water. If there was a standard for alternative water then manufacturer could test using that standard.

Whilst British Standard BS 8515:2009 and BS 8525-1:2010, the two codes of practice for rainwater harvesting systems and greywater systems respectively, do set out guideline water quality values for 1) bacteriological monitoring and 2) general systems, such monitoring is unlikely to take place within a single property domestic system. The Standards do also add a comment that there are currently no specific regulatory requirements for water quality that apply to systems which re-use rainwater or greywater for non-potable water use.

AMDEA suggested that owners in the UK could use alternative water, but would need to accept responsibility for their action, i.e. the manufacturer might not be able to honour the appliance warranty in those circumstances. Warranties generally refer to 'mains water'. AMDEA advised that in Germany, Sweden and the Netherlands, manufacturers such as Miele, Bosch and Electrolux do sell 'all-water' washing machines that use both mains and alternative water. There are some commercial 'all-water' machines in the UK, but AMDEA suggested "they tend to get issues with WRAS", around compliance with the Water Fittings Regulations. DCLG, responsible for the Building Regulations, confirmed that they are not aware of any Standard that limits alternative water use in washing machines, other than the backflow protection required by the Water Fittings Regulations.

Miele confirmed that they do market 'all-water' machines in other European countries. They did remark that whilst a good idea they have never taken off in the UK. They commented that greywater had been used for many years in Germany and that water was more expensive there than in the UK. They suggested that alternative water systems may be part of the building regulations in Germany though could not confirm this. All new homes generally have alternative water (i.e. re-use) systems installed. Miele do not market 'all-water' machines in the UK though they do supply a few for specific laboratory or commercial applications. The Miele 'all-water' machines come with two separate inlets, one for mains water, one for alternative water, unlike UK specification machines that have a single inlet. The programme within the machine decides when to use which water source, potable being used at least for the final rinse. Miele advised that such a machine would have to go through the WRAS Product Approval process and be approved before being made available in the UK.

In the WRAS / water companies 'Alternative water supply systems Information Leaflet and Guide' it states *'there is one area where caution is needed – clothes washing machines'.* It goes on to say that standard domestic machines do not have the fluid category 5 protection that is needed and therefore must not be connected to both mains water and an alternative water source. It advises that washing machines with suitable backflow protection are not readily available in the UK.

3.3 Further factors

One commentator noted that since the earlier Standards had been written there had been a change in the UK market with a move from small domestic alternative water systems to larger community or commercial systems. This was subsequently confirmed by one of the systems suppliers – GRAF. They also suggested there are now more opportunities for water re-use in the non-household market. In addition where sustainable drainage systems (SuDS) and rainwater harvesting systems are integrated on developments the approach becomes more viable.

One new entrant water company suggested the proximity of the incumbent water company's nearest infrastructure, and hence cost of infrastructure provision to a new development, can be a driver in providing a community size re-use system. This had benefits over single-property systems in that the subsequent risk, i.e. a lack of maintenance or a cross connection, was reduced as a central competent body was responsible. The new entrant was also suggesting that smart metering can be used to help identify any future inadvertent cross connection, therefore mitigating the risk further. Another commentator suggested that whilst there are many Standards now to stop poor products and practice there are very few to encourage water re-use.

The introduction of retail competition in April 2017 in England for non-household water customers could have a positive impact on the uptake of re-use systems. One commentator, from the Scottish retail market noted that the new licensed providers may help customers with the installation and operation of water re-use systems, not so much for water saving and efficiency but to help with customer retention in the competitive retail market.

4. CONCLUSION

The investigation covered by this paper included a mapping exercise of the main Standards, codes and advisory documents - Scope item 1. It has covered Scope item 2 to a partial extent but since it found no evidence or suggestion of conflict, the report does not propose any change. For that reason Scope item 3 was not pursued. The paper does however major on Scope item 4, i.e. delivering an easy to understand guide on the subject, identifying the big issues for an uninitiated policy maker.

Specific conclusions drawn from the research and responses are:

- No evidence of British Standards being a barrier to take up of water re-use in the UK was found or reported.

- There is some indirect discouragement of specifying water re-use systems in new dwellings in the Building Regulations, Part G2, simply because of the complex and convoluted calculation required to prove compliance with the water efficiency standard set by the Secretary of State.

- Water Regulations in the UK have specific and robust requirements to prevent contamination and protect public health, especially where mains water and alternative water systems are used together. The regulatory requirements in other European countries and markets may be different.

- There is a wide variety of other reasons to explain the limited take up of water re-use in the UK, including understanding, customer desire, cost and payback, additional complexity and the risk of failure.

- The water re-use industry is seeing a move to community-based systems, rather then individual property systems, in the household market.
- The water re-use industry sees more opportunities developing in the non-household market.
- Community systems can partly mitigate one of the barriers to take up, by reducing the risk of failure or contamination through a lack of maintenance or faulty repair.
- Community re-use schemes can also be driven by the high costs to connect to, or the lack of availability of, nearby existing water and/or wastewater infrastructure.
- There are many standards to prevent poor products and practice but few to encourage water re-use.

5. RECOMMENDATIONS

To understand and to be able to better explain the low uptake of water re-use in the UK compared with other European countries, the following further items of work are suggested.

In line with stakeholders' request for both 'light touch' changes that could be made without regulatory intervention, plus more radical, regulation based approaches, these recommendations are presented in two categories

i) Lighter touch / no regulatory intervention

- Engage with the major developers to get a better understanding of their perceptions around water re-use and why there is a low uptake in new homes in the UK.
- Review the differences between the drivers, incentives and public perceptions around the uptake of water re-use systems in Germany and the UK, including the application of water fittings regulations and building regulations.
- Identify actual cost savings available from adopting water re-use systems, taking into account both water saved and energy used.
- Carry out a review of communal re-use systems and develop case studies to help understand the risks, installation and operating costs, and consumer acceptability, with the aim of improving awareness amongst developers and decision makers.
- Carry out a review of non-household re-use systems and develop case studies, with similar aims.

ii) Regulatory intervention

- Remove the requirement to use the complex Water Efficiency Calculator methodology set out in the Building Regulations where a water re-use system is proposed for a new property.
- Include a requirement in revised Building Regulations to provide water re-use systems in new dwellings as part of the water efficiency measures.
- Consider a more integrated requirement for new developments to incorporate both sustainable drainage systems and rainwater harvesting systems.
- Having developed case studies and further evidence, then promote water re-use through the UK governments' sustainability agendas and water strategies.

- Review the Water Industry Act requirement that suggests wholesome water is required for toilet flushing (though this is not cited as a real barrier to take up of re-use).

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Organisation
AMDEA (Association of Manufacturers of Domestic Appliances
BMA (Bathroom Manufacturers association)
BRE Global
Centre for Water Systems, University of Exeter
CIBSE (Chartered Institution of Building Services Engineers)
CIPHE (Chartered Institute of Plumbing and Heating Engineering)
DCLG
Defra
Future Water Association
JPJN Partners
Miele
Severn Trent Water
Southern Water
UK Rainwater Management Association
University of Exeter, Centre for Water Systems
WATEF Water Re-use Technical Committee
Water UK Water Efficiency Network
Waterwise
WRAS
WRc

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The Long-term accumulation of contaminants in sustainable drainage systems (SuDS) and end-of-life

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ABSTRACT

Sustainable drainage systems (SuDS) have been implemented in the UK to enhance flow attenuation and remove contaminants from urban run-off. The long-term treatment performance of SuDS could be inhibited by the accumulation of pollutants. End-of-life is determined by the behaviour of contaminants retained or released from SuDS where high concentrations of pollutants contaminate the sediment and water quality released from the system to severe effect levels.

This paper will discuss the progress of this study as data collection continues. Sampling and monitoring of the Hopwood Motorway Service Area (HMSA) spillage basin and a decommissioned porous paving system (PPS) from SEL in Bury will be completed using a combination of field and laboratory techniques. This will determine processes that contribute to the deterioration of water and sediment quality in SuDS with a focus on non-degradable metal contaminants that are trapped in the systems.

In preliminary experiments, the sediment quality of the HMSA spillage basin exceeded sediment quality guideline values for Cu and Zn. This could be attributed to the discharge from the oil and silt interceptor that precedes the spillage basin. The bedding layer and sediment accumulated in the joints between the blocks of a decommissioned porous paving system from Bury, after twelve years of operation, did not exceed sediment quality guideline values for metals. Water quality results from both systems were below drinking water quality standards with the exception of Ni in the spillage basin inlet. Future work will establish potential issues that may arise from waste management of the material at end-of-life.

Keywords: Sustainable Drainage Systems, End-of-life, Metals, Biovailable

1. INTRODUCTION

Sustainable drainage systems (SuDS) (e.g. ponds, wetlands and porous paving) have been recognised as a key tool for improving natural drainage and enhancing the treatment of stormwater pollutants unlike conventional drainage systems [1]. The exceedance of the pollutant retention capacity in SuDS could negatively impact on the receiving local water course. Heavy metals are non-degradable and will remain trapped in the system for the duration of the design life if not maintained. The toxicity of metals accumulated in SuDS could affect the aquatic biota and interfere with the microbial treatment of pollutants (e.g. petroleum hydrocarbons) [2]. Previous studies have not defined the fate of SuDS, where the long-term accumulation of contaminants could have a negative impact on the water and sediment quality in these systems. This is particularly a concern if maintenance activities are minimal or decline during the operation of the system.

SuDS at end-of-life, where the treatment of contaminants has failed, could potentially affect the waste disposal route of SuDS material. Poor design and lack of maintenance may prove

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costly to the optimal lifetime of SuDS and could reach end-of-life sooner than expected. Studies on vegetated pond systems (e.g. [3]) have shown that metal concentrations of the sediment accumulated increases over time. Therefore, the lack of maintenance activities implemented in SuDS, such as the regular removal of contaminated sediment, could potentially categorise the sediment as hazardous waste at end-of-life. Additionally, Mullaney *et al*. [4] found from permeable paving test rigs that up to 60% of metal contaminated sediment was in the upper layers and had suggested that it would usually only be necessary to replace the paving blocks and bedding layer to rectify the treatment performance of the system. Although the infiltration performance will improve and the capacity to retain sediment will increase to extend the optimal life of the system, it is unknown in the long-term whether the geotextile could eventually exceed the capacity to trap pollutants in the lower layers of the system.

Total concentrations of contaminants are not the main concern for SuDS at end-of-life. In terms of environmental deterioration (e.g. ecology and water quality) the soluble fractions of metals will be of interest as they would be available for uptake in the surrounding biomass and is integral in determining the toxicity of the sediment. The bioavailability of contaminants could negatively impact on the aquatic biota in SuDS and a potential risk to human health, particularly those publicly accessible as green space. As environmental conditions at each SuDS site affect physical, chemical and biological processes, it is difficult to determine and generalise the behaviour of contaminants for all systems [5]. However, this study will attempt to define a baseline for the potential end-of-life issues that may occur in SuDS as a consequence of long-term contamination and minimal maintenance with a specific focus on metals.

2. MATERIAL AND METHODS

The Hopwood Motorway Service Area (HMSA) in Bromsgrove, Worcestershire, has been in operation since 1999 (Figure 1a and b) and is one of the sites chosen for this study. The spillage basin receives contaminated runoff from an oil and silt interceptor, and is part of a management train (preceding two wetlands, a shallow drainage ditch and pond) that receives runoff from a coach park and fuel filling station. Water and sediment grab samples were collected from the oil and silt interceptor outlet and spillage basin outlet for preliminary testing. Additionally, the limestone aggregate bedding layer and sediment between the joints of a decommissioned porous paving system (PPS), installed as a car park bay for SEL, was excavated (Fig 2a). Figure 2b illustrates the design of the PPS where a geotextile layer has been installed below the bedding layer. The PPS was in operation for approximately 12 years and was not maintained during this period. Prior to excavation, water samples were collected from the outflow of the PPS. Sediment samples were collected during October and February 2015-2016.

Figure 1. a) Inlet of the HMSA spillage basin. b) Outlet of the HMSA spillage basin

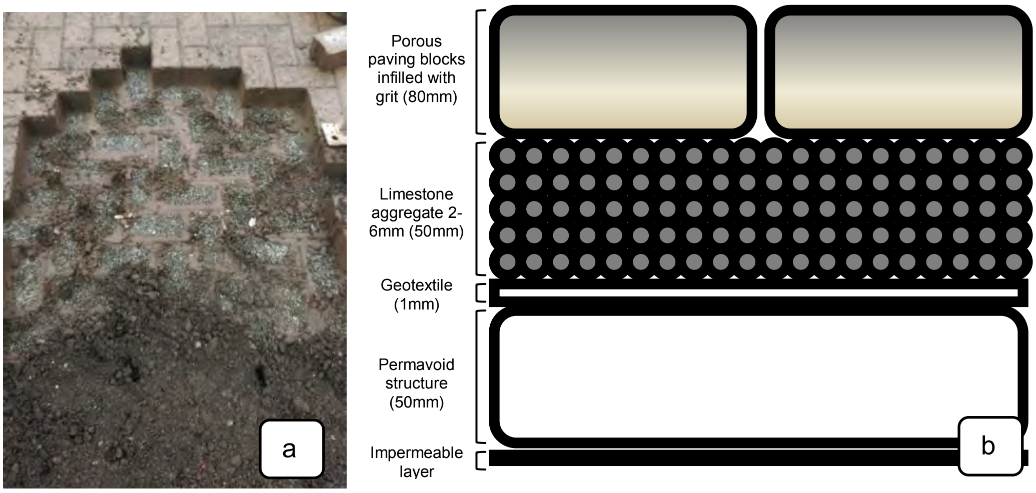

Figure 2. a) Decommissioning of PPS in Bury. b) Schematic of Bury PPS design.

Organic matter (%OM) was determined by weight differences through loss on ignition [6]. The pH of the sediment was determined using de-ionised water in the ratio of 1:2.5 w/v [7]. Sediment and water samples were analysed using a Fisherbrand Hydrus 300 pH meter.

2.1 Metal Analysis

Sediment samples were dried overnight at 80°C, homogenised using a pestle and mortar and passed through a 2mm sieve. The metals analysed for this study are contaminants associated with polluted road runoff (Zn, Cu, Pb, Ni, and Cr). Triplicate samples of approximately 1g were added to a reverse *aqua regia* ($HCl:HNO_3$ in the ratio 1:3 v/v) solution prior to microwave digestion, an adaptation of EPA Method 3050b [8]. Sediment for total extractable metal concentrations was prepared using Ethylenediaminete-traacetic acid (EDTA) and total water extractable concentrations using R/O water according to the Ministry of Agriculture, Fisheries and Food method [9]. Water samples were filtered using Whatman 541 filter paper prior to analysis. Metal concentrations of both sediment and water samples were determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES) accompanied with blanks and spikes to assess quality control. Mixed standard solutions were made for the elements of interest using analytical standards supplied by Fisher Scientific, UK.

3. INITIAL RESULTS & DISCUSSION

3.1 Sediment quality analysis

Preliminary testing has shown that total Cu and Zn concentrations exceed severe effect levels in the inlet and outlet of the HMSA spillage basin when compared to Ontario Sediment Quality Guidelines [10] of 110 mg kg^{-1} and 820 mg kg^{-1} respectively. Approximately 12.5% of Cu concentrations and 20% of Zn concentrations were extracted using EDTA. Readily water extractable concentrations remained below 5% for all metal concentrations at both the inlet and outlet of the spillage basin. Although metals are trapped in the sediment, as indicated by the water extraction results, extractable concentrations could be potentially bioavailable to organisms if changes in the environment occurred (e.g. increased presence of chelating agents or changes in redox potential). Additionally, %OM exceeded the 10% requirement for waste acceptance into a hazardous waste landfill facility by up to three times [11]. However, this result is most likely influenced by seasonality as samples were collected during the winter period.

Contaminants trapped in these systems could be potentially released in the spillage basin and transported through the management train that succeeds this device, having a negative impact on the surrounding biota. Metal concentrations have increased in comparison with results previously recorded on the HMSA SuDS management train [12]. Maintenance of the HMSA SuDS (e.g. sediment removal) has not been evident since the previous study and has contributed to the increase in contaminants reaching the spillage basin from the oil and silt interceptor. This is apparent as a layer of oil was observed at the inlet and sections where water had ponded in the spillage basin (Figure 3). Further investigation into contamination hotspots of the spillage basin and assessment of Total Petroleum Hydrocarbons (TPH) will be included in further study.

Figure 3. Oil sheen on ponded water in the HMSA spillage basin

Sediment recovered in between the joints of the PPS and the fines of the bedding layer had shown the majority of contaminants had been trapped at the surface. Total metal concentrations did not exceed sediment quality guideline values and on observation, prior to decommissioning, infiltration had not been significantly compromised. EDTA extractable and water extractable metal concentrations for Zn, Cu, Pb, Ni and Cr were below 10% and 0.5% of the total concentration respectively in the joint material. Metal concentrations on the geotextile layer are yet to be determined to provide a complete representation of metal pollution in the PPS. For further study, accelerated loading experiments of the PPS material reconstructed in laboratory rigs will establish potential end-of-life issues associated with the treatment capacity and waste disposal of this system.

3.2 Water quality analysis

Water quality results for metal concentrations and pH in the HMSA spillage basin and outflow of the PPS are presented in Table 1. Values have been compared to WHO [13] drinking water quality standards to establish the best case scenario for water quality in these systems. After 12 years of operation and no maintenance, the PPS had effectively trapped pollutants as the concentrations of metals from the outflow were below drinking water quality standards. Metal concentrations in the spillage basin are below drinking quality standards with the exception of Ni at the inlet. However, this decreases to 0.003 mg l^{-1} at the outlet, suggesting effective treatment of discharge from the oil and silt interceptor. Further monitoring of metal concentrations in water samples over an extended period will establish whether Ni concentrations are a concern in the spillage basin and the overall management train. The water quality results re-iterate how contaminants are effectively trapped in both systems and contribute to pollutant accumulation in SuDS. Overall, the preliminary study indicates the contaminated sediment has not had a significant impact on the water quality of these systems.

Table 1. Water quality results from the HMSA spillage basin and Bury PPS.

Site	Zn	Cu	Pb	Ni	Cr	pH
Spillage Basin inlet (HMSA) *($mg\ l^{-1}$)*	0.087	0.002	ND	0.03	0.01	6.9
Spillage Basin outlet (HMSA) *($mg\ l^{-1}$)*	0.107	0.009	ND	0.003	0.002	6.9
PPS outlet *($mg\ l^{-1}$)*	0.003	0.002	ND	0.002	0.001	7
WHO drinking water quality standards (mg/l) (WHO 2011) *($mg\ l^{-1}$)*		2	0.01	0.02	0.05	

4. CONCLUSION

Data collection for this study is still ongoing and preliminary results have shown the complexity and potential issues associated with establishing SuDS at end-of-life. Although metal concentrations exceeded sediment quality values for Zn and Cu in the spillage basin, the water extractable concentrations and water quality results have indicated that the treatment efficiency of the system has not declined. Further monitoring of the whole management train and leaching tests on the sediment will establish the waste disposal route of the accumulated sediment.

Material from the PPS has shown metal contamination below severe effect levels after 12 years of operation. The water quality of the outflow during operation was below drinking water quality standards indicating effective treatment. Future work on accelerated contaminant loading in PPS rigs will establish whether PPS components, including the geotextile, could exceed its treatment capacity and potentially release contaminants into the receiving water body before the hydraulic performance of the system is compromised.

Making assumptions on end-of-life issues for the HMSA spillage basin and PPS are premature. This presentation will show progress on this study and potential end-of-life issues that have arisen from the long term contamination of the HMSA spillage basin and PPS as a result of lack of maintenance. Despite these initial findings, it is possible that SuDS end-of-life could be potentially hazardous and have an impact on the surrounding environment.

COMPETING INTERESTS

Authors declare no conflict of interest.

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Water Efficiency Conference 2016

Attenuating and managing flows through source control principles within sewer systems

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ABSTRACT

This paper explores the benefits of employing source control principles, though the installation of plot-based flow controls, compared to installing in-sewer flow controls and installing no additional flow controls at all. In this work, vortex flow controls were chosen to be the flow controls installed into the sewer system models. The work was completed by simulating four scenarios on two anonymized case study sewer system models and recording the depth of rainfall that caused the sewer system to flood or over-discharge. The four scenarios were when: no additional flow controls were installed; when only in-sewer flow controls were installed; when only plot-based flow controls were installed; and when both in-sewer and plot based flow controls were installed. The two sewer system models were also simulated during exceedance conditions to investigate the flood volumes and number of locations that flooded. The results of the investigation have shown that, through the installation of plot-based flow controls, an increase in the depth of rainfall by 124% was needed before flooding or over-discharge was recorded. From the simulations of the sewer systems when flooding or over-discharge occurred, it was found that the installation of the plot-based flow controls reduced the maximum flood volume for each scenario (3,034m^3 to 1,490m^3), although also significantly increased the maximum number of flooded nodes (34 to 59).

Keywords: Flow attenuation; flow controls; plot based attenuation; source control;

1. INTRODUCTION

Within urban developments, the flow of surface water runoff needs to be controlled to a safe rate to prevent flooding. This can be achieved in a variety of ways depending on the hydraulic and hydrologic characteristics of the catchment. Examples of the ways in which flows can be controlled are:

- Storage volumes (e.g. ponds, tanks, etc.);
- Sustainable drainage systems (SuDS); and
- Flow controls (e.g. orifice plates, weirs, vortex flow controls (VFCs), etc.)

Flow-rates can also be controlled at varying locations within the catchment. In some instances, flow-rates are controlled at few central locations within the drainage system. This is referred to a 'centralized solutions' and commonly requires large storage volumes and large construction projects to install the design. Alternatively, flow-rates can be controlled at numerous locations, generally, within the upstream sections of the drainage system. Controlling flow-rates towards the top of the drainage system close to where runoff enters the sewer is referred to as 'source control'. This commonly requires the installation of many smaller flow control structures. The most extreme application of source control is to control surface runoff flow-rates on each plot within the catchment. In this paper, this approach has been termed the 'plot-based' approach.

The decision whether to design and install centralized or localized flow management solutions, by employing source control principles, can be complex due to ownership and maintenance issues.

Literature discussing the benefits of employing source control principles have been published [1,2,3,4,5,6, etc.]. Andoh and Andoh & Declerck [1,2] discuss the benefits of installing passive flow controls in upstream sections of sewer systems to reduce flood risk levels in the downstream catchments. In Andoh and Declerck's paper, it was shown that installing flow controls in a source control approach compared to conventional drainage solutions could save 25-80% in costs. Andoh and Declerck's work, however, does not assess whether attenuating flows on a plot-based approach also provides benefit.

The aim of this paper is to simulate the hydraulic behavior of two sewer system models (one small and one large) to analyse the benefits of:

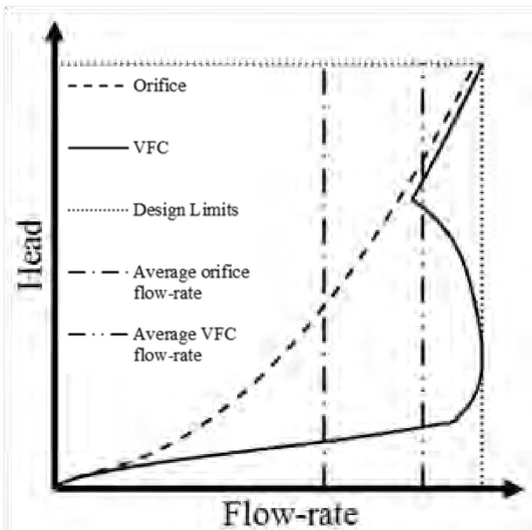
1) Installing VFCs at a plot scale to control flow-rates;
2) Installing VFCs solely within the sewer system; and
3) Installing VFCs at both a plot scale and within the sewer system (Section 5).

Section 5 quantifies the effects by comparing the depth of rainfall that causes flooding or over-discharge and the number of flooding locations and the flood volumes when the sewer system is overwhelmed.

2. VORTEX FLOW CONTROLS

VFCs are passive, self-activating, devices (Fig. 1a). The flow is throttled due to the generation of a vortex within the geometry of the device. In comparison to an orifice plate, VFCs allow a greater volume of water to flow downstream at low head levels (Fig. 1b). This means, that over the design head range, VFCs achieve a higher average flow-rate compared to the orifice and, subsequently, means that the volume of upstream storage required would be smaller.

a) Image of a VFC used in sewer systems to attenuate flow [7].



b) Comparison of the hydraulic characteristic behaviour of an equivalent orifice plate and VFC [8].

Fig. 1. a) Image of a typical VFC and b) a comparison of the hydraulic characteristics of an orifice plate and VFC designed for the same design flow-rate and head level.

3. METHODOLOGY

To compare the benefits of employing source control principles with positioning flow controls within the sewer system itself, four hypothetical scenarios on two sewer system models were simulated (the sewer system models are described in Section 4). The four scenarios compared were:

1) When no additional flow controls were installed into the sewer system (Scenario 1);
2) Only installing larger in-sewer flow controls into the sewer system (Scenario 2);
3) Installing individual plot-based flow controls on each dwelling in the catchment (Scenario 3); and
4) Installing a combination of plot-based flow controls and the larger in-sewer flow controls (Scenario 4).

The positions and designs for the in-sewer flow controls, used in Scenario 2 and 4, were chosen from the proposed solutions generated when the sewer system models were analysed by an assessment framework presented by Newton *et al*. [8]. The assessment framework searches the sewer system for existing un-used capacities within the sewer system and positions and designs vortex flow controls and orifice plates into the sewer system to make use of those capacities and reduce flood risk.

The plot-based flow controls, used in Scenario 3 and 4, were designed to have a design head of 0.5 m and a design flow-rate of 0.5 l/s. In the scenarios when the plot-based flow controls were installed, the plot-based flow controls controlled the surface runoff from a 0.0145 hectare subcatchment into the sewer system. The area equates to 10 m x 14.5 m house plot. Within each sewer system model, the existing subcatchments were divided into 0.0145 hectare sections and the plot-based flow controls inserted.

The four scenarios, for each sewer system models, were each simulated using three individual historical rainfall hyetographs (with varying durations of half-a-day to two days) to investigate the depth of rainfall that caused to sewer system to either flood or over-discharge. All of the simulations were completed using SWMM 5 Version 5.1.010 [9]. The three hyetographs for each case study were generated using the Pluvius program from Micro Drainage Ltd [10]. The historical rainfall hyetographs were scaled using a multiplication factor to cause either flooding and over-discharge. The minimum depth of rainfall that then caused the sewer system model to flood or over-discharge was then recorded and used to compare the scenarios.

The extent of flooding was assessed for each scenario during exceedance conditions. Each of the scenarios were simulated using the same hyetographs as above and the flood volume and number of nodes that flooded were recorded. To conclude whether the installation of source control principles through plot-based flow controls is beneficial the following parameters were compared:

1) The rainfall depths;
2) Flood volumes; and
3) Number of nodes flooded.

4. CASE STUDIES

Two sewer system models were used to investigate the benefits of employing source control principles compared to installing flow controls within the sewer system only (Section 4.1 & 4.2). The two sewer system models are both of existing sewer systems within the UK, but, have been anonymized.

4.1 Small anonymized sewer system

The first sewer system model considered in this body of work was the ‘small anonymized sewer system’ (Fig. 2.). The sewer system is a stormwater sewer system that collects surface water runoff from a housing estate located within the South West of the UK. The housing estate covered 1.5 hectares and contained 105 dwellings. Fig. 3. shows the cumulative depth curves of the three rainfall hyetographs used in the analysis. Each of the three hyetographs start with a period of heavy rainfall and are then followed by both periods of dry-weather and wet-weather over the hyetograph's duration. Table 1 shows the number flow controls that were positioned within the sewer system in each scenario and the estimated cost of the controls.

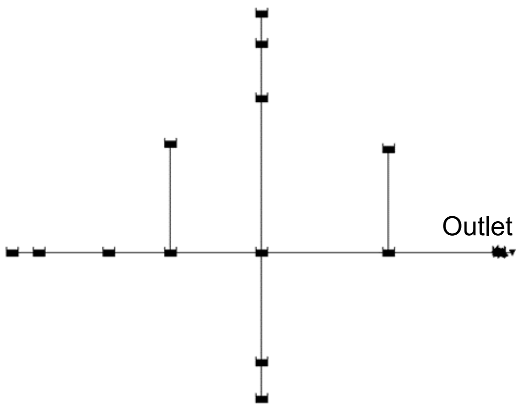


Fig. 2. Schematic of the small anonymized sewer system.

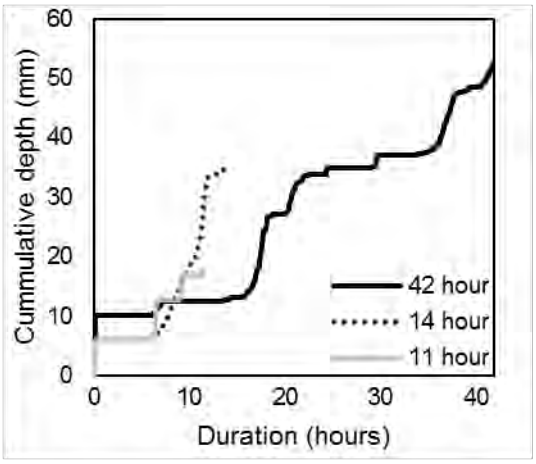


Fig. 3. Plot of the cumulative depth of the hyetographs applied to the small anonymized sewer system.

Table 1. Number of flow controls installed in each scenario for the small anonymised sewer system.

		Number of in-sewer flow controls	Number of plot flow controls
Scenario	No additional flow controls	0	0
	Only sewer flow controls	2	0
	Only plot flow controls	0	105
	Both plot & sewer flow controls	2	105

4.2 Large anonymized sewer system

The second sewer system model considered in this body of work was the 'large anonymized sewer system' (Fig. 4.). The sewer system is a combined sewer system that collects both surface water runoff and wastewater from a town located within the North-East of the UK. The town covered 15.6 hectares and contained 1,073 dwellings. Fig. 5. shows the cumulative depth curves of the three rainfall hyetographs used in the analysis. Each of the three hyetographs, again, start with a period of heavy rainfall and are then followed by both periods of dry-weather and wet-weather over the hyetograph's duration. Table 2 shows the number flow controls that were positioned within the sewer system in each scenario and the estimated cost of the controls.

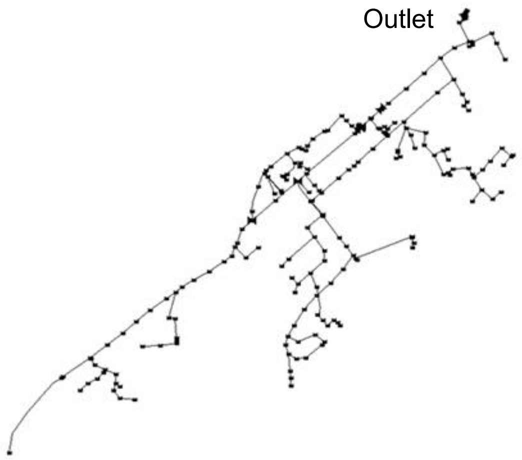


Fig. 4. Schematic of the large anonymized sewer system.

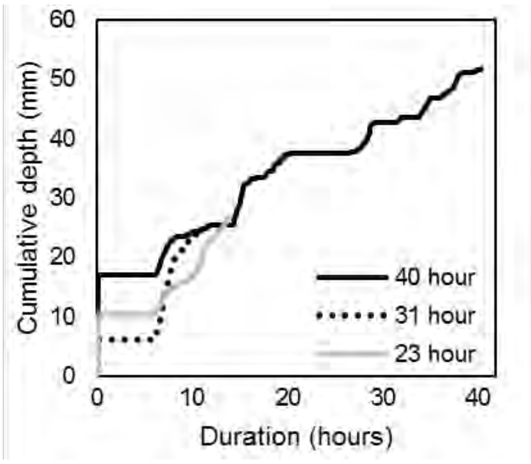


Fig. 5. Plot of the cumulative depth of the hyetographs applied to the small anonymized sewer system.

Table 2. Number of flow controls installed in each scenario for the large anonymised sewer system.

		Number of in-sewer flow controls	Number of plot flow controls
Scenario	No additional flow controls	0	0
	Only sewer flow controls	8	0
	Only plot flow controls	0	1,073
	Both plot & sewer flow controls	8	1,073

5. RESULTS AND DISCUSSION

Section 5.1 presents the rainfall depths that cause flooding or over-discharge for each simulated scenario. Section 5.2 presents the maximum flood volumes and maximum number of flooded nodes when the sewer system was exceeded.

5.1 Depth of rainfall that caused flooding or over-discharge

5.1.1 Small anonymized sewer system

Table 3 presents the depths of minimum rainfall that caused flooding or over-discharge from the small anonymized sewer system for the four scenarios. Table 3 shows that, for each of the four scenarios, the 11 hour rainfall hyetograph required the least depth of rainfall to cause the sewer system to flood or over-discharge. The 11 hour rainfall hyetograph was also the shortest of the three hyetographs and contained three short periods of high intensity rainfall. Comparing the minimum rainfall depths that caused flooding for each of the four scenarios, the scenarios with the plot-based flow controls, Scenario 3 and 4, required a greater depth of rainfall before flooding or over-discharge occurred. Scenario 3 and 4 were the two scenarios that contained the plot-based flow controls. There is, however, no difference between the minimum rainfall depth values between Scenario 3 and 4. This shows that the installation of the two in-sewer flow controls, Table 1, did not further reduce the flood risk level of the sewer system. This result shows that the installation of the 105 plot-based flow controls, Table 1, was more beneficial, increasing the minimum rainfall depth that caused flooding or over-discharge from 17.7 mm to 39.6 mm (+124%).

Table 3. Depths of rainfall that caused the small anonymised sewer system to flood or over-discharge.

	Rainfall hyetograph	42 hour	14 hour	11 hour	Minimum rainfall depth that caused system flooding (mm):
Scenario	No additional flow controls	73.2	33.9	17.7	17.7
	Only sewer flow controls	116.6	49.6	24.8	24.8
	Only plot flow controls	81.0	43.5	39.6	39.6
	Both plot & sewer flow controls	81.0	55.6	39.6	39.6

5.1.2 Large anonymized sewer system

Table 4 presents the depths of rainfall that caused flooding or over-discharge from the large anonymized sewer system for the four scenarios. Table 4 shows that, for each of the four scenarios, the 31 hour rainfall hyetograph required the least depth of rainfall to cause the sewer system to flood or over-discharge. Comparing the minimum rainfall depth that caused flooding or over-discharge for the four scenarios, the scenario with both the in-sewer and plot-based flow controls, Scenario 4, required a greater depth of rainfall before flooding or over-discharge occurred. Scenario 4 contained both the 8 in-sewer flow controls and the 1,073 plot-based flow controls. Interestingly, the scenario with only the in-sewer flow controls, Scenario 2, required the lowest rainfall depth before flooding or over-discharge occurred. This shows that the installation of the in-sewer flow controls increased the flood risk level of the sewer system compared to when no flow controls were installed (Scenario 1). Overall, these results show that the installation of the plot-based flow controls were beneficial. Installing both the in-sewer and plot-based flow controls was the most beneficial configuration and increased the minimum rainfall depth that caused flooding further from 5.4 mm to 6.9 mm (+28%).

Table 4. Depths of rainfall that caused the large anonymised sewer system to flood or over-discharge.

	Rainfall hyetograph	40 hour	31 hour	23 hour	Minimum rainfall depth that caused system flooding (mm):
Scenario	No additional flow controls	6.2	5.4	6.9	5.4
	Only sewer flow controls	7.8	4.8	8.6	4.8
	Only plot flow controls	6.7	6.0	7.5	6.0
	Both plot & sewer flow controls	8.8	6.9	9.9	6.9

5.2 Extent of flooding when the sewer system was overwhelmed

5.2.1 Small anonymized sewer system

This section of the paper presents the results from the simulations of when the sewer systems were overwhelmed and caused to flood for the four different scenarios. Table 5 and 6 show the maximum flood volume and maximum number of nodes that flooded in the simulations of the small anonymized sewer system. Table 5 shows that both the 42 hour and 14 hour rainfall hyetographs caused the greatest volumes of flooding over the four scenarios. These two rainfall hyetographs were the longer duration rainfall events out of the three. Table 5 also shows that the lowest maximum flood volume predicted when only the two in-sewer flow controls were installed, Scenario 2. The greatest maximum flood volume, for any scenario, was when only the plot-based flow controls were installed, Scenario 3. Table 6 shows the number of nodes that flooded in the small anonymized sewer system model when it was simulated to exceedance. Table 6 shows that, when the plot-based flow controls were installed (Scenario 3 and 4), a greater number of nodes flooded (16 compared to 7). The scenario that had the fewest maximum number of nodes flood was when no additional flow controls were installed into the sewer system (Scenario 1).

Table 5. Comparison of the flood volumes when the small anonymised sewer system was flooded.

	Rainfall hyetograph	42 hour	14 hour	11 hour	Maximum flood volume predicted (m^3):
	Depth of rainfall applied (mm)	261.3	178.3	88.7	
Scenario	No additional flow controls	1,351	1,444	282	1,444
	Only sewer flow controls	613	1,004	5	1,004
	Only plot flow controls	1,690	1,590	630	1,690
	Both plot & sewer flow controls	1,340	1,198	630	1,340

Table 6. Comparison of the number of nodes that flooded when the small anonymised sewer system was flooded.

	Rainfall hyetograph	42 hour	14 hour	11 hour	Maximum number of nodes that flooded:
	Depth of rainfall applied (mm)	261.3	178.3	88.7	
Scenario	No additional flow controls	7	2	2	7
	Only sewer flow controls	9	6	3	9
	Only plot flow controls	14	15	13	15
	Both plot & sewer flow controls	16	16	13	16

5.2.2 Large anonymized sewer system

Table 7 and 8 show the maximum flood volume and maximum number of nodes that flooded, respectively, in the simulations of the large anonymized sewer system. Table 7 shows that both the 40 hour and 31 hour rainfall hyetographs caused the greatest volumes of flooding over the four scenarios. These two rainfall hyetographs were the longest and shortest duration rainfall events respectively. Table 7 also shows that the lowest maximum flood volume predicted during exceedance conditions when both the eight in-sewer flow controls and the 1,073 plot-based flow controls were installed, Scenario 4. The greatest maximum flood volume, overall and for each of the simulations with the different rainfall hyetographs, was for Scenario 1 when no additional flow controls had been installed. Table 8 shows the number of nodes that flooded in the large anonymized sewer system model when it was simulated to flood. Table 8 shows that, when the plot-based flow controls were installed (Scenario 3 and 4), a greater number of nodes flooded (59 compared to 34). The scenario that had the fewest maximum number of nodes flood was when no additional flow controls were installed into the sewer system (Scenario 1).

Table 7. Comparison of the flood volumes when the large anonymised sewer system was flooded.

	Rainfall hyetograph	40 hour	31 hour	23 hour	Maximum flood volume predicted (m^3):
	Depth of rainfall applied (mm)	51.8	29.9	34.3	
Scenario	No additional flow controls	3,034	1,276	2,022	3,034
	Only sewer flow controls	1,858	1,070	816	1,858
	Only plot flow controls	2,940	1,192	1,731	2,940
	Both plot & sewer flow controls	1,490	714	353	1,490

Table 8. Comparison of the number of nodes that flooded when the large anonymised sewer system was flooded.

	Rainfall hyetograph	40 hour	31 hour	23 hour	Maximum number of nodes that flooded:
	Depth of rainfall applied (mm)	51.8	29.9	34.3	
Scenario	No additional flow controls	34	11	22	34
	Only sewer flow controls	38	19	27	38
	Only plot flow controls	53	8	8	53
	Both plot & sewer flow controls	59	19	10	59

6. CONCLUSION

This investigation has shown that by employing source control principles, through the installation of plot-based flow controls, a reduction in flood risk can be achieved, as seen in both cases. In the first hypothetical case study considered, an additional 124% depth of rainfall could be controlled and conveyed through the sewer system before flooding or over-discharge occurred. It was also found that, with the additional in-sewer and plot based flow controls installed in Scenarios 2 to 4, the total flood volumes were reduced during exceedance conditions, however, the number of flooded locations increased. This would mean that, even though the overall flood risk of the sewer system has been reduced, the sewer operators would also have to consider whether wide spread shallow flooding is more suitable than localized potentially deep flooding.

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Water Efficiency Conference 2016

Using catchment scale field data to validate MicroDrainage: Results from the North Hamilton, Leicestershire, SuDS Management Train

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ABSTRACT

SuDS present a sustainable method for flood management, with systems slowly being implemented across the UK. Much of the research to date focused on either modelled data, or monitoring runoff from single devices, however this research presents a novel methodology for monitoring a wider management train. A rain gauge was installed on site in Hamilton, Leicestershire, with runoff monitored after five different rainfall events at eight sections of the management train. The site was simulated in MicroDrainage®, the UK industry standard drainage modelling system, with each rainfall event simulated. This enabled a comparison, and ultimately a validation of the program, to determine the accuracy of its runoff predictions. The validation calculated a Nash-Sutcliffe efficiency of 0.88, with an r^2 of 0.98. This was a favourable outcome when compared to other model validations, which have typically focused on small scale, individual devices, as opposed to the 16ha scale of this research.

Keywords: SuDS Management Train, Model, Validation, MicroDrainage®, Hamilton

1. INTRODUCTION

Sustainable drainage systems (SuDS) provide an alternative approach to conventional drainage. Whilst piped drainage is an efficient system for removing water, the aim of SuDS is to change the principle that water should be rapidly transported away from towns and cities [1]. Although their implementation in both new and existing developments is slowly increasing across the UK, they are far from being the standard approach for drainage. The new Non-Statutory Standards for SuDS [2] attempted to engage developers with SuDS by ensuring that new developments do not produce peak flows greater than greenfield runoff. However, to further engage planners and developers to adopt SuDS, more confidence is needed with the models and tools that are used in design.

MicroDrainage® is the industry standard drainage modelling tool in the UK and contains a SuDS functionality module [3]. Although the industry standard, no research exists to validate it in the field. Previous validation of other SuDS models has focused at the single device scale [4];[5], while the only previous study to monitor a SuDS management train analysed water quality [6]. This overall aim of this paper is to present the results of a field study to validate the industry standard model from a SuDS management train in Hamilton, Leicester, UK. The findings determined the accuracy with which MicroDrainage® can predict runoff, therefore providing additional confidence in the program.

2. METHODOLOGY

Field data was collected from the eight sites of a 16ha SuDS management train in Leicester, United Kingdom which incorporated swales, vegetated wet ponds and dry detention ponds. This was then compared to a modelled version of the site in *MicroDrainage*® which enabled a validation of the program using the Nash-Sutcliffe Efficient (NSE) and the coefficient of determination, as implemented by [7]. Figure 1 outlines the main processes of the research.

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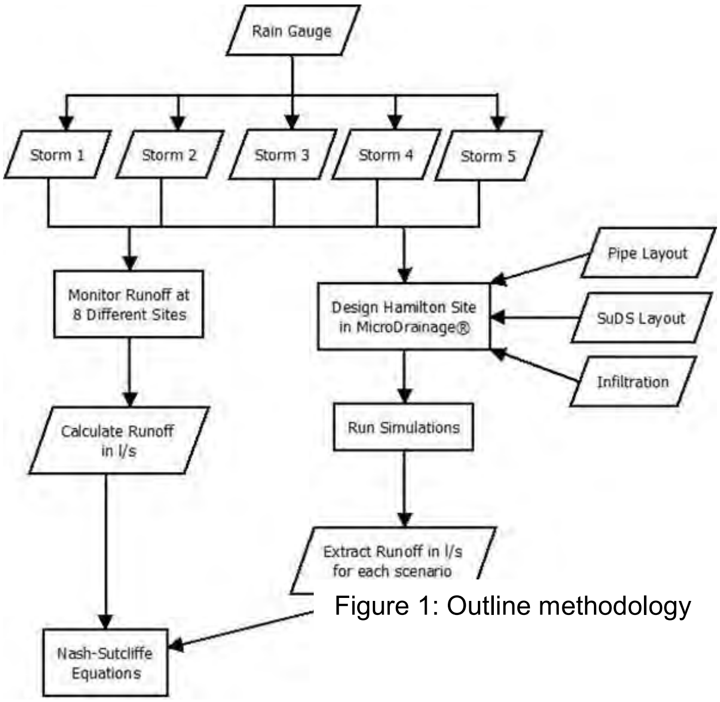

Figure 1: Outline methodology

2.1: Study site: Hamilton, Leicestershire

Field data was collected between November 2014 – January 2016, across 26ha at Hamilton, Leicester, approximately 5 km from Leicester city centre (Figure 2).

Previously farmland, construction began on the SuDS management train in 2001, and the housing in 2002 [8]. The geology is predominantly Wilmcote Limestone, whilst the soils range from clay to clayey loam, leading to reduced infiltration capacity across the site [9]. Three SuDS management trains comprising swales and detention ponds were installed to ensure the site remained close to greenfield runoff rates. Runoff was designed to be treated through each train, with the flow controlled via weirs and conveyed north, from east to west into the Melton Brook through constructed wetlands. Flow was measured at 8 sites (see Figure 3). Figure 4 presents an outline configuration of the devices installed at the management train.

Figure 2: Outline of Hamilton, Leicestershire a) Map of Leicester, with Hamilton highlighted in red [10]; b) Leicester in relation to the rest of the UK c) Satellite image of Hamilton, Leicester [11]

Figure 3: SuDS Management train at Hamilton, Leicester highlighting each site modelled [11]

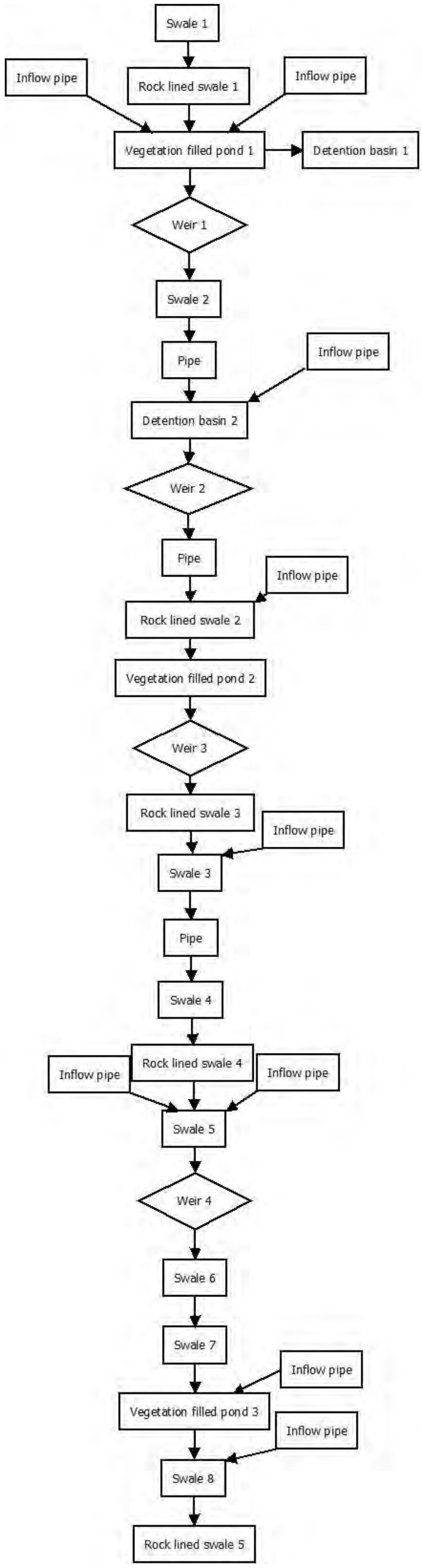

Figure 4: Configuration of SuDS Management train at Hamilton, Leicester

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2.2: Field equipment

A telemetered Casella Tipping Bucket was used for its reliability and ease of continuous data collection; this was remotely uploaded to an online server [12].

An OTT MF Spot Velocity Meter was used to calculate flow speed. Measurements during or after five rainfall events were taken by hand due to the likelihood of tampering if they were permanently sited outside of the pipes.

2.3: Validation

The drainage system was designed in MicroDrainage®, using a 5m resolution LiDAR image. Each measured rainfall event was defined in the program to ensure a comparison between the model and field data. Manning's values were estimated, based on channel characteristics at each measurement site as suggested by [13]. Values ranged from 0.045 for sparsely vegetated, rock lined channels, to 0.06 for those that had a greater density of vegetation. In the pipe-base system, a standard roughness value of 0.6mm for concrete pipes was used. Adding this information ensured that the design reflected the site, therefore enabling a validation of MicroDrainage®.

3. RESULTS AND DISCUSSION

Runoff from five rainfall events at different times of the year were measured at the eight sites shown in Fig 3 and were compared to the simulated data (Figure 5). The NSE was used to determine the validity of the model, since it is specifically designed to validate hydrological models with field data [14], with the coefficient of determination (r^2), as in [7] (NSE values range from –infinity to +1, with a value of 1 corresponding to a perfect match). Although [5]; [15] and [16] have previously used the NSE method to determine model accuracy, no studies have measured a combination of SuDS devices.

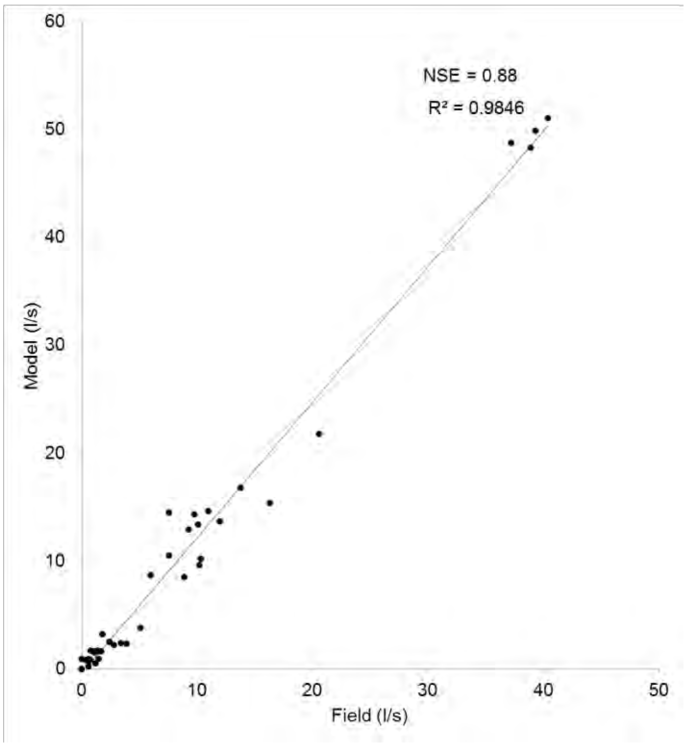

Figure 5: Comparison between field and model data for Hamilton, using MicroDrainage®

The NSE calculated a 0.88 level of confidence in MicroDrainage®. Previous research focussing on model validation at the small laboratory scale achieved results between 0.85-0.97 [15] for different SuDS components and different models. Such a high level of confidence for a 16ha site, and acknowledging the uncertainties outlined in section 2.3, provided strong confidence in the model. The additional r^2 statistical test calculated an even greater level of confidence in the ability of MicroDrainage® to simulate flow; returning a coefficient of 0.98.

In comparison, [5] utilised the Model for Urban Stormwater Improvement Conceptualisation over five different urban sized catchments (105.6ha – 10.5ha) in Australia. They calculated an average NSE for the model of 0.61, with the best being 0.8. Therefore a NSE of 0.88 over a complex 16ha site that integrated four ponds and 280m of swales suggests the model performed extremely well.

There were uncertainties in constructing the model. Values of Manning's roughness attributed to the density and types of vegetation simplified the model, when in reality vegetation changed markedly for each device, influencing flow characteristics. Previous model validation

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focussed at the small scale (typically one unit), as increasing the size of the simulation had the potential to introduce inaccuracies [4]; [5]. At 16ha, it was also probable that infiltration rates were not consistent across the site; however MicroDrainage® required a constant infiltration value. Field-walking found that the location of some of the pipes were not consistent with the mapped layout; in some cases outflow pipes were slightly offset. This therefore questioned the reliability of the data and added further uncertainty to the model. To overcome these uncertainties, state tests were undertaken to determine whether the model accurately replicated the site. Once a state was achieved, the only variable to change was the Manning’s value to replicate vegetation growth or removal.

4. CONCLUSION

This research presented a novel approach to a wider scale monitoring project for a SuDS management train. Previous research has focused at the single device scale [4]; [5], and any monitoring tended to focus on the water quality aspect of the four pillars of SuDS [6].
The UK industry standard drainage modelling tool, MicroDrainage®, was validated to determine the accuracy with which it predicted runoff. Five flow generating events were monitored at the Hamilton SuDS management train and accurately re-modelled in MicroDrainage®. The NSE calculated a 0.88 correlation between the field and model data, with an r^2 value of 0.98 highlighting the accuracy of MicroDrainage® in simulating runoff. As the UK industry standard drainage modelling tool, this will further engage developers with the software and provide further confidence regarding the impact SuDS can have at reducing runoff.

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COMPETING INTERESTS: authors declare no competing interests

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Water Efficiency Conference 2016

Investigation of Potential Application of Modified Pervious Paving Biofilters to Vent Ground Gas and Prevent Groundwater Contamination in Historic Landfills

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ABSTRACT

Much of the solid municipal waste generated by society is sent to landfill, where biodegrading processes result in the release of methane, a major contributor to climate change. This work examined the possibility of installing a type of biofilter within paved areas of the landfill site, making use of modified pervious paving both to allow the escape of ground gas and avoid contamination of groundwater, using specially designed test models with provision for gas sampling in various chambers. It proposes the incorporation of an active layer within a void forming box with a view to making dual use of the pervious pavement to provide both a drainage feature and a ground gas vent, whilst providing an active layer for the oxidation of methane by bacterial action. The methane removal was observed to have been effected by microbial oxidation and as such offers great promise as a method of methane removal to allow for development of landfills.

Keywords: Landfills, Waste, Methane, Methanotrophs, Biodegradation, Biofilter, Pervious Pavements, Groundwater

1. INTRODUCTION

Whilst recent practices in some developed countries (such as UK, USA, Canada and the EU) have reduced landfill disposal of biodegradeable material to some extent, much biodegradeable waste is still sent to landfill. Biodegrading processes inevitably produce methane, a greenhouse gas that contributes to climate change to a greater extent than the same mass of carbon, in the form of carbon dioxide (Woolf *et al*., 2010). Modern practices such as active gas collection (incorporating electricity generation) or, when the gas has insufficient energy content to make electricity generation worthwhile, active collection followed by flaring or actively ventilated biofilters are effective at reducing both the potential health and safety hazards and achieving GHG reductions. However, the systems are not cost effective or environmentally sound for older landfills or other brownfield sites where low, but unacceptable, concentrations of methane are present, inhibiting development. This is particularly important when ground gas concentrations are just above concentrations at which simple barriers in the floor slab would be effective. One method that could address this issue would be to encourage the gas to vent passively from the site and in this case reduce climate change impact by the biological conversion of the methane to carbon dioxide. It would be more optimal to do this as the CO_2 was vented, a method that has been actively pursued by Einola *et al*. (2008) Scheutz *et al.* (2011) and Schroth *et al.* (2012). Passive bioreactors have been investigated by several researchers such as Barlaz *et al.* 2004, Huber-Humer *et al*

2008, and Borjesson *et al* (2001). Straka *et al.* (1999) came to the conclusion that the use of a passive venting system with bio-filtration is a much cheaper mitigation technique than the active venting system with advantages especially in small and old landfills. However, covering with a compost biofilter can prevent certain after-uses of such sites especially if the provision of hard standing is needed.

Pervious pavements systems (PPS) are an integral and widely implemented component of sustainable drainage system (EA 2012) designed to deal with stormwater at source and provide stormwater treatment, volume control and amenity. The traditional design of PPS includes the natural stone sub-base layer which acts as both load bearing structure and a water storage reservoir. PPS that use plastic void forming boxes to provide some or all of the sub-surface storage volume offer an alternative to PPS based on aggregate sub-bases. Plastic boxes within a PPS have also proved useful to allow incorporation of additional treatment options within the system. The extended void space of the plastic void forming units has been exploited to incorporate floating mats to absorb oil (Newman *et al* 2004) and specialized foams to provide long-term water storage as well as additional pollutant retaining capacity (Nnadi *et al* 2014). The incorporation of additional treatment enhancement layers such as sorbents or biodegradation enhancements into traditional stone sub-based pervious pavements has also been proposed (Puehmeier and Newman 2008, Bentarzi et al 2013). This paper proposes the incorporation of an active layer within a void forming box with a view to making a dual use of the pervious pavement providing both a drainage feature and a ground gas vent whilst providing an active layer for the oxidation of methane by bacterial action which could help to reduce the mass of methane released and hence diminish the greenhouse gas contribution of the site as well as prevent landfill leachates from migrating into the groundwater. This approach would be suitable where hard surfaces need to be incorporated into historic landfill sites. This could allow the implementation of suitably designed development options to take place. Such circumstances could include parking areas at visitor centres, where the landfill has been devoted to recreational use, or hard standing areas on industrial sites built on closed landfills. The layer of compost within a plastic load bearing box could also be incorporated into venting conduits used in passive gas venting systems such as the Virtual Curtain System (EPG Ltd, 2009).

2. MATERIAL AND METHODS

The test models were constructed on the footprint of a Permavoid® void forming unit which in plan measures 71cm x 36cm. The models consisted of a welded polypropylene chamber sufficient to hold 3 layers of these units with a flange on the upper lip to allow a lid to be bolted down, forming a sealed system with a depth of 45.2 cm (Figure 1) and a series of gas entry/exit ports for sampling from upper or lower sub-chambers. A lower, empty, permavoid® unit was used to support the active unit containing a loose fill of compost which was wrapped in geotextile to prevent loss into the lower box. Green compost (garden and farm waste) was characterized before application. Before sealing the lid, sufficient distilled water was added to provide starting water content of 25%v/v in the compost. A humidification system was used to ensure that the gases passing into the boxes would be saturated with water vapour. This system was replicated as well as the control. Dynamic “slug” experiments were conducted with the designated methane-exposed model and gas was introduced simultaneously as air was passed into the box using a gap-meter type flow meter in order to understand the lag time between the introduction of a slug of pure methane into the lower box and its appearance in the upper box and to develop an appropriate mechanism to allow the compost to be exposed to relatively high concentrations of methane for the development of methanotrophic bacteria. In a typical experiment, with the air flowing through the humidifier at 2 l/min, slugs of methane from 1 to 10 litres were introduced into the lower box and sampling ports in both the upper and lower void box sections were used to draw sample into a gas data gfm400 analyser for measurement of CH4 and CO2. Methane free air was pumped into the lower box until the concentration of the CH4 in upper box appeared to have exceeded its peak concentration and had started to decline. Initial static tests were carried out on 5 occasions with a range of starting methane concentrations.

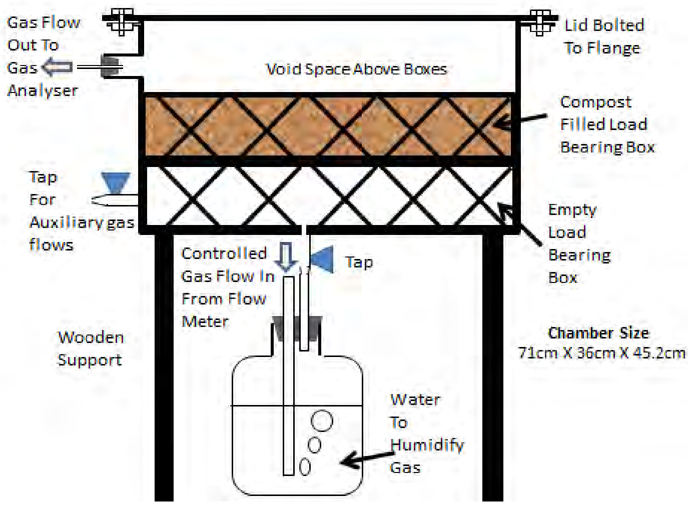

Figure 1: Test Set-up

The system was pulsed with 5 to 10 litres of methane and airflow was applied until a methane concentration of between 30% and 60% of the lower explosive limit was present in both upper and lower boxes. Series of dynamic tests were initiated on methane exposed box starting with a blank run using methane free air. The airflow rate was 100ml/min. This box was sealed 4 days prior to experiment and the initial concentration of CO2 in the upper chamber was 8.7%. After 24 hours pre-equilibration, regular (half hourly) sampling was started. A subsequent repeat experiment using hourly sampling gave essentially similar results. Three experiments were then conducted, using a 2.5% methane (21% oxygen, balance nitrogen) mixture as feed gas at a flow rate of 100ml/min. Finally an experiment was conducted using a feed gas flow rate of 200ml/min. In all cases, the feed gas was applied for 24 hours prior to analysis.

3. Results and discussion

The summary results for the four runs with a feed gas containing 2.5% methane which were scheduled 1 week apart are shown in Table 1, with the full results obtained for runs 3 and 4 shown graphically in Figure 2.

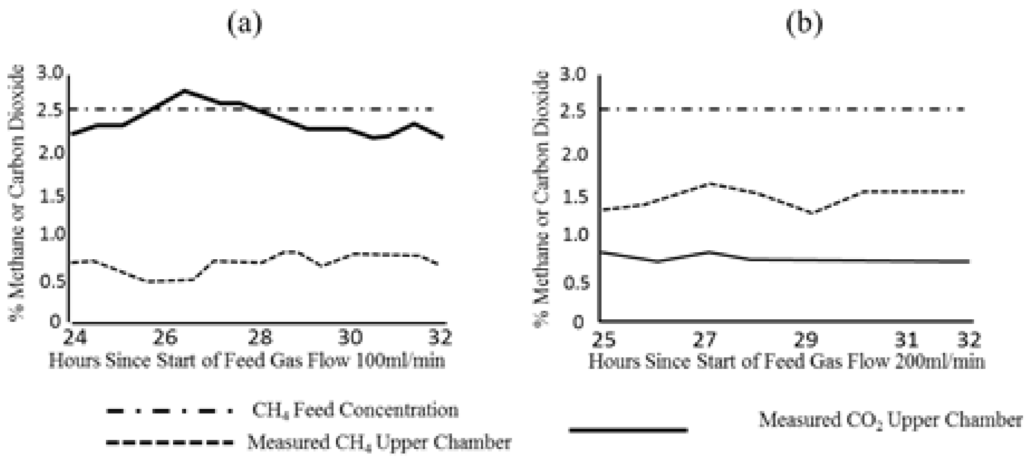

Figure 2 (a) 100ml/min Experiment 1 (b) 200ml/min Experiment 2.
Feed conc. 2.5% CH4 in each Experiment

The results indicate that the passage of methane laden air at a concentration of 2.5% at 100ml/minute through a compost filled permavoid box gives sufficient methane removal to offer the potential benefits in both proposed applications. Although the removal was not 100% we need to consider that these systems would be installed where there was no attempt to remove methane at all and thus any significant removal would provide a worthwhile environmental benefit.

Table 1: Mean Concentrations of constituent gasses sampled from upper chamber of model

	Flow Rate ml/min	Sampling Period	Sampling Interval	% CH4	% O2	% CO2
1	100	8 hr	0.5 hr	1.45	19.9	0.725
2	100	8 hr	1hr	1.2	19.5	0.99
3	100	8 hr	0.5hr	0.8	18.9375	1.625
4	200	7 hr	1hr	1.4	19.9	0.7

4. CONCLUSION

The results indicate that a flow of 2.5% methane gas at 100ml/min through treatment models gives sufficient methane removal relative to the control. Also, methane oxidation by methanotrophic organisms was effective and can be potentially optimised. The significant methane removal observed in this study can potentially offer a worthwhile environmental benefit in reduction of emission of CH4, which impacts highly on the climate and find application in the management of landfills especially the historic landfills. Also, this technology could enhance proposals for sustainable remediation of contaminated sites as it incorporates greenhouse gas reduction component.

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Water Efficiency Conference 2016

User preferences and behaviour change owing to washbasin taps retrofit: A case study of the DECivil building of the University of Aveiro

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ABSTRACT

In the last decades, achieving water efficiency became an increasingly important challenge in the scope of sustainability. Despite the various technological improvements in equipment and appliances, whenever water consumption is directly related to individuals their performance will be affected by preferences and change of behaviour.
The present communication evaluates the impact of the user preferences and behaviour change in the water efficiency performance of tap aerators using the Department of Civil Engineering Building of the University of Aveiro, Portugal, as a case study. Four aerators with different discharge reduction were installed in the toilet washbasins and the user's preferences and behaviour change measured through direct and online questionnaires.
It was observed that the water consumption reduction (15% to 49%) was less than the discharge reduction (30% to 70%). Also, there were significant differences in terms of both user preferences and behaviour change depending on the gender, with female users changing their behaviour less than male users when facing the discharge reduction in the tested range (2.0 l/min to 6.7 l/min). It was also observed that an awareness of sustainability prevails amongst the users. When confronted with the information that the lower discharge aerator would contribute to a reduction of about 70% on the water discharge, 25% of the users agreed with its use, even if it resulted in a certain degree of dissatisfaction, against only 8% of the users disagreeing completely with its installation. The remaining 67% were not dissatisfied about the use of this equipment.

Keywords: water efficiency; user preferences; behavioural change; sustainability; university buildings

1. INTRODUCTION

Amongst the various environmental issues faced by mankind nowadays, fresh water shortages and pollution are amongst the most critical global problems. A significant portion of water consumption takes place in buildings and since it is used to satisfy basic human needs, its requirements in terms of quality tend to be higher than in remaining uses (e.g., energy production, industry, agriculture). In Portugal the urban water consumption accounts for only 8% of the total water consumption (agriculture accounts for 87%) but represents 48% of the total water cost due to the infrastructure needed and resources spent on water treatment and supply [1]. Therefore, the benefits from water saving in buildings have a wider scope.

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The approaches that can be employed to reduce the amount of water consumed in buildings can be grouped into two categories: i) behaviour change; and ii) system change. While the former involves mostly non-structural measures (e.g., education campaigns; water cost; water pricing policies) the later includes structural measures such as water efficient fixtures and appliances retrofit (e.g., [2], [3]), rainwater harvesting (e.g., [4], [5]) and water re-use (e.g., [6], [7]). Planning and management studies making use of structured integrated water resources management models for water management (e.g., [8]) allowed to conclude that highly efficient water fixtures and appliances are an economical primary water saving strategy, with recent studies indicating reductions up to roughly 50% in the USA [2], of almost 14% in Australia [9] and, in general, between 35 and 50% in the western (developed) world [10]. However, it is difficult to predict future water consumption when applying system changes since water consumption depends not only on the characteristics of the new equipment but also on the social trends and change [11]. System changes will affect user preferences and will contribute to behavioural change, which can reduce, eliminate or even reverse the benefits of the retrofitting. Fidar et al. [12] found that low discharge taps resulted in an increase in water consumption when compared to conventional taps, indicating that the event duration is more relevant to water consumption than the nominal flow rate. In this regard, this paper is focused on the evaluation of user preferences and behaviour change due to washbasin taps retrofit. Since [13] refers that tap retrofitting is more viable in public buildings, such as universities, due to their high occupancy, the Department of Civil Engineering of the University of Aveiro (DECivil), Portugal, was used as case study. The results show the existence of distinct short and long term preferences for female and male users, resulting in different behavioural and water consumption changes depending on the gender of the user.

2. CASE STUDY

The present study evaluates the user preferences and behavioural change due to washbasin taps retrofit, focusing on the Department of Civil Engineering (DECivil) building at the University of Aveiro as case study (Figure 1).

Fig. 1. Aerial and terrestrial view of the DECivil building

The DECivil building is a 3 floor rectangular building, with a total area of 4 320 m^2, composed of classrooms, offices and laboratories. The building has several water consumption points in the existing toilets and laboratories. The six main toilets (three for female users and three for male users) are responsible for roughly 70% of the building's water consumption, according to previous studies [14], [15]. These toilets have 14 washbasins, equally divided between the ladies and gentlemen toilets.

The DECivil community (students, researchers, professors and administrative and lab workers) comprises of about 300 people, the majority being students. Since this population varies throughout the day and over the academic year, the water consumption pattern varies accordingly. However, except for occasional intensive water-use experiments in the laboratories, the water consumption end-use distribution is fairly uniform, with the washbasins consumption accounting for 17% of the water consumption in the toilets [14], [15].

3. MATERIAL AND METHODS

The base situation and four different aerators certified by the Portuguese Association for Quality and Efficiency in Building Services (ANQIP), which represent discharge reductions between 30 and 70%, were studied during two subsequent academic years. The base situation consisted of the existing laminar flow push taps with a discharge of 6.7 l/min and 6.1 seconds shut off time. The four alternative aerators tested had the following characteristics (Figure 2): aerator A - aerated flow with Q = 4.7 l/min; aerator B - spray flow with Q = 3.9 l/min; aerator C - aerated flow with Q = 3.4 l/min; and aerator D - spray flow with Q = 2.0 l/min. The method used by Meireles et al. [5], consisting in measuring the tap operation time and the corresponding volume discharged, was used to determine the water discharges. The values presented herein correspond to the average of 4 measurements made in all taps studied, but the average variation between the highest and lowest discharge recorded is of only 7.6%. Since the operation time is small and more prone to human error in the measurement, 20 random users (10 female users and 10 male users) were requested to twice push 3 different taps each and the variation of the total water discharged was found to be less than 10%. Consequently, it is possible to claim that the operation time is independent of the user and the error in measuring the tap's shut of time is consistent in all measurements. Therefore, the error in the absolute discharge values estimation has limited effect on the discharge differences.

a) b) c) d)

Fig. 2. Characteristics of the different aerators: a) aerator A (aerated flow; Q = 4.7 l/min); b) aerator B (spray flow; Q = 3.9 l/min); c) aerator C (aerated flow; Q = 3.4 l/min); d) aerator D (spray flow; Q = 2.0 l/min)

The evaluation of the user preferences and behaviour change was performed through two different types of questionnaire: i) direct questionnaires, with enquiries about water consumption behaviour and preferences; and ii) online questionnaires, focused only on preferences issues. The study was performed during the teaching and exams periods and the average building occupancy was of 150 people during the work hours (9 am to 6 pm).

The direct questionnaires were performed on Tuesdays, from March to May 2015, during the teaching period, to maximize the number of data, since a previous study reported the largest occupancy of the building on those days [4]. These questionnaires were performed from 8:30 am to 6:30 pm, in the toilets with the highest number of uses, which were also the toilets with the most heterogeneous users. The aerators were installed with decreasing discharge (i.e., from A to D) to allow progressive users adaptation. When studying a different aerator, all taps were replaced at the same time, warrantying that all users were experiencing the same conditions when inquired. The reply rate of the toilets directly monitored was of 100%, corresponding to about 50 uses per day. Given the size and dynamics of the DECivil building community, this was an expected result and the number of replies per day did not vary significantly between the days of the direct monitoring campaign.

The online questionnaires were focused only on the two lower discharge aerators (aerators C and D) and on the base situation. In this case the aerators were installed by increasing discharge in order to evaluate also the influence of a decreasing or increasing discharge in the user's behaviour, especially since the users were previously introduced to the study during the direct monitoring campaign. Aerator D was installed in every toilet without previous notice at the beginning of week one. At the end of week one, an online questionnaire was made available, and stayed online during week two. Subsequently, aerator D was replaced without previous notice by aerator C in the beginning of week three. At the end of week three a new online questionnaire was made available, and stayed online during week four. In the beginning of week five the base situation was again restored and an online questionnaire was made available during week six. Weeks one and two corresponded to the teaching period, weeks three and four to break and exams periods and weeks five and six to exams period. The reply rate of the online questionnaires varied between 29% and 35% of the total DECivil building universe, representing roughly 90 responses per questionnaire. A decreasing trend in the replies to questionnaires 1 to 3 was observed, which may be in part explained by the fact that they were performed at different academic periods. More information can be found in [16].

4. RESULTS AND DISCUSSION

4.1 Consumption reduction

The potential population of users in each monitoring campaign is the same, but there was no way to ensure the samples to be statistically equivalent at the onset. Using the Chi-Squared test to compare the sample of users in each monitoring campaign it was found there were no statistically significant differences in terms of age ($\chi^2(15)=11.572$, $p=0.711$) and gender ($\chi^2(4)=2.306$, $p=0.680$).

Independently of the aerator used, it was observed a reduction in water consumption when compared to the base situation (Figure 3). Still, the reduction is not linear, with a significant reduction with aerator A but no additional reduction with aerator B and then further reduction with aerators C and D. Comparing the results of aerators A and B the only possible explanation with information available is that the type of flow (aerated or spray) also affects the behaviour of the users. However, between aerators C and D the same was not observed, indicating that other factors may exist.

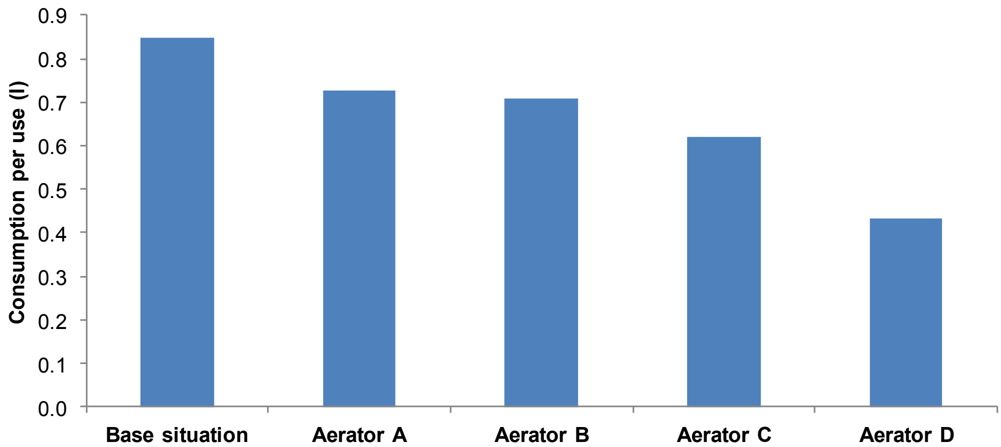

Fig. 3. Comparison of the average water consumption per use for the base situation and tested aerators

There is a statistically significant difference on consumption between aerators and base situation as determined by one-way ANOVA ($F(4,715)=16.280$, $p=0,000$). Levene's test indicated unequal variances ($F(4,715)=5.155$, $p=0,000$), but both the Welch ($F(4,113.3)=40.183$, $p=0,000$) and the Brown-Forsythe ($F(4,217.2)=25.536$, $p=0,000$) confirm that there is a statistically significant difference on the consumption. The Games-Howell post-hoc test revealed that the consumption was statistically significant lower with aerators C (0.62 ± 0.29 l, p=0.000) and D (0.43 ± 0.17 l, p=0.000) compared to the base situation (0.84 ± 0.36 l). Aerator D (0.43 ± 0.17 l) was also found to produce a statistically significant lower consumption than aerators A (0.72 ± 0.28 l, p=0.000), B (0.71 ± 0.32 l, p=0.000) and C (0.62 ± 0.29 l, p=0.000). There were no statistically significant differences between the aerators A and B (p=0.998), A and C (p=0.240) and B and C (p=0.232).

The Kolmogorov-Smirnov test indicate that the consumption also violates the assumption of normality in the base situation (K-S=0.362, p=0.000) and all aerators (A: K-S=0.256, p=0.000; B: K-S=0.228, p=0.000; C: K-S=0.199, p=0.000; D: K-S=0.291, p=0.000). Since the number of cases in each group is higher than 15 (minimum 35), the results of the ANOVA are still valid. Nevertheless, the Kruskal-Wallis test ($\chi^2(4)$=88.723, p=0.000) also indicates a statistically significant difference on consumption between aerators and base situation.

On average, the water consumption reduction was 46% smaller than the discharge reduction achieved with the aerator. In fact, while the aerators contributed to discharge reductions between 30% and 70%, the reduction on water consumption was only between 15% and 49% (Table 1).

These differences resulted from behaviour change from the users, namely the number of tap pushes in each use. However, the change was not uniform with the gender. While it was observed a distinct difference in male users' behaviour with the different aerators (Figure 4 a)), female users consistently operated the taps the same number of times, independently of the aerator (Figure 4 b)). For instance, while 33 to 37% of the female users operated the taps once for all aerators, 53% of the male users operated the tap once when aerator A was installed, against 30% for aerator B, 38% for aerator C and 23% for aerator D. Nevertheless, was observed a distinct difference in the user behaviour from the base situation to the tested aerators situations, noticeable from the comparison between Figure 4 with Figure 5.

Table 1. Relation between discharge and consumption reduction

Aerator	Discharge reduction	Consumption reduction	Rel. diff. discharge and consumption reduction
A	30%	15%	51%
B	42%	17%	60%
C	49%	27%	44%
D	70%	49%	30%

There is a statistically significant difference on the number of tap pushes between aerators and base situation as determined by one-way ANOVA for both male users (F(4,466)=22.645, p=0,000) and female users (F(4,244)=6.566, p=0,000). Levene's test indicated unequal variances only for male (F(4,466)=6.295, p=0,000), but both the Welch (F(4,58.1)=12.661, p=0,000) and the Brown-Forsythe (F(4,106.8)=12.737, p=0,000) tests confirm that there is a statistically significant difference on the number of tap pushes. For female users, the Tukey HSD post-hoc test revealed that the number of tap pushes was statistically significant different only with aerators B (1.74 ± 0.65 tap pushes, p=0.043), C (1.75 ± 0.64 tap pushes, p=0.028) and D (1.92 ± 0.86 tap pushes, p=0.007) compared to the base situation (1.31 ± 0.62 tap pushes). For male users, the Games-Howell post-hoc test revealed that the number of tap pushes was statistically significant different only with aerators B (2.03 ± 0.96 tap pushes, p=0.001), C (1.84 ± 0.92 tap pushes, p=0.009) and D (1.91 ± 0.68 tap pushes, p=0.002) compared to the base situation (1.25 ± 0.51 tap pushes).

The Shapiro-Wilk or Kolmogorov-Smirnov tests indicate that the number of tap pushes by female users also violates the assumption of normality in the base situation (K-S=0.444, p=0.000) and all aerators (A: S-W=0.613, p=0.000; B: S-W=0.784, p=0.001; C: S-W=0.780, p=0.000; D: S-W=0.808, p=0.000). The same occurs for male users (base situation: K-S=0.467, p=0.000; aerator A: S-W=0.718, p=0.000; aerator B: S-W=0.826, p=0.000; C: S-W=0.748, p=0.000; D: S-W=0.719, p=0.000). Since the number of cases in each group is only less than 15 (minimum 13 for females using aerator D), the results of the ANOVA are still valid. Nevertheless, the Kruskal-Wallis test also indicates a statistically significant difference on the number of tap pushes for both female ($\chi^2(4)=32.854$, $p=0.000$) and male users ($\chi^2(4)=75.999$, $p=0.000$).

It was observed that male and female reacted differently to the discharge reduction. Male users adjusted their behaviour in terms of the number of times the tap is operated in each use to compensate the reduction in water discharge introduced by the aerators. In practice, this behaviour change resulted that the volume of water per use was reduced by only about 10% in the interval of discharges between 3.9 and 6.7 l/min, effectively reducing the volume of water per use for the aerators with lower discharges. The reduction in water consumption was 22% and 48% for the aerators with discharges of 3.4 and 2.0 l/min, respectively. Female user behaviour on the other hand was less affected by the discharge reduction in the tested interval (2.0 to 6.7 l/min). As a result, the water consumption reduction was closer to the water discharge reduction, being higher with female users - between 19 and 50% (Figure 6).

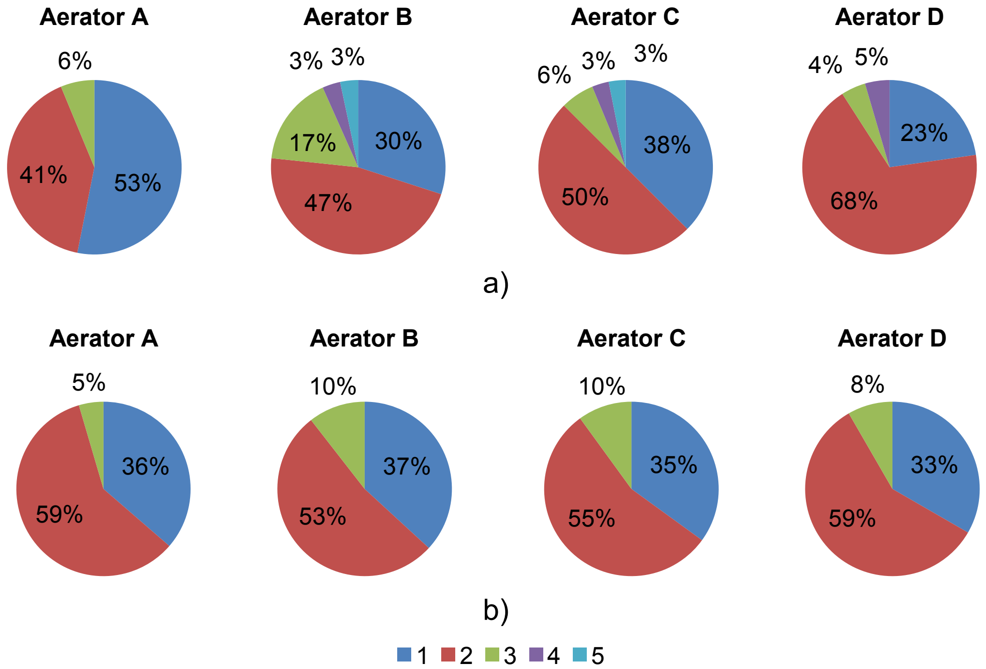

Fig. 4. Number of tap pushes per use for a) male and b) female users

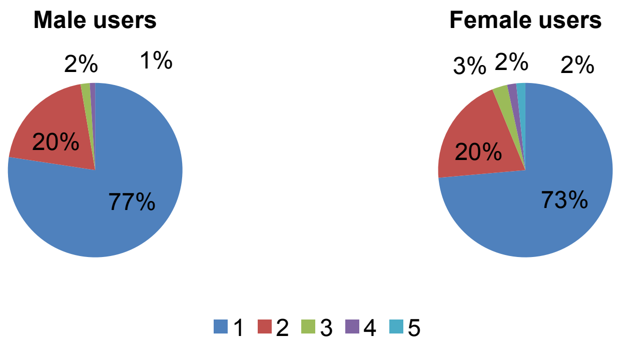

Fig. 5. Number of tap pushes per use for the base situation according to gender

For the base situation and for each aerator separately there was no statistically significant difference on number of tap pushes by female and male users both using ANOVA and Mann-Whitney U tests. However, comparing the relative differences between the proportions of uses by number of tap pushes per gender for all scenarios it can be concluded that there were cases with statistically significant differences. The t-test was statistically significant from the base situation to aerator B ($t(4)=5.37$, $p=0.006$) and C ($t(4)=4.05$, $p=0.015$) and from aerator A to aerator C ($t(4)=2.99$, $p=0.040$). All other cases were not statistically significant, but the maximum p-value was only 0.14. Adopting a less stringent significance level (e.g., 0.1 or 0.15) would yield that most or all cases could be regarded as statistically distinct. Additionally, the taps do not have the same discharge or shut off time, resulting in different consumption per use. There were statistically significant differences in the consumption per use by gender as determined by the Mann-Whitney U test for the base situation (U=34 446.00, $p=0.038$) and aerator B ($U=434.00$, $p=0.002$), C ($U=452.00$, $p=0.012$) and D ($U=210.00$, $p=0.022$), but not for aerator A ($p=0.076$).

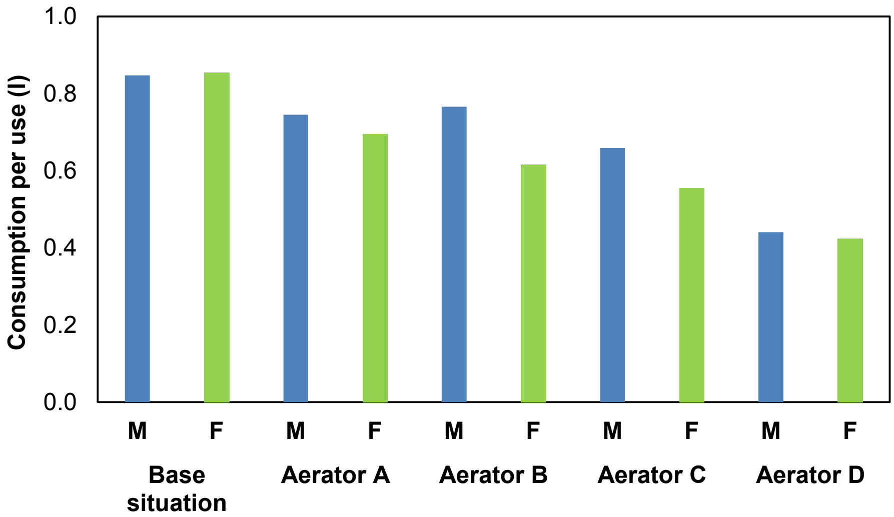

Fig. 6. Comparison of the consumed volume of water per use for the base situation and tested aerators, per gender (M for male users and F for female users)

The female users have a fairly linear relation between water consumption reduction and discharge reduction, whereas male users do not respond linearly to this relation and are more distant from direct proportion between consumption and discharge reduction (Figure 7).

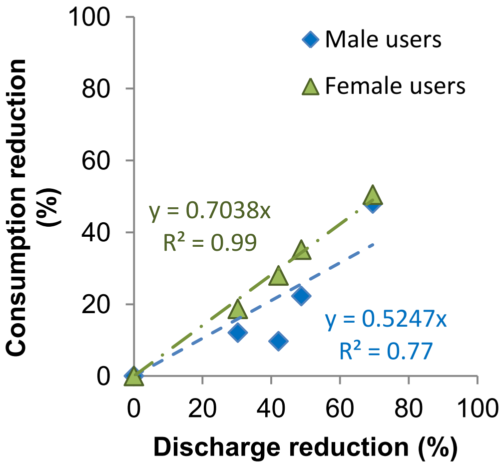

Fig. 7. Comparison between discharge reduction and consumption reduction by gender

It is also interesting to notice that, although female users consumed less water per use with any of the tested aerators, their consumption for the base situation was fairly equal to the consumption of male users. It should be noticed that, despite the difference observable in the discharge pattern between the base situation and the aerators (also between aerators but less noticeable), the installation of the aerators was not publicized neither any information regarding their performance provided. Therefore, the probability of behaviour change due to the fact of being under study is expected to be reduced.

4.2. User preferences

The users were requested to classify the use of the aerators in terms of preference in a scale from 1 to 5 (1 - *very dissatisfied*; 2 - *not satisfied*; 3 - *somewhat satisfied*; 4 - *satisfied*; 5 - *very satisfied*) in the direct questionnaires, which were carried out coincidently with the installation of the aerators to report on the first preference results. None of the users classified any of the aerators as *very dissatisfying* (classification 1) and only with aerators C and D some users (less than 10%) considered their use *not satisfying* (classification 2). On the contrary, more than 45% of the users considered to be *very satisfied* about the use of any of the aerators.

In addition, the online questionnaires were intended to reflect user preferences after a usage period of at least one week. In the online questionnaires it was also requested the professional position (undergraduate student, graduate student, researcher, professor or staff). Again, since there was no control over the users replying to each online questionnaire, was performed the Chi-Squared test to compare the sample of users in each. There were no statistically significant differences in terms of age ($\chi^2(10)=6.603$, $p=0.762$), professional position ($\chi^2(8)=5.270$, $p=0.728$) and gender ($\chi^2(2)=0.689$, $p=0.709$) between the samples of users replying to each online questionnaire.

The respondents perception of discharge change and preference results were found to be statistically significant between the base situation and with aerators (perception: $\chi^2(2)=18.138$, $p=0.000$; preference: $\chi^2(8)=15.852$, $p=0.045$). Between aerators, the respondents had a statistically weak perception of discharge change ($\chi^2(1)=3.217$, $p=0.073$) and there was no statistically significant difference on the preference results ($\chi^2(4)=0.601$, $p=0.963$).

Not more than 15% of the online questionnaires respondents considered to be *very satisfied* about the use of aerators C and D (Figure 8), as opposed to the 46 and 45% of the users in the direct questionnaire. A possible explanation may be from the fact that for the direct questionnaires the aerators were installed by decreasing discharge, with the users having time to progressively adapt to smaller discharges, while in the online questionnaires the aerators were installed by increasing discharge, and the users were faced with the lowest discharge immediately. Even though, in the online questionnaires only about 12% of the users classified negatively aerators C and D, against about 70% considering these aerators satisfying or very satisfying. In addition, no more than 20% considered the base situation very satisfying and 5% classified it negatively, even without reports of water splashing occurrences.

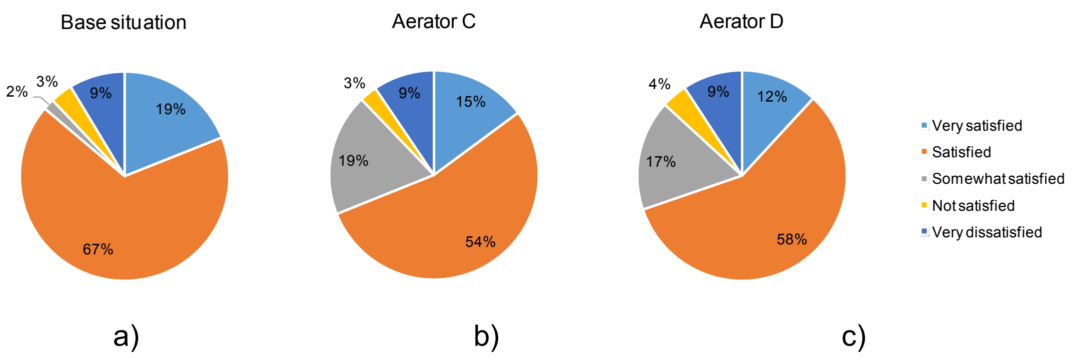

Fig. 8. Users preferences: a) base situation; b) aerator C; c) aerator D

In the base situation the perception of preference between male and female users was not statistically different ($\chi^2(4)=2.436$, $p=0.656$), but it became with the aerators ($\chi^2(4)=9.236$, $p=0.050$). On average, 26% of male users considered the use of aerators C and D not satisfying, against 12% of female users (Figure 9). In addition, aerators C and D obtained roughly the same percentage of positive responses, by gender, although the distribution between "satisfying" and "very satisfying" was very different. In fact, although 82% of female users and 63% of male users classified each of the aerators C and D positively, male users gave better classification to aerator D, while female users' classified aerator C better.

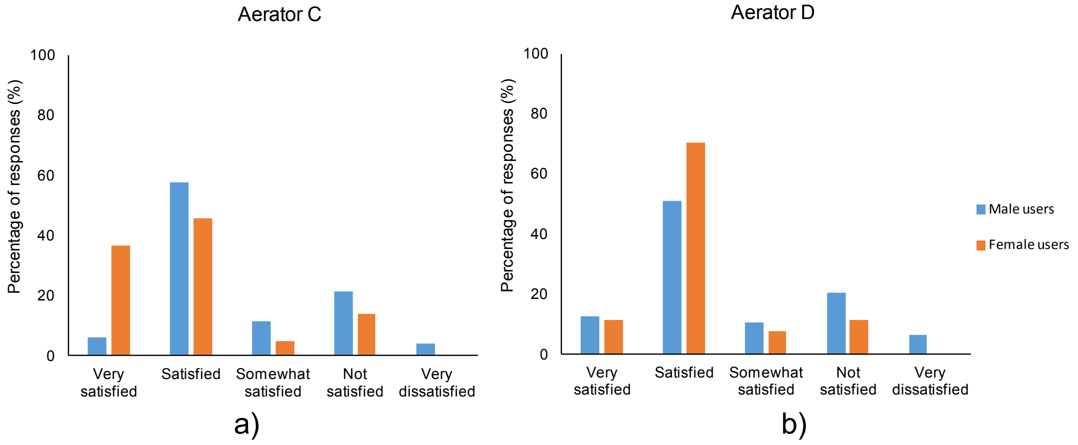

Fig. 9. Users level of satisfaction per gender: a) aerator C; b) aerator D

Inquiring users which aerator would serve them better, around 50% preferred aerator D to aerator C, against 28% choosing aerator C as first choice (Figure 10). These numbers are notable, not only because aerator D provides a smaller discharge than aerator C, showing that the type of flow is very important for the user preference, but also because the discharge of aerator D is under the limit of 3-4 l/min recommended by ANQIP for washbasin taps, in general, to be attained a minimum level of satisfaction.

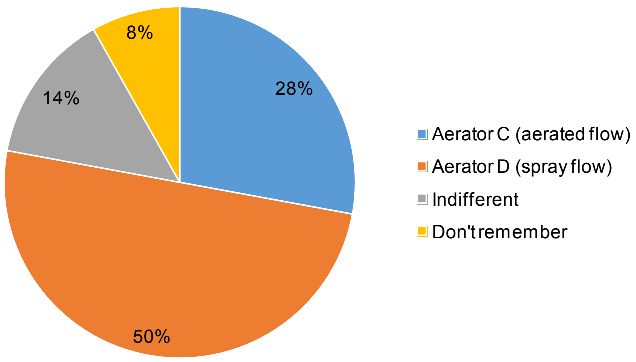

Fig. 10. Users choice based on their preferences

The Chi-Square test of the preference with the age and professional position of the respondents also resulted in a $p<0.1$, but a significant number of the classes of this variables had less than 5 replies, hindering any conclusion.

4.3. Attitude to saving water

A question on attitude to saving water was performed in the first two online questionnaires, confronting users with the information that aerator D (or C, for questionnaire 2) would contribute to a discharge reduction of approximately 70% (or 50%, for questionnaire 2) (Figure 11). 25% of the respondents agreed with the use of the aerator D, even if they considered it to be not satisfying, against only 8% of the respondents disagreeing completely with its installation. The remaining 67% agreed with the use of the aerator since they did not feel dissatisfied about the use of this appliance. Similar conclusions were attained for aerator C. This finding is in agreement with the study by Adeyeye and Piroozfar [17] where was found a positive perception in most of the studied people towards saving water and a relatively high awareness.

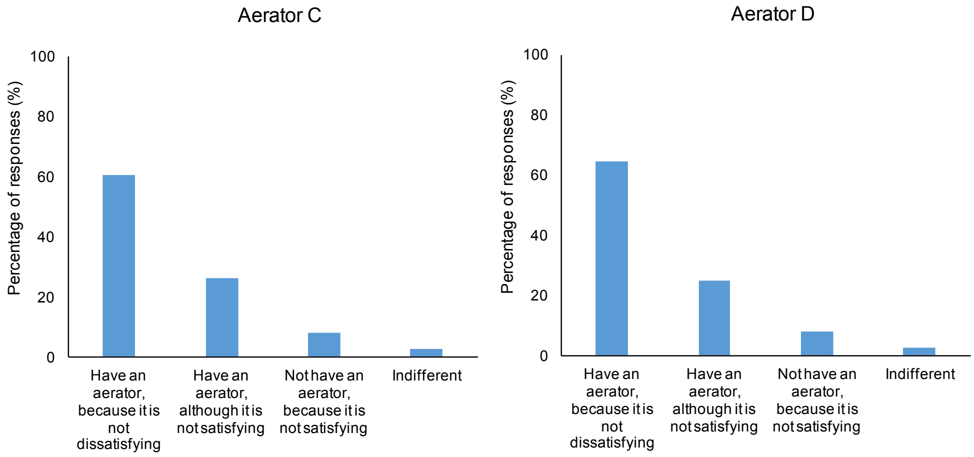

Fig. 11. Attitude to saving water: a) aerator C; b) aerator D

5. CONCLUSION

The present study shows that there are user behaviour changes and preferences due to washbasin taps retrofit that affect water consumption in practice. As a consequence, the water consumption reduction potential due to the water discharge reduction of the tested aerators was never fully used because the use pattern changed to compensate for the lower discharge.

It was also found that the behaviour change and preferences are different with gender and time. Female users were found to be less sensitive than male users to the water discharge reduction between aerators, leading to a higher water consumption reduction. Male users, on the other hand, adjusted their behaviour to compensate for the lower discharge, resulting in a marginal water consumption reduction for aerators A and B. In addition, the users have distinct preferences when confronted with the water efficiency measures for the first time and in the short term (one to two weeks).

The results demonstrate that the assessment of the performance of water efficiency measures is highly dependent on the user reaction. Using discharge reduction to estimate water consumption reduction may induce high error, at least on the short term. Future research should evaluate how the behaviour and preferences evolve with time with the adjustment of the users to a new water discharge pattern.

Lastly, an existing positive attitude on the action to save water was observed among users in general.

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Adolescents and showering – in their own words

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ABSTRACT

Two billion litres of water are used in the UK's showers every day and heating hot water at home results in 6% of the UK's CO_2 emissions. There is a concerted UK campaign to reduce shower times to four minutes. Anecdotally adolescents have longer showers than the UK average of 7.5 minutes. Data was collected from 356 adolescents to find out how often they showered, for how long, and what would persuade them to shower for less time. 21% of adolescents shower more than once a day, and the average shower frequency is 7.5 times a week compared to 4.4 for all UK users. 62% of adolescents shower for longer than ten minutes compared to 32% of the UK as a whole, and 30% shower for more than 20 minutes compared to 3%. Just 3% of adolescents currently meet the four minute shower challenge. 35% of adolescents say they could meet it, but 58% say they would not be able to reduce their shower down to four minutes whilst 13% of adolescents say that nothing would persuade them to shower for any less time than they currently do. The top drivers that adolescents say would get them to spend less time in the shower are: the environmental impacts, rewards, other household members (usually parents), and technology that turns the shower off after a specified time and does not allow it to be turned back on.

Keywords: Showers. Adolescents. Four minute shower challenge.

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A Holistic Dissemination Strategy to Deliver Water Conservation Messages through Gamification and Social Networks

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ABSTRACT

In the last few years, new ways of engaging people have been proposed, on the matter of water conservation: gamification, water pricing and social networks are examples of the new approaches used to alter the users' perception on water use. The WaterSocial platform is an advanced social media platform developed in the context of the ISS-EWATUS EU project. It applies gamification and it is specifically designed for promoting a more efficient water use.

Similarly to other social networks, increasing the user participation on WaterSocial will be a key determinant of its success and sustainability. One of the fundamental challenges for the platform is to deliver the message to a wider population with a low dropout rate: for this, a holistic, three-tiered strategy was designed to increase the number of social media network users and maximise the message relevance to these users.

In order to reinforce water efficiency, the focus was on three types of activities: Social media activities, Publications and Offline campaigns. Their monitoring and triangulation help in evaluating whether a measurable user uptake has been observed and the types of messages used and the degree of relevance to users.

This overall, "holistic" method of dissemination proved to increase user uptake and contribution to the social network. Among all dissemination activities defined in the dissemination strategy, it was found that Twitter can be a particularly effective method to reach a wide audience and kick-start the user uptake on WaterSocial. At the same time, the gamification elements are effective in encouraging user generated content.

Keywords: Water saving, social media, gamification, user uptake, online referral.

1. INTRODUCTION

The ICT4Water initiative (ict4water.eu) is a European initiative that, in 2015, published the "ICT for Water Management roadmap", detailing the key objectives around water usage and conservation, and focusing on water providers, customers and policy makers. Several challenges and gaps were identified for the future of the ICT (i.e., Information and Communications Technologies) and water management. One of the key aspects, joining the computer science, economics and engineering domains, is how to raise the end-user awareness (single consumers, households, schools and municipalities) by leveraging network effects (e.g., through social media) or using water pricing as an incentive to manage perceptions. The roadmap reported that "*Consumer awareness has been low so far, with the general population at large still considering water as a perishable resource*[1]."

Among the possible solutions and implementations proposed to raise water-related awareness, a focus should be on the activities that gradually shift the overall perception of water as a scarce resource. Social networks, gamification and adaptable pricing systems (to project potential savings) are all aspects that were deemed as necessary in order to manage

[1] European Commission, ICT For Water Management Roadmap, *Emerging topics and technology roadmap for Information and Communication Technologies for Water Management* (2015): 7

perceptions and induce behavioural changes. A "social network" is an online community in which people with common interests, goals, or practices interact to share information and knowledge, and engage in social interactions [2]. On the other hand, "gamification" is a recent development trend of persuasive technologies that present the systems to users in a game like manner. Gamification is generally defined as the use of game design elements in non-game contexts [3]. With growing popularity of gamification systems in markets and research fields, gamification is argued to be next generation method for marketing and customer engagement [4] and has been proposed as a design pattern for persuasive systems [5].

The WaterSocial platform (www.watersocial.org) is a social network with gamification elements for various user tasks, which aims to encourage user feedback and to support water use behavioural changes. In order to achieve these, the platform needs to deliver the message to a wide population and sustain user participation.
The critical challenge for WaterSocial (and for any other social network) is to engage a large number of users, enabling new content to be generated, which will encourage regular users and result in higher influence on individual water use. It has been reported that most contribution to online social production communities is by a few contributors [6]. The majority of participants are information consumers (around 90% of the community), who never contribute. A few members (around 9% of the community) contribute sporadically: this group may be learning about the community [3,7,8], and transition into contribution and organization-related activities as they gain more experience [9]. The remainder of the community (around 1%) are actively updating their contributions. This subset of members is fundamental to any community, since they enable content to be generated, which will attract regular users.

A preliminary literature review on the subject of increasing user participation [10,11,12,13,14,15] reveals that a range of perspectives are indeed present, but that they lack a broad consensus on how to achieve and increase participation [16]. The majority of the approaches are based on one or a few methods, but a wider, holistic approach, mixing online and offline campaigns, is still not widely deployed. For this reason, there is a clear opportunity to evaluate the issue of increasing user participation by evaluating the different activities.

To tackle this challenge, this paper describes some preliminary results of the dissemination activities as currently undertaken in the context of the ISS-EWATUS European project (part of the ICT4Water cluster of sister projects). The dissemination activities of the WaterSocial platform are aimed at increasing user participation on the platform; they are targeted at two main audience groups, the water-aware stakeholders, and the general public. An overall strategy was defined for the dissemination activities; next, a set of activities for the engagement, retention and increase of user participation; and finally, a set of metrics to determine whether the activities were on the right track.

Following the same dissemination strategy, the structure of this paper is based on three parts:

1. the strategy of the dissemination activities, and considered as the *input* to our approach to increase users participation (Section 2);
2. the main *engine* of the dissemination and its gamified features (Section 2.2.4);
3. the results of the activities, as the *output* of the dissemination activities (Section 3).

Section 4 concludes the report.

2. METHOD AND DISSEMINATION STRATEGY

As a dissemination strategy, and in order to effectively attract and sustain new users to a social network, it was reported that content needs to be generated regularly to sustain engagement [17]. In addition, in the case of the WaterSocial platform, there needs to be enough active members to facilitate the gamification layer and reinforce the competitive element [18]. Finally, participation can take multiple forms and degrees, connected to human intention and behaviour: therefore, user participation will necessarily be a multifaceted and complex phenomenon, which can be studied from multiple disciplinary and methodological perspectives [16].

2.1 Strategy Overview

This paper will outline the method of each input activity, as shown in Figure1. Each activity will be evaluated in Section 3 using the website analytical data and a set of metrics. This process is illustrated in Figure2. These activities are currently being carried out, and this paper reports on those happening between Monday 15th February 2016 and Sunday 24th April 2016.

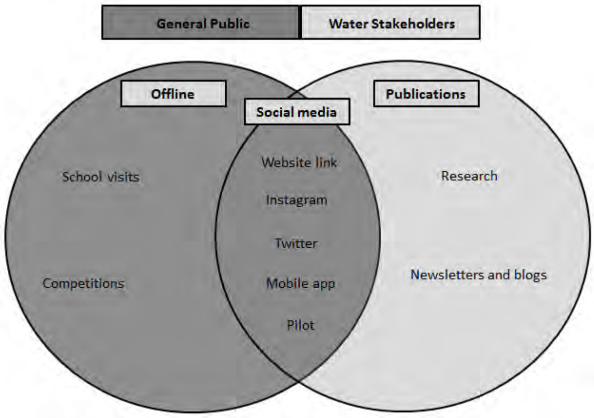

Fig. 1: Evaluation of Dissemination Strategies

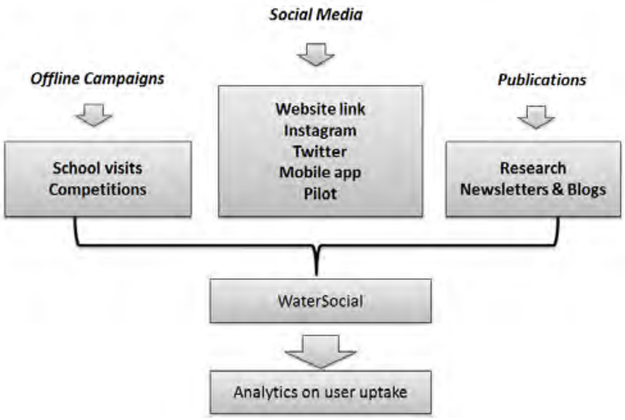

Fig. 2. Dissemination strategy for the WaterSocial platform

2.2 Target Users & Activities

Figure1 shows a Venn diagram of the types of activities, which are aimed at two different sets of users: the **Water Stakeholders** and the **General Public**. The reason to attract Water Stakeholders was because this group is already interested in water conservation and could generate water saving content on the WaterSocial platform. Activities also endeavoured to engage the general public: this group poses the hardest challenge to engage, although they could create more impact if they use WaterSocial, and learn to reduce their water wastage.

1. **Offline campaigns**: this type of activity targets mostly the general public; defined, in general, as any activity or event that showcases the WaterSocial platform outside the online world. This method introduces the gamification layer to the audience, as users are encouraged to earn points by uploading a photo or a water saving tip to the platform.

2. **Social media**: this type of activity targets end users, conversant in IT and social media platforms. Both Twitter and Instagram were chosen as user their demographics reflected the target audience. WaterSocial's main activities, photo and knowledge sharing, were conveyed via these external platforms.

3. **Publications**: this type of activity targets academic audiences and water stakeholders, by issuing newsletters and blogs, as well as journal papers, which detail the platform's results.

2.2.1 Offline Campaigns

Offline campaigns were selected as a method to connect groups of people who may not otherwise discover WaterSocial organically online.

- **School visits**: were chosen as Government policy encourages water efficiency to be taught to pupils [19]. Holy Trinity COE Primay School was chosen as it is located in London, which is under water stress, and due to the size and the diversity of the pupils. A whole school assembly and water workshops were carried out on March 14th 2016. Dissemination was also targeted at older students at Silesia University (Poland), situated is one of the nations with the least available water per capita [20].

- ***Competitions:*** Competitions were chosen to enhance the competition component of the gamification layer. Prizes were selected to offer an incentive to participate in producing content on the WaterSocial platform.

2.2.2 Social media

Social media was selected to increase online awareness of WaterSocial, as the majority of the online adult population use social platforms. It also provided a method to produce timely and relevant information, which can be quickly and easily shared to a vast audience.

- ***Website link:*** A reciprocal web link was placed between the Rain Catcher Ltd website and the WaterSocial platform. This harnesses the online users from the Rain Catcher Ltd website, and directs them to similar, relevant content on WaterSocial.
- ***Instagram:*** Instagram is a photo sharing system and considered popular on the Internet [22]. It has 400 million active users in 2016 [23], and photo sharing reflects one of the main activities on WaterSocial. 55% of online adults ages 18 to 29 and 28% of online adults aged 30 to 29 use Instagram [24]. Water photographs and images of water saving tips were shared on the WaterSocial Instagram account. Almost all posts include a web link and hashtags #WaterSocial, #watertip, #waterphoto, #savewater.
- ***Twitter:*** Twitter is a social network that allows users to share tweets, which are text-based posts of up to 140 characters. Twitter has 320 million active users [23], some 38% of those on Twitter use the site daily [24]. All content uploaded on the WaterSocial platform would produce an automatically generated tweet with a link to the WaterSocial webpage. Manual tweets were also generated and included a web link and relevant hashtags, as echoed in Instagram.
- ***Mobile App:*** The WaterSocial mobile app was created to enable users to participate via their mobile device in the three main gamified tasks: photo sharing, water saving tips, and the Water Diary. Other functions that were included in the mobile app are the leaderboard, to reinforce the competition element of the platform, and location based missions, which direct users to discover water bodies in nearby locations.
- ***The Pilot:*** A pilot study was conducted on the WaterSocial platform for three weeks from 15th February to 6th March 2016. The study involved 40 participants from the UK, Greece, and Poland; 16 male and 24 female participants, aged between 18 to 64 years of age. The objective was to recruit users to generate content and test the gamification impacts on users. During the pilot, weekly emails invited participants to take part in online missions.

2.2.3 Publications

Newsletters and blogs offer an inexpensive and relatively easy way for organisations to gain visibility [25]. They provide dynamic platforms, which allow users to browse and share information, and interact with others on websites. All organisations were chosen for their wide and diverse online audiences; from the general public, to industry and Government bodies.

- ***Newsletters:*** News bulletins were shared via email with members in the consortium three times a week. These emails would highlight the weekly activity on the platform and introduce game elements, such as a weekly quiz. A segment on was included in ech$_2$o's Summer Newsletter. The platform was also publicized in the March and June edition of the Waterwise newsletter. Waterwise is the leading authority in the UK for water efficiency [26].
- **Blogs**: Blog posts enable a detailed story to be expressed, which can attract readers to visit a website for more information [27]. Organisations have learned to embrace blogs to promote new products and information [28]. WaterSocial featured as a guest blogger on The Blueprint for Water website. This organisation is a coalition of 16 influential environmental, water and fisheries organisations in the UK.
- ***Research:*** The method is to summarise ideas or solutions and circulate them to scientific conferences or workshops. This activity aims to attract expertise from different disciplines so that proposed solutions can be discussed and new solutions generated.

2.2.4. The WaterSocial Platform

WaterSocial is unique in its vision to harness gamification and social media to reinforce water saving behaviours [29]. It incorporates a set of gamification designs into online activities in which the users are able to get rewarded upon each accomplishment of a task or even are able to compete with each other through the WaterSocial monthly leaderboard. Each of the gamified tasks are tailored to a set of water saving related social media activities. The tasks are supported by potential system users in Greece, Poland and UK [30] while also supporting instrumental roles according to the water conservation management theory [31]. Some of the tasks reported in this paper include sharing water saving tips and photos on a global map and also recording daily water use in an online water diary.

WaterSocial plays a pivotal role in the designed dissemination strategy from both implementation and strategic aspect. During implementation of the strategy, WaterSocial can be the final destination of all target users, i.e. they will be directed to the platform from different sources via different activities designed in [Figure 2] as WaterSocial is the original place where all activity related information will be published or gathered. It is also the source of analytical information on amount of user visits and content generated, which is used to assess the effectiveness of the implemented strategy. From a strategic perspective, promoting WaterSocial to a wider population is the ultimate goal. However, it has proven to be difficult to promote a niche topic social media platform to the mass population. The proposed dissemination strategy puts WaterSocial at the end of the dissemination chain and uses a gamification approach to welcome different users via different sources.

According to the gamification definition [3], the current design introduces the gaming elements such as tasks, rewards and competition and applies them to the water saving online user tasks. Table 1 lists the gamified user tasks in WaterSocial with the gamification reward types and rewards content. The current implementation uses a point based system which allows users to earn points such as in tasks #1-3, and to redeem rewards/ titles or to compete with other users via leaderboard such as in task #4.

Table 1: Gamified User Tasks in Watersocial with the Gamification Rewards Types

WaterSocial Gamified User Tasks	Gamification Rewards Types	Rewards Value/Content
#1 Sharing water use photos on a world map	Points	90
#2 Sharing water use tips on a world map	Points	30
#3 Individual water diary recording water use such as shower duration and duration of dish washing by hand	Points	30
#4 Earn rewards on user tasks and compete with friends	Leaderboard	monthly competition
	Virtual title	“Drop” =100 points “Cup” = 300 points “Bottle” = 600 points “Bucket” = 900 points “Ponds” = 1200 points “Lake” = 1500 points
	Physical Rewards	Water saving shower heads Trigger hose nozzle Cistern displacement device

3.RESULTS

The analytical metrics for evaluating the success of the dissemination activities are

- The outreach of the activity, i.e. how many users are exposed to water-awareness message.

- The user referral from the message, i.e. how many users are visiting the WaterSocial after being exposed to the water-awareness message.
- The user content generated on the platform, i.e. information created or shared by users on WaterSocial.

Online reach in the application of media analysis refers to the total number of different people or households exposed, at least once, to a medium during a given period. User referral is the reported visits to a site from sources except when typing a web page directly. When someone clicks on a hyperlink to go to a new page on a different website, Analytics tracks the click as a referral visit to the second site.

3.1 Offline Campaigns

- **School visits**: As a result of 360 pupils being introduced to the WaterSocial platform a group of 26 students took over 100 water related photos to share with the school visit. Silesia University: on April 6th 2016, around 50 students were invited to browse the platform. This resulted in six water saving tips and five photos being uploaded.
- **Competitions**: A competition was run as part of the pilot users, and a prize offered to participants based in the UK. This proved an effective method to encourage User Content as UK users generated the majority of the content during the pilot study.

3.2 Social Media

- **Web link:** The link was added on 24th February 2016. It was estimated, using Analytics, that 5 new users accessed the WaterSocial platform via the Rain Catcher Ltd website. These users visited an average of 4 web pages.
- **Instagram**: The number of user sessions on the WaterSocial platform as a result of Instagram cannot be measured. The level of engagement of the WaterSocial Instagram account can be gauged using an online analytical tool. The average weekly growth rate of Instagram followers from February 15th to April 24th was 8%. This was an average of 6 new followers a week. The average engagement per Instagram post was 7%. Profile engagement was calculated as the sum of all likes and comments divided by the number of followers.
- **Twitter**: Awareness and engagement of WaterSocial on Twitter grew by an accumulative rate of 21% over a 10-week period. On average the WaterSocial Twitter profile gained around 8 new followers a day, 56 a week. During this 70 day period, WaterSocial earned over 4.5 thousand impressions a week. Tweet impressions are the number of times a tweet has been delivered to Twitter streams. The Twitter engagement rate takes into account Replies, Retweets and Likes of each tweet to the total number of followers to date. The average rate of engagement for the WaterSocial account was 1.4%.

Over the course of 10 weeks close to 400 user sessions were referred from Twitter (figure 3). Users spent an average of 8 minutes browsing the platform. The effectiveness of Twitter to generate user sessions steadily increased at the accumulative rate of 31% over 10 weeks. In addition, WaterSocial demographics (figure 4) now reflect that of Twitter's [22].

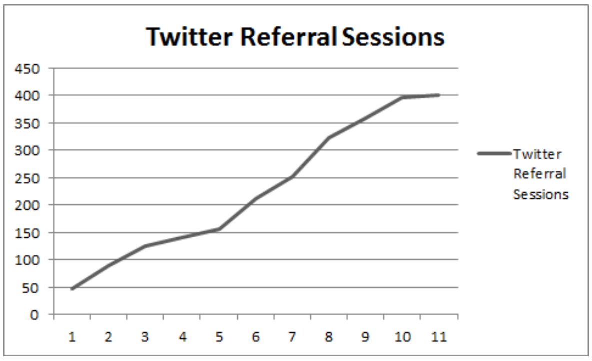

Fig. 3: Accumulative network referral sessions from Twitter

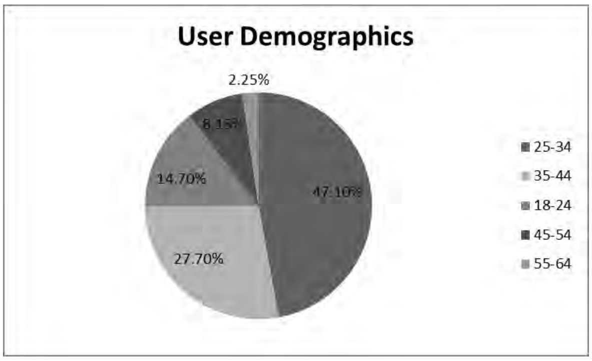

Fig. 4: WaterSocial User Demographics

The week with the highest Twitter engagement was during a UK initiative called Water Saving Week, Monday 20th to Friday 25th of March. The week generated a high amount of activity centred on water efficiency. As a result, the WaterSocial tweet engagement was higher than average. WaterSocial will continue to link to water campaigns using the relevant hashtags.

- **Mobile App**: The mobile app was made available on the Google Playstore and can now be freely downloaded[2]. Daily notifications are received by mobile users asking them to engage in the chosen weekly task. During the period from 15th February to 24th April, 19 photos were uploaded by seven mobile users.
- **The Pilot**: Of 40 registered participants 23 were active on the platform. Feedback obtained from a survey showed that the sizeable majority of users enjoyed the gamification element of the social media platform and would recommend WaterSocial to friends. During the pilot, users actively provided a total of 80 photographs and water saving tips and a total of 361 user inputs into the online Water Diary.

3.3 Publications

- **Newsletters and blogs**: At least 300 news bulletins were distributed to the ICT4Water consortium. The reach of the Waterwise newsletter was 1,667 recipients. As a result of the Blueprint for Water blog it is estimated that 5 users were referred to the platform.
- **Research**: There are different scientific reports about the work circulated in various research communities. They include gamification design community [30], software engineering community [32]. They also include contributions from ISS-EWATUS project consortium which further allows us to reach other communities such as sensors and application [33] and even psychology study community [34]. The results from these research activities give more insights on how to improve the current implementation of the strategy.

3.4 The WaterSocial Platform

This section reports the analytical results from 15th February to April 24th 2016. The set of metric used are: (i) User Uptakes, (ii) User Content generation and (iii) New Users. User Uptakes is the number of time the WaterSocial platform has been visited and by how many users. User Content refers to each time a member has engaged with a gamified task on the platform: uploaded a photo, shared a tip or enter their water use into the Water Diary. New users is the number of new registered members on the platform.

3.4.1 User Uptakes

In this time period all activities collectively resulted in 483 users accessing the platform, which had an average of around 5 pages per session. There were 1,244 user sessions, resulting to a total of 6,173 pages viewed. The average time spent browsing the WaterSocial platform was just under 7.5 minutes. Of all the WaterSocial platform activity, 34% were new user sessions.

[2] https://play.google.com/store/apps/details?id=com.ega

Figure 5 shows the percentage of referral sessions from each channel, excluding sessions that were generated by direct searches for WaterSocial. 'Other' includes links on the RainCatcher Ltd website, the Blueprint for Water blog page, and the link from the ISSE-WATUS project website. 'Organic search', in this circumstance, is when WaterSocial has been searched for using a search engine or when a direct weblink has been entered. Twitter activity alone referred 401 of the total referrals during this period. Referral from Twitter were 46% of user sessions, when excluding sessions accessed by entering the WaterSocial url.

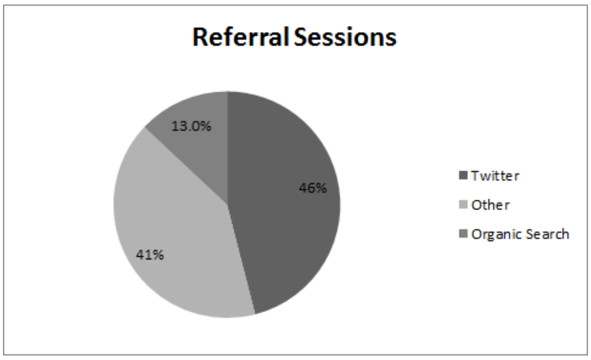

Fig. 5: Channel Referral Sessions

It has been noted that tweets that resulted in higher than average levels of engagement were posts using photos or images. Tweets that included an image that contained information on saving water were more likely to be retweeted, thereby increasing audience of WaterSocial.

When observing the fluctuation of user sessions, it is evident that there is a strong influence of Twitter user sessions on the overall sessions of the WaterSocial platform (figure 6). Therefore, Twitter could be considered as a successful and efficient method to generate engagement.

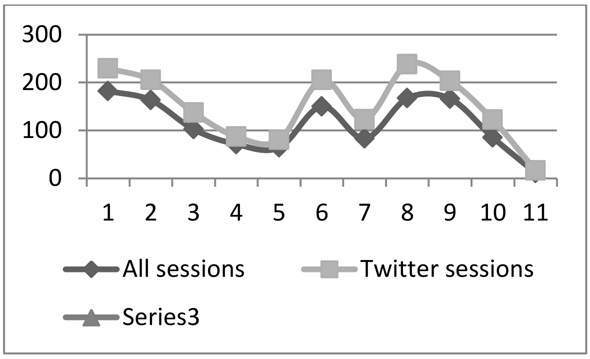

Fig. 6: Twitter referral and all user sessions per week

3.4.2 User Content Generated

Between February 15th and March 6th 2016 there was a 65% increase in new registered members. This resulted in users generating new content. A total of 24 users uploaded 76 photos, 38 water saving tips were shared by 15 members, and 34 users entered water use data a total of 375 times into the Water Diary (Table 2). Of all the WaterSocial members 16% uploaded photos, 15% shared a water saving tip, and 37% used the Water Diary. According to previous research into user participation, this is higher than average for content generation.

Table 2: User engagement and participation

Engagement	Amount	Participation	Amount
Measured referrals from inputs	401	Photos	76
Overall user sessions on WaterSocial	483	Tips	38
Overall engagement (New registered member increase)	65%	Water diary	375
		Overall content	489

4. CONCLUSION

It is important to engage more people in new ways on the matter of water conservation. For this reason the gamified social media platform, WaterSocial was created. To encourage a shift of perception to conserve water, through use of the gamified platform, it was identified that there needs to be sustained engagement and user content. To evaluate the method of dissemination two aspects of the WaterSocial platform were considered. 1. User engagement, measured by user sessions and referrals. 2. User generated content, measured by number of photos, tips and Water Diary entries.

The “holistic” strategy to disseminate the WaterSocial platform resulted in user engagement and an increased user uptake to the social network. In addition, the gamification layer proved effective in promoting user content on a social media platform. Among all dissemination activities defined in the dissemination strategy, Twitter was discovered to offer a valuable approach to launch engagement and direct users to the platform. It was the balance of all elements that allowed for visibility and awareness among both water stakeholders and the general public. The pilot study will be repeated with previous and new users. The aim will be to explore if gamification has an effect of changing the perception of water usage.

ACKNOWLEDGEMENTS

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Water Efficiency Conference 2016

Socio-cultural Drivers of Water Demand in Student Residential Accommodation

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ABSTRACT:

In 2012 UWE, Bristol entered into partnership with Bristol Water to initiate a longitudinal, multimethod study of water consumption by students in first year accommodations on the main UWE campus at Frenchay, Bristol. Now in the third cycle (each runs from September to June, following the academic year) of this study we are in a position to report on patterns of water consumption, underlying socio-economic drivers and the impacts (or not) of both "hard" (new fixtures such as low flow showerheads) and "soft" (conservation messaging) attempts at achieving greater water savings. So far, one of the "surprise" findings has been that behavioural adaptation to hard interventions can easily offset any initial water savings. We have also found that our growing dataset has considerable application in facilities management as well as water conservation programming.

Keywords:

1. INTRODUCTION

In late 2012 UWE, Bristol and Bristol Water Plc agreed to jointly support a long-term programme of research into water use at an on-campus student accommodation facility known as the "UWE Student Village". Total occupancy for the Village as at 01/02/2015 was 1878 students against a total capacity of 1932. In effect, the Student Village became a "laboratory" for studying the effects of different sorts of interventions on water consumption. Both UWE, Bristol and Bristol Water expected that this work could improve the information base for such measures elsewhere and help both institutions achieve business objectives (e.g. UWE's KPI around water demand and, indirectly, energy consumption and Bristol Water's company targets around demand management).

Scientifically the Student Village is very useful because it is well-understood both in terms of infrastructure and also demographics, and changes over 100% each summer. This means that, almost uniquely, it is possible run and re-run "experiments" in water efficiency through "hard" (e.g. new fittings) and "soft" (behaviour change) measures for water efficiency. It was also felt, especially after Bristol Water completed a site investigation in July 2012, that there were also changes to the overall site facilities (e.g. water tanks, pumps, etc.) that could realise additional water efficiencies and cost savings.

In this paper we focus on what has been learned to date about the patterns of water use within the Student Village and the relative impact of certain "hard" versus "soft" water conservation measures. We end with a brief discussion of planned activities for the 2016-2017 phase of the project.

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According to peer-reviewed and gray literature, water efficiency can be achieved essentially through either “hard” or “soft” measures. Hard water efficiency measures are devices and fixtures installation resulting in reduction of water uses. Soft water efficiency measures are behaviour-based methods, usually involving user education towards more sustainable use. These measures are important in influencing consumer behaviour and in ensuring the take-up and use of water efficiency devices and products. Soft measures are generally underpinned by theoretical assumptions about the links between attitudes and behaviours. Such assumptions fall into three broad classes:

- Those who view resource use choices as largely determined by the associated material incentive (price). Such models tend to depend heavily on the idea of “price elasticity of demand”, something for which there is only weak evidence in residential water systems
- Behavioural models which, whilst acknowledging the importance of price elasticity, also insist that non-materially focussed attitudes, perceptions and beliefs also play a part in constraining resource use choices.
- Practice based models which proceed from a rejection of the individual decision maker as the unit of analysis and instead focus attention on resource-using practices such as showering or car-washing or gardening practices.

A number of studies find the association between positive attitudes toward water conservation and actual water conservation behaviour to be weak (Bagozzi. 1979; Miller and Buys, 2008). This means some individuals may have positive attitudes in relation to water conservation but may not put them into practice. Nevertheless, most attention to “soft” measures has tended to focus on measuring attitudes and then attempting to change them. Our approach is broadly behavioural, but eschews crude message based didacticism in favour of more sophisticated ways of engaging study participants. These are currently under development for implementation in the 2016-2017 cycle and will be discussed briefly in the final section of this paper.

In recent decades, University and Educational institutions have become increasingly interested in measures, such as those noted in Table 2, to reduce water consumption and therefore, costs. In 2013, Yale University’s Office of Sustainability released a Sustainability Strategic Plan for 2013–2016. The university identified four technologies that could provide the best water efficiency:

- Sub-Metering: Yale relies on water meters capturing the total extent of campus water use. The university installed 23 additional building-level sub-meters in 2012 to obtain more detailed water-use data. The intent of this effort was to permit building-level water consumption benchmarking.
- High-efficiency plumbing fixtures: The university installed high-efficiency plumbing fixtures within all buildings. Installations generally included low-flow appliances and the sorts of measures noted in Table 2.
- Reclaimed water systems: System that retains non potable water to be used for non-potable demand. Yale has installed seven reclaimed water systems in six buildings since 2005, with various design and operational approaches and a range of performance outcomes.
- Water-Use Monitoring: Real-time monitoring of makeup and losses in campus enabled quick response in the case of leaks.

The Smith College has conducted a study on soft measures in 2011. The purpose of the study was to test the hypothesis that increased signage, shower timers, and educational events would change behavioural patterns and encourage students to reduce water consumption. The campus consists of seven houses, each with a water meter. Three houses were chosen for the study based on their capacity to meter daily water use. Two houses received educational materials while one did not, and the impacts on water consumption were measured and compared to data recorded before the educational programme. The results of the study provided support that educational materials and increased awareness of water could alter behavioural patterns and encourage students to conserve more water. In addition, students across campus were encouraged to participate in an online survey to measure water-use patterns. Findings from the online surveys also supported the proposed need for increased education and transparency.

2. METHODOLOGY

The UWE Student Village was opened and occupied for the first time in 2005. As Figure 1 shows, the Student Village is made up for four “Courts” (Brecon, Cotswold, Mendip and Quantock), each constituted of two seven or eight story “Blocks” arranged in facing pairs across “Courtyards”. Each Courtyard contains a few small communal buildings, including reception, post and laundry facilities, which are water metered separately and do not form part of this study.

Each building is made up of contiguous of physically and functionally separate Blocks. Each Block is comprised of seven or eight levels, with two flats on each level, either side of a small landing/common space. Flats typically have 6 rooms, though some flats may have only five where larger rooms have been designed to accommodate disabled students. Each room is provided with a single toilet/shower room, which includes a hand washer basin, a shower with a thermostatic control valve and a dual flush lavatory. The five or six occupants of a single flat share a dedicated communal kitchen/lounge area equipped with a wash basin, two hobs, two refrigerators and sofas and chairs.

Each Block is separately metered, with the supply meter located in the nearby externally accessed services room, implying a meter coverage of one meter per 66 to 84 students depending on the exact configuration of each Block. These meters report every 30 minutes directly into the university building management system (BMS) and reports are sent on to us monthly by the UWE Estates Department. We are therefore receiving data one month in arrears. Work is underway to have the meter readings report directly to a different system which would be automatically available to the study team, providing much nearer to real time data access (a key issue to support real-time alarms and other decision triggers).

In line with the aims of the project, it was decided to analyse water consumption using an experimental approach, by means of different degrees of intervention and the implementation of specific water efficiency measures in each of the Courts. Specifically, Mendip (400 rooms) has been selected as a representative Court, with no intervention (the “control”). For the other Courts, both "hard" and "soft" measures were implemented, as shown in Table 1. Simple tap inserts were installed in all hand basins in Brecon Courtyard (564 rooms). Tap inserts and low flow showerheads were installed in Cotswold Courtyard (500 rooms). In Quantock Courtyard (468 rooms) soft measures including shower timers and paper posters promoting water conservation were installed. Using the reported water consumption data we hoped to test the following commonly-held ideas:

- Hard measures such as flow restrictors and low flow showerheads should reduce water consumption by “forcing” users to use less water per activity (e.g. teeth brushing or showering)
- Additional soft measures, such as shower timers and passive messaging may further reduce water consumption, though the additionality may be transitory.

We were also able to explore the relationships, such as they may exist, between water consumption and certain demographic and lifestyle characteristics of the studied population, including:

- Is there a measurable difference between male and female water use?
- Are there differences in water use by national/regional origin?
- Does involvement in sporting activities increase water use?

Exploration of these questions has thus far involved use of anonymised occupancy data provided by UWE Accommodation Services but in future could involve direct surveys of the student-occupants themselves.

Each month, monthly per occupant consumption figures are examined to ensure that obvious discrepancies (e.g. leaks) can be quickly observed and discussed with the estates team. Boxplots are produced to visualise the distribution of the consumption values, usually reported as “per capita consumption” on a half-hourly or daily basis, by Block and Courtyard. Statistical comparison with available demographic data highlighted that some observed differences could be due, in part at least, to the quite different demographic make-up of the different blocks in the study. As students are not randomly allocated to rooms, but are often grouped together for their own comfort, this has made the analysis much more complex.

General linear models were then used to model the per occupant consumption based on occupancy figures in February 2015, including “day number” [number of days since October 1st]; the day of the week; whether the date was during the academic teaching block; the proportion of UK students; proportion of gym members; proportion of females and the proportion of African/Asian students as explanatory variables. Consumption was modelled for each courtyard separately, with the socio-demographic factors used to help explain the differences in consumption within each courtyard.

3. RESULTS & DISCUSSION

Figure 2 shows the median water consumption per capita per Courtyard across an average day during February 2015. Extreme outliers (see below) have not been removed from this calculation. The diurnal water consumption pattern revealed is similar to what one sees in other studies of residential water consumption. From a late evening/early morning low, water consumption quickly rises during the “waking up” period towards a peak before falling off again as occupants attend to their daily affairs. Because these students live on campus and because they often prefer to study in their flats, water use does not fall off as much as might be expected in more “normal” residential communities. There is a second early evening peak in water use which falls off after about 11 pm as occupants either retire for the evening or go out.

Intriguingly Figure 2 suggests that, visually at least, the control Courtyard did not actually consume less water than the test Courtyards, in fact Mendip seems to have recorded the lowest water use. This obviously runs counter to original expectation, and the finding caused us to very carefully explore and re-validate the meter data system and to re-engage with Student Accommodation Services regarding occupancy rates and the rules/procedures for allocating students to rooms and flats. Data systems were found to be valid and reliable and, as we discuss below, demographic variables do seem to make a measurable difference to water consumption, but there are other issues at work too.

First among these is intra-Courtyard variability. Figure 3 shows box and whisker plots for all the constituent Blocks within the four Courtyards. As is readily apparent, intra-Block variability is considerable, particularly within Cotswold and Quantock. By Block median consumption ranges from about 120 litres/day to well over 300, a phenomenal range given average domestic consumption across the UK ranges from 140-160 litres per person per day. Also, the *spread* of values around the medians (the thicker black lines within the boxplots) challenges our initial assumptions about homogeneity within Blocks and perhaps even Flats. Holding that issue to one side for a moment, if we remove the more extreme outliers (M1, B4, B7, C4-6) from consideration then we obtain average water consumption figures more in line with expectation: Mendip=135 lpd, Brecon=160 lpd, Cotswold=125 lpd and Quantock about 150 lpd. As we will see below (from the regression model presented later on in this paper) part of this variability can be explained by different habitation styles linked to different student national origins. Another portion of this variability is, however, due to inefficiency in fittings themselves, including leaky loos and user tampering with fittings, something that we discuss in the conclusion to this paper.

The original design of this study was predicated on an assumption, confirmed in 2013 with Accommodation Services, that students were allocated non-systematically to rooms and Flats. The results reported above caused us to go back to Accommodation Services to probe this issue further and we then discovered that there are in fact allocation rules, though they are somewhat ad hoc. For example, whilst there is no general policy to create majority male or female Blocks, this has been done for some non-EU nationals where it has been deemed culturally-suitable. So, for example, during academic year 2014-2015, Brecon 6 was 100% female and Cotswold 6 was 75% male (all other Blocks were at least 60:40 or better). The gender composition of Brecon 6 is not easily explained as a function of the cultural needs of non-EU nationals, since 50% of its population were actually UK nationals. Cotswold 6 was 85% non-EU. Comparing with the 2013-2014 and 2015-2016 study cycles we discovered similar non-randomness, with the added complication that different Blocks are implicated each year – e.g. whilst Cotswold 6 was 85% male in 2014-15, it was only 53% male in 2013-2014. This had implications for our research in the 2015-2016 academic cycle (still under review) and caused us to create a different strategy for defining our control Blocks in future.

With the above constraints and discoveries in mind, we used regression modelling to see if we could explain a useful proportion of the variance in water consumption with reference to a variety of variables including:

- Day of week
- Day number within the month
- % UK nationals
- % male

More detailed results of this analysis are the subject of future papers, but we can report here that:

- Time of day explains about 25% of hourly per capita water consumption
- There is a modest falling off of water consumption as the study month progresses, perhaps as a function of students disengaging, travelling, etc.
- UK nationals consume less water, possibly as a function of spending more time at home
- Males tend to consume less water overall, though there is a high degree of intra and inter Courtyard variability on this measure.

Within our models there remain considerable residuals and the errors around the beta parameter estimates are reasonably large and non-uniform between Block and Courtyards. This is prima facie evidence for complex interactions between independent variables, the need to identify additional independent variables (to account for remaining residuals) and the possibility of systematic variations in fixtures and fittings. It may be that Factor Analytic techniques are a useful way forward.

Complicating the interpretation of data is the mounting evidence, from maintenance records and periodic audits, that there is considerable water consumption as a function of leaky and poorly maintained fittings and fixtures.

4. CONCLUSIONS

Generally, 2014-2015 results have marked a leap forward toward a better understanding of water consumption dynamics within the Student Village. Water meters have consistently reported “cleaner” data during the academic year, which has given the opportunity to work with 383,162 (out of a possible maximum of 384,792) half-hourly readings. In addition, 2013-2014 results have been analysed more in depth and used as a temporal baseline for subsequent years. Finally, with the new academic year student arrivals, we were able to analyse the effects of demographic changes for the first time.

Overall, the following key findings were identified:

- Demographics seem to play a big role in water consumption.

  The discrepancy between the Mendip actual data and the expected values has been an important matter for the whole year. After confirming that appliance issues could explain all the variation, demographic analysis was undertaken. The models produced attempt to explain the inconsistency looking at the important demographic differences found between the two years as well as day of week and time within the academic term. The models confirm that demographics seem to play a big role in water consumption. In 2016-2017 we hope to intervene in the allocation of students such as a large enough group of Blocks is essentially randomly assigned.

- Maintenance is still a big factor

  Many extreme readings were reported throughout the whole year. While part of the explanation could be explained by the periodical flushing done for maintenance purposes (esp. Legionella control), poor water systems maintenance is also clearly a culprit (confirmed also during “Water Audits” conducted in summer 2015). Consequently we have engaged with Accommodation Services to help them design a more robust water systems maintenance programme, which may actually save the University thousands of pounds per year in unnecessary water charges. Switching over to a fully automatic telemetry system (e.g. Elcomponent) will also enable the creation of an “alarms” system that could notify Accommodation Services whenever there are water use anomalies. This will benefit maintenance schedules and costs.

- Within-Courtyard variability is so high that a Block-level control (reference) group is required

  The “Mendip baseline issues” showed the importance of a much more sophisticated approach to defining the control group. The models proposed for the project have the benefit of being extremely flexible, permitting to work on different levels. However, it has showed that Courtyard-level analysis are not “fine” enough. Specifically, within the same Courtyards the results and the demographics have been different year on year. This pushes the project towards the identification of Court-level representative groups for the no-intervention and water-efficiency measures.

- Analysis of “soft measures” and “student behaviour” is likely to become an important requirement for the project in future.

  The significance of demographics in explaining this year’s results confirms that user attributes and behaviour is an important factor in water consumption. While “hard measures” effects have been easier to calculate, behavioural compensation is a much more powerful confounding factor than originally anticipated. “Soft” measures require more work. The results of both academic years imply that “hard measures” simply reinforce lower water consumption without really affecting behaviour – those who want or need to consume more water usually find ways to do so.

The work programme for 2016-2017 calls for the testing of a particular hard measure, pressure-reducing flow restrictors, in the UWE Student Village. Research to date suggests that pressure management is as important as flow control because users often value pressure highly and often intervened when it was found unsatisfactory. The devices selected for study are less visible and therefore less likely to be tampered with than low flow shower heads (which were often removed and replaced) and work to regulate both pressure and flow.

In another area of recently completed student accommodation we are proposing a focus on soft measures, in particular the roll-out of in-unit messaging (standard didactic model) alongside a phone based game which draws on near real time data to enable users to actually “game the data”. Such “gamification” processes are gaining traction in environmental thinking and may offer an exciting way forward.

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COMPETING INTERESTS

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FIGURES & TABLES

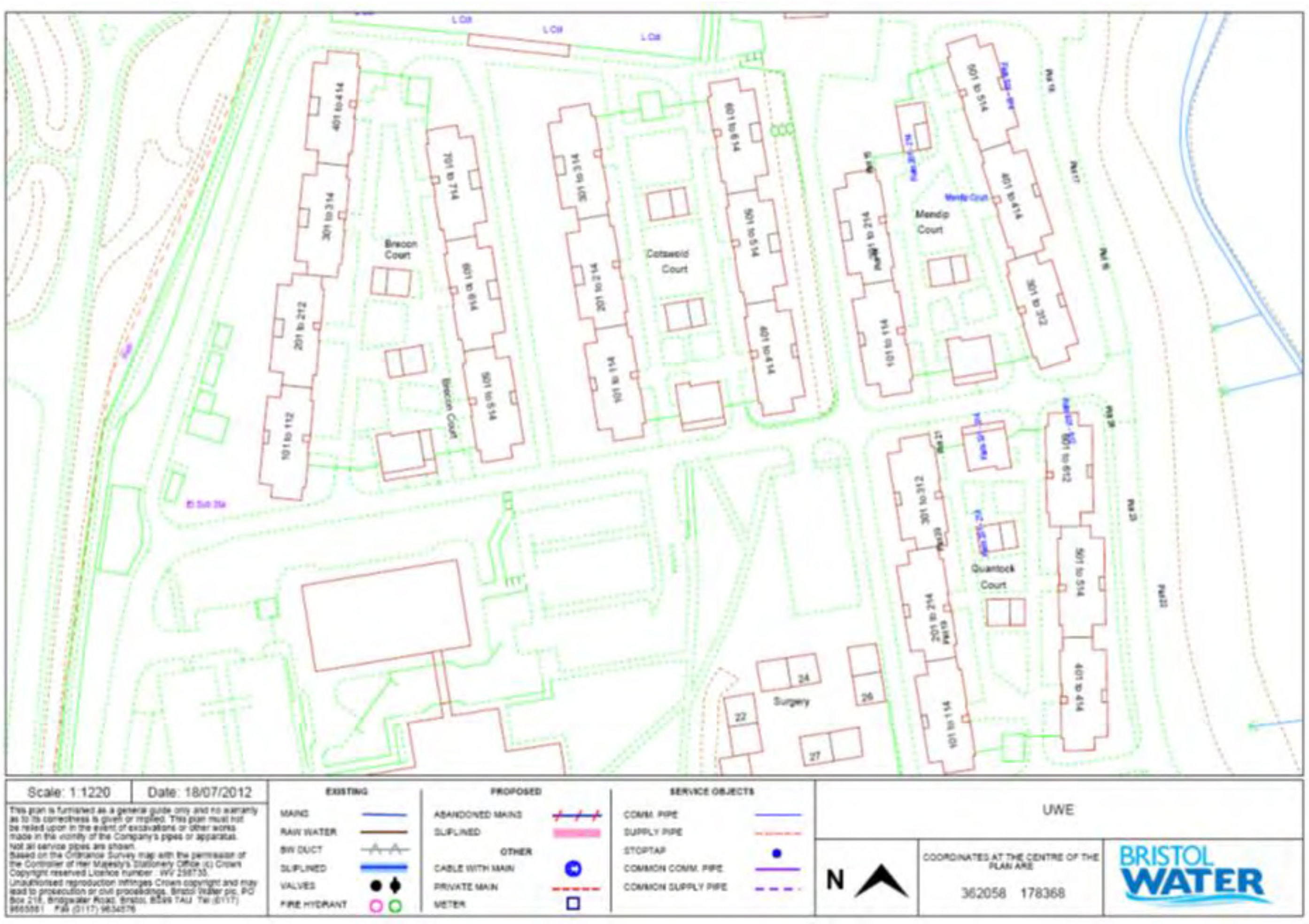

Figure 1: plan view of the UWE Student Village

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	Mendip	*Brecon*	*Cotswold*	*Quantock*
Experimental Measures	*No intervention*	*Flow Restrictors*	*Flow Restrictors* *Low Flow Showerheads*	*Flow Restrictors* *Showerheads* *Shower Timers and other conservation messaging*

Table 1. Water efficiency measures implemented in Spring/Summer 2013

Water Efficient Technologies	Examples
Efficient showers	Low flow shower heads, aerated shower heads, thermostatic controlled showers and auto shut off showers
Efficient taps	Automatic shut off taps, electronic taps, low flow screw-down/lever taps and spray taps
Efficient toilets	Low flush toilets, retrofit water closet flushing devices and urinal controls
Efficient washing machines	Efficient continuous tunnel washers, efficient professional washer extractors

Flow controllers	Flow limiting devices and control devices
Grey water recovery and re-use equipment	Standardised grey water recovery and re-use units
Leakage detection equipment	Data loggers, pressure reducing valve controllers, remote meter reading and leak warning devices
Rainwater harvesting equipment	Monitoring and control equipment, rain water filtration equipment and rain water storage vessels

Table 2: Hard Measures. SOURCE: DEFRA, 2003

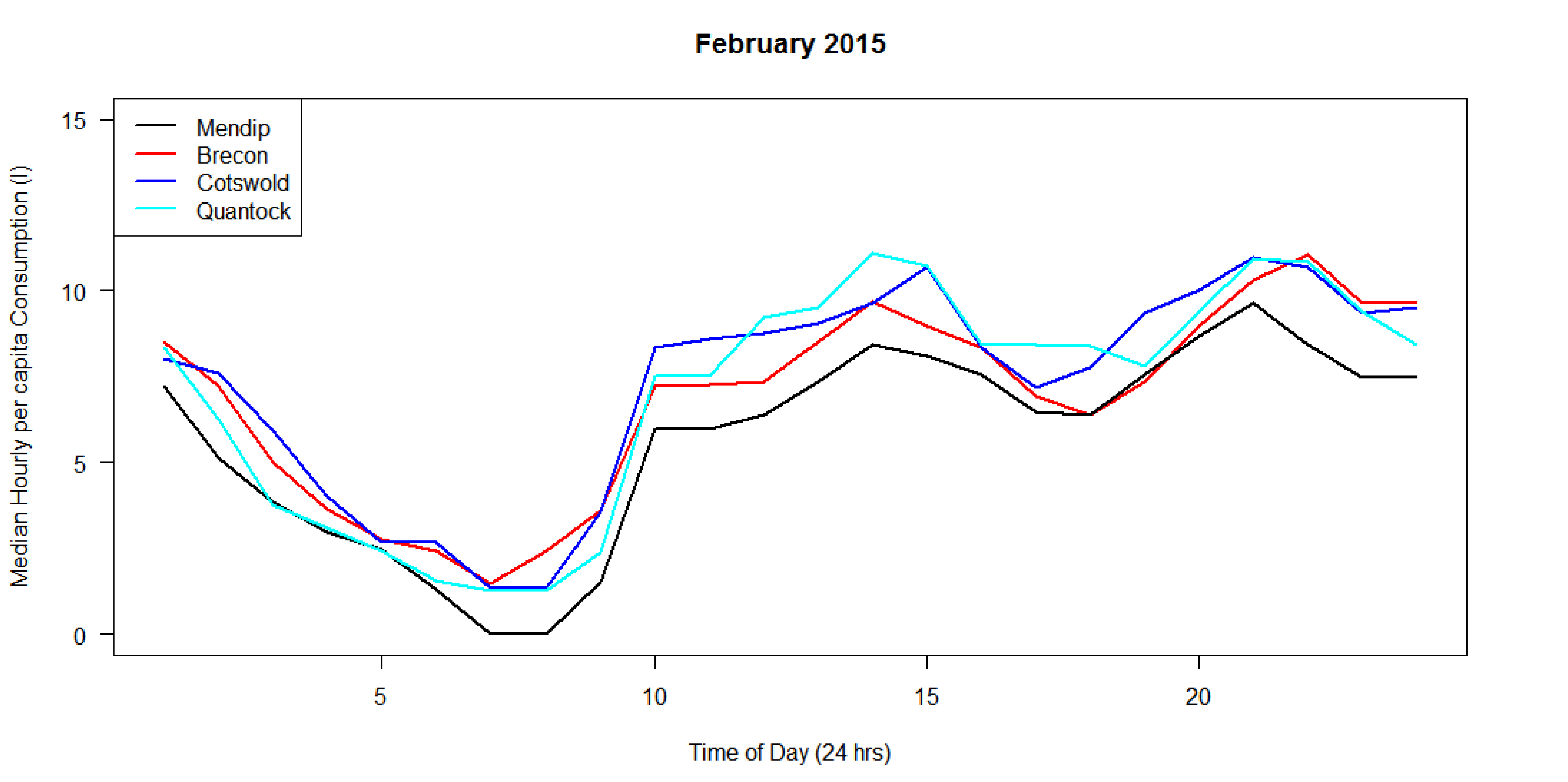

Figure 2: Median Hourly Water Consumption Per Capita, February 2015

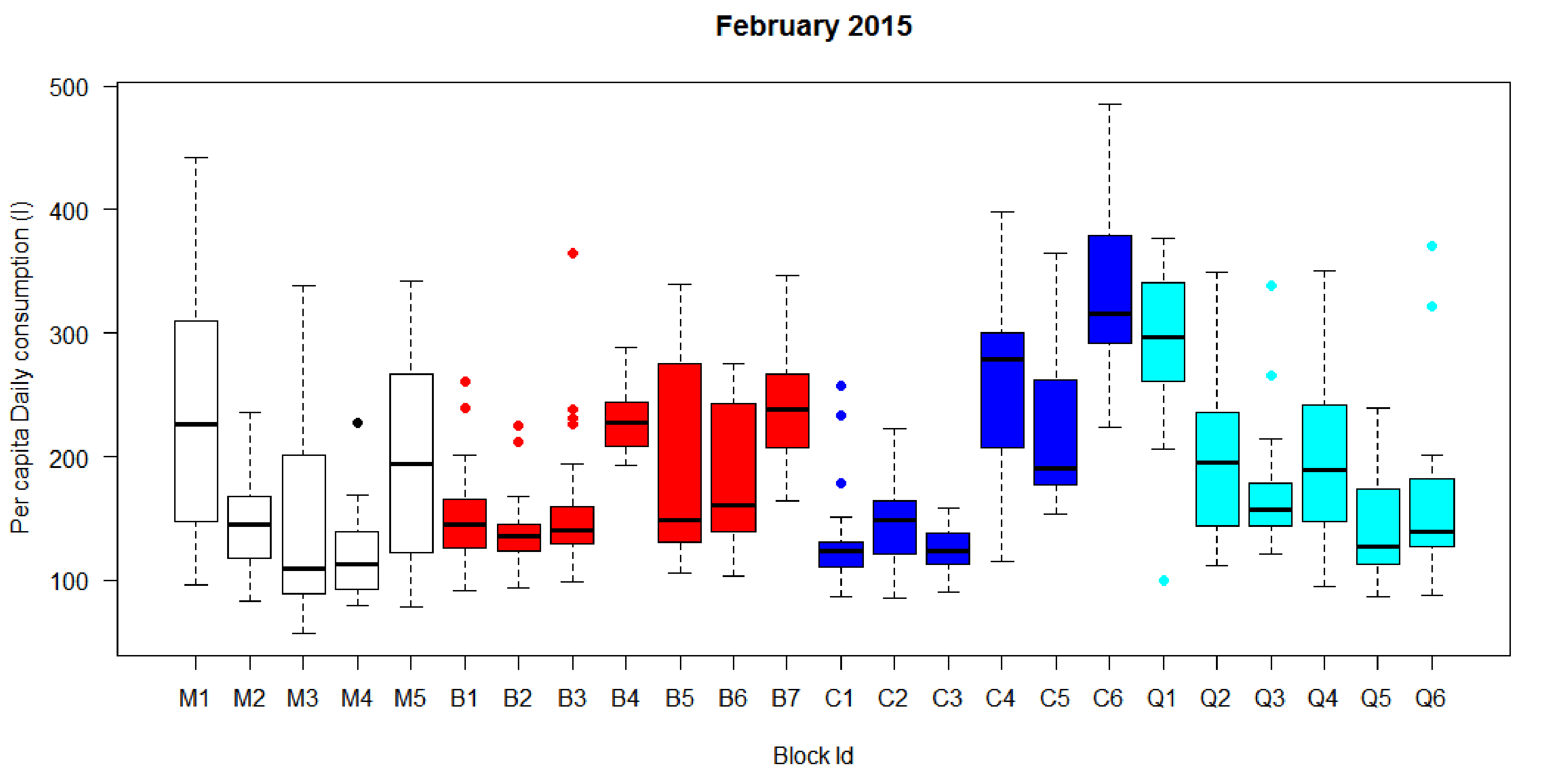

Figure 3: Median Per Capita Daily Water Consumption (in litres) by Block, February 2015

Water Efficiency Conference 2016

Designing innovative water demand management interventions

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ABSTRACT

This paper reflects on existing social theory and industry collaborations to reconceptualise demand management interventions. The aim is to provide examples that are both practically relevant and theoretically robust to support the development of water demand management that engage with the collective socio-material context of everyday domestic water use. Three alternative conceptualizations of demand management are presented; re-design, re-attune, re-locate. Each is illustrated through the use of 'imagined initiatives', those designed in one of two practice innovation workshops held with professionals in the field to develop practical insights from theoretical research. It is anticipated that these 'imagined initiatives' will provide fertile ground for ongoing discussion and development of ideas in both research and practice.

Keywords: Behaviour change, intervention, demand management, domestic water use, everyday practice, water efficiency

1. INTRODUCTION

Globally, water scarcity is one of the most significant socio-environmental challenges, underpinning several of the UN's Millennium Development Goals. While the worst of these impacts may be avoided in the UK, a growing imbalance between supply and demand poses complex challenges for those who manage water resources. In response, demand management has become an important feature of water management policy and practice, designed to supplement improvements to network efficiency in order to balance supply and demand. More recently emphasis has shifted towards people and their behavior in an effort to understand how to curb end-use demand [1]. However social science research raises concerns regarding the persistence of simplistic models of demand and consumption that reduce the scope of the management agenda and are poorly equipped to manage change in socio-technical systems [2–5].

Amidst this research various authors seek to re-conceptualize demand management in order that it may better contribute to long-term sustainable water management [2,3,6–8]. The most extensive developments in this regard lie within the literature on social practices where researchers argue that conventional water efficiency activities, focused as they are on individual decisions and circumstances, address only the tip of an iceberg [9]. Instead social practice theorists look to the shared and collective elements that structure routine behaviour [10]; elements including conventions around water supply and use [11]; social standards regarding clothing, cars, gardens and homes [12]; the design of appliances, homes and infrastructures [13]; and the spatial and temporal structure of everyday life [14,15].

These collective elements shape patterns of everyday water use, thus pose interesting avenues for demand management. However as Shove et al. [9] observe, they "do not lead directly to prescriptions for action" (p.141). The stylized discussions presented in these critical literatures do little to inform intervention which inhibits their impact on policy and practice. The aim of this paper is to explore what interventions grounded in such theoretical developments might look like for the water industry, drawing on imagined initiatives designed during a pair of 'practice innovation workshops' to illustrate a variety of avenues for intervention.

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2. METHODOLOGY

This paper introduces three avenues to inform the ongoing development of water efficiency in the water sector, based on a pair of practice innovation workshops held with water company representatives. This methodology was developed to aid the translation of theoretical and empirical research in academia into practical insights for the water industry.

Two workshops were held, each with 12 participants. The first with representatives of different water companies, the second with representatives from various departments within a single company, a distinction that enabled the breadth and depth of Water Company experience to feed into discussions. Each was initiated by a series of propositions based on a critical evaluation of existing water efficiency activities [6]. Structured facilitation then lead to the development six 'imagined initiatives' that engage with the collective contingencies of demand in order to reduce domestic water use.

While hypothetical, these initiatives present useful platforms for critical development of both practice and theory; promoting discussion regarding what practice-oriented interventions might look like, and providing intellectual fodder to facilitate theoretical developments. This paper develops the insights gleaned from these workshops, proposing three avenues for intervention based on their findings. In two cases, imagined initiatives from the workshops are used to illustrate how water efficiency interventions might implement the principles of these alternative approaches. The third identifies an absence in the discussions to present a third line of enquiry that is supported by existing critical research.

3. RESULTS

Existing research demonstrates that techno-economic interventions, whilst common, make relatively shallow changes to how water is incorporated in everyday life and therefore lack the urgency required to manage demand in the context of growing populations and a changing climate. Further, by failing to engage with habits and routines, interventions fall short of delivering the anticipated reductions in domestic resource use [1,16,17].

Based on such critical reflections this paper identifies three avenues for intervention that extend existing water efficiency activities. These lines of intervention engage with the social and material fabric from which demand emerges in an effort to shape the ongoing evolution of everyday practice in water sensitive directions [18]. Table 1 states the core principle(s) of each and identifies existing examples of these approaches that may provide further evidence to support their implementation. The following discussion uses examples from the workshop to illustrate how water efficiency interventions might implement such approaches to bring about deep, largescale changes to domestic water use.

Table 1: Summary of three avenues for intervention

	Principles	Existing examples
Re-design	Interventions enable lower levels of water use and challenge assumptions regarding how the services derived from water are met by substituting specific elements of practices (social and material), or whole bundles of practice, for water sensitive alternatives	• Dry-shampoo [19] • Cool Biz [20] • Designing-out the lawn [21]
Re-attune	Interventions reconnect people, communities and technologies to local hydro-social characteristics; where relevant taking consideration of alternative supply systems & decentralized technologies	• Distributed supply systems [22,23] • Alternative supply systems [24]
Re-locate	Water efficiency activities destabilise existing unsustainable behaviours and create opportunities for new routines to emerge by reconfiguring boundaries of ownership and responsibility for water use.	• Outsourcing (for example domestic laundry to launderettes or workplaces [25,26])

1.1.1. <u>Re-design:</u>

Re-design focuses on technologies of demand including elements such as hair and hair products, clothing, gardens and domestic spaces, all of which influence how much water is used required to meet social standards and conventions (for example of cleanliness and comfort) [2].

Imagined initiative: "3-day blow-out"

The '3-day blow out' is a hair-care regime designed to fulfill individual desires for clean, healthy, shiny hair while playing on the convenience of low maintenance hair-care for busy people in order to reduce the frequency and duration of showering. The initiative markets a product bundle that enables hair to be washed only once every three days, thereby allowing less frequent and/or reduced duration showering. The routine is as follows; Day 1 the hair would be washed and dried as usual; Day 2 hair is worn 'up', so it is 'fiddled with less' and therefore becomes less greasy; and on Day 3 dry-shampoo is used to freshen hair. The initiative aims to use social networks (both immediate and online) to facilitate uptake and generate a dialogue between consumers relating both to the product but also the 'up-do' which potentially stands alone as an means of reducing hair washing. The initiative offers a palatable, non-invasive interjection into personal bathing routines that in the long term may stand to reconfigure the perceived need for hair washing.

This initative focuses on a specific, water intensive, form of showering and by substituting key elements aims to popularize an alternative form of practice, so that people may achieve the same benefits in a less water intensive manner. Unlike convetional measures that seek to incentivize shorter shower this initiative immediate intervention into the way water is used and in the long term stands to devalue the shower as the daily means of keeping hair clean and fresh. The initiative seeks to establish a new haircare routine and disseminate the products that support it via conventional means of marketing hair products. In order to maximize the success of this project the initiative uses social media and marketing. This inherently positions consumers now as water users, or Water Company customers, but as people styling hair to fit with social conventions [1]. Thus the initiative is promoted as a means of busy people caring for their hair, rather than a focus on water use. The partnership model underpinning this initiative aims to maximise this effect, aspiring to work with the health and beauty industry who already shape hair care routines to offer leadership and expertise.

1.1.2. <u>Re-attuning:</u>

Re-attuning focuses on reacquainting people, communities and water supply systems with the hydro-social characteristics of the local area; taking stock of water supply sources within the target region including potential sources of both potable and non-potable water supplies, regeneration and substitution options, and developing the appropriate infrastructure to work with these characteristics. In addition, measures might be included to enhance the embodied experience of water in the community, such that people become familiar with where their water comes from, and the seasonal variance of water.

Imagined initiative: "Stop sprinkling!"

The second initiative aims to develop a hierarchical model of regionally sensitive garden design with the objective of replacing garden watering in water scarce regions. For areas with limited levels of existing water stress the initiative aims to aid the diffusion of alternative gardens, including options such as drought resistant planting, artificial lawns, wild-flower meadows and practical spaces. For areas with a more urgent need to reduce water demand options include measures to improve soil water retention, to increase the uptake of sustainable drainage systems, and to establish small-scale greywater harvesting. This tiered response offers a practical means of identifying opportunities to mitigate garden water use whilst prioritizing areas that have the greatest need for water saving measures. Whilst initially designed on a household scale, the initiative could work at a neighborhood and/or community level where there were benefits in doing so.

This initiative seeks to undo the disconnection between water use and water supply [27], proposing sensitive interventions into garden watering. These interventions each make an immediate step to reduce demand for garden watering, however in addition aim to foster an different understandings of what water is for, better attuned to the ecological limits of local areas. The initiative incorporates elements of re-design however the hierarchy of options seeks to ensure that interventions focus on providing solutions tailored to local supply-demand characteristics to ensure costs are kept low and the opportunity for impact is increased. There is a strong focus on tacit forms of consumer engagement to increase the visibility of a range of less water sensitive options, with the aim of increasing the acceptability of, and desire for, water sensitive alternatives.

1.1.3. Re-locating:

Re-location challenges the ‘domestic’ in domestic water use, looking for opportunities to displace everyday practices such as laundry and gardening into different spaces to create opportunities for large-scale efficiency measures and for the broader reconfiguration of everyday activity.

Imagined initiative: “Workplace washing”

Workplace washing make washing uniforms at work normal practice. Uniform washing is a highly energy and water intensive practice as they are washed regularly and may be washed separately from other items, thus resulting in high frequency low volume laundry [6]. To counter this, workplace washing aims to shift a highly intensive practice from the domestic sphere into a commercial one where the opportunity for efficiency measures are enhanced. There are two principle methods this may be achieved. Businesses with a large workforce may benefit from investment in laundry infrastructure in the workplace. However, as laundry is both energy and water intensive, and therefore costly, a more viable option may be to outsource uniform washing to a commercial laundry.

This initiative is a strong intervention into everyday routine that stands to make deep changes to the way water use is organized. Tailored to address a specific water intensive practice, the initiative stands to make considerable changes to demand [3], if only at an organization level. Further, as employees are encouraged to leave uniform in the workplace to be washed overnight the interruption of routine might also create a space for the reconfiguration of other behaviours by un-locking unstainable routines [28]. In some cases these may offer further potential for water demand management, such as showering, or other co-benefits e.g. altering commuting habits. To further support water savings this initiative could incorporate element of redesign (e.g. it may be possible to design uniforms that require less washing in certain circumstances), and re-attuning (e.g. certain businesses may offer opportunities to substitute mains water for a non-potable alternative for uniform washing).

4. DISCUSSION & CONCLUSION

This paper presents the outputs from a pair of workshops that develop the ideas from social theory into practical recommendations and example cases studies for managing demand in the water industry. The cases presented are hypothetical, but bridge the gap between social theory and practical example to consider how water efficiency might contribute to a deeper reconfiguration of everyday life in order to reduce domestic demand. While there are examples in the real-world that provide inspiration for ongoing activity these tend not to be directly related to water in the UK, and therefore gloss over important contextual intricacies. Further critical theory, while rich in empirical detail, often lacks the practical recommendations that enable its insights to be applied in policy and practice, and their stylized accounts of social works poorly map onto the complexity observed in everyday life [30]. This paper aims to address these difficulties by using insights from critical social science research as a platform to interrogate everyday understandings of water use and water management of those employed to manage demand in the water industry. By taking this step away from concepts and theories, this paper demonstrates how academic-industry collaboration can develop approaches that navigate the complexity of everyday life. Each of the three avenues for intervention, engage with the situated social and material world of water use in an effort to enable more sustainable habits and routines to emerge.

These benefits are also the potential weaknesses of this research; this is not a comprehensive list of possibilities but inspiration to extend the remit of demand management. Further this is not an evaluation, and the imagined initiatives may be idealistic. However existing research suggests that truly critical enquiry is most effective if it contains "anticipatory-utopian" dimensions [29], insights that divert from current patterns of thought and action to explore alternative options and possibilities. Further research could usefully develop scenarios around discussions such as these to approximate their impact; identify specific circumstances in which such interventions might have the greatest effect, and understand the preconditions for their implementation. It is anticipated that this paper will provide the grounds for ongoing discussion and development of ideas in both research and practice.

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Water Efficiency Conference 2016

Music Festivals: How are people encouraged to be mindful in their uses of finite resources and not waste water? Where does water go after use?

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ABSTRACT (RESEARCH AND PAPER IN PROGRESS)

During the last few months, People and Communities Technical Committee in Water Efficiency network has been interested in and selected specific case studies to be proposed for further analysis and discussion by members of this committee. Most members decided to bring to the attention of the committee one case study for further development. Some case studies, such as, for example, 'Water and its use by people at a music festival' appeared to be triggering further investigation from members of the committee with the potential to become new and original research projects; this particular case study is going to be analysed through videos to be produced on the occasion of next Reading Festival. Organised by Festival Republic (FR), this annual event is held over the August Bank Holiday weekend. Thus, this paper intends to discuss some large performance venues and sites' planning and organisation on methods and solutions having an immediate impact to people's behaviours in relation to the uses of water and the impact to the environment through water management. The researchers and members of this technical group wish to understand how organisers can plan water uses, how they may be contributing to specific guidance of the public by introducing specific guides on water management at outdoor events and by also creating plans to overcome some unexpected outcomes of overflows or failure of provision at times. The team working on this project hopes to get some detailed overview on water and its use by people during these events; they hope to be able to do some recommendations and draw some important conclusions at the end. Amongst other relevant outcomes the research team is hoping to help organisers to develop useful guides for the public and enhance the people's awareness on the water uses and management. The organisers and the audience should be able to build confidence and joint support also in extreme cases when something could happen unexpectedly, such as failure to drainage or supply systems. They should be able to be putting on place a relevant plan of emergency and this could be feasible by contributing to important reports in progress, such as, for example, 'The show must go on' report. By documenting this coming event via filming the team hopes to create a freely available resource that demonstrates globally how people interact with water, a precious and essential source. Whenever possible the team aims to show how water can be used carefully, mindfully and efficiently during large size events, such as music festivals through their chosen case study in the UK. A short video will be shown during the Conference as well.

Keywords: Water uses and management; People and Communities; human behaviours; water management at outdoor events/festivals.

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Water Efficiency Conference 2016

EXAMINATION OF DOMESTIC COLD WATER STORAGE TANKS

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ABSTRACT

A fundamental problem is estimating water supply system demand so that designs can satisfy the operational needs of a building in a cost efficient and safe manner e.g. Legionella risk, water quality etc. The design of domestic cold water systems traditionally relies on fixture unit or demand unit methods to establish the design peak flow rate. Further, calculating cold water storage capacities requires reference to these same design guides that also recommend periods of storage; final tank capacity is often amended as a result of individual engineers experience, engineering discretion and in response to knowledge about refill time. Contributory factors such as the building water usage and turnover, occupancy times, and sanitary appliance specification (low water use devices) should be considered when sizing domestic cold water storage tanks.

This paper presents an examination into the importance of sizing domestic cold water storage appropriately and the effect design standards have on expected operational performance. Also, through the experience of multiple engineers from many consultancies over several years a summary of service issues in buildings is presented along with potential methods to mitigate excessive capital cost, running costs and public health issues.

Keywords: *Frequency, demand, storage, plumbing codes.*

1. INTRODUCTION

This paper examines the high level issues with Domestic Cold Water Storage Tanks (DCWST) and cold water delivery systems. Where it is necessary to guarantee the hygiene and quality of the water at water outlets, eliminating Legionella risk requires the avoidance of stagnation in oversized tanks and eliminating the potential for low velocities in pipework system due to over sizing. Each concern requires a better knowledge of the water consumption in buildings. This paper is fundamentally based on the experience of several Building Services engineers who have in recent years reported that there is a growing trend in rising cold water temperature in cold water systems and regular occurrences where water temperatures exceed 20^{o}C, thereby contravening Health and Safety Executive's (HSE) L8 [1] guidance. This document is seen as the authoritative guidance in the construction industry, setting a maximum permissible temperature of 20^{o}C in domestic cold water systems.

A common finding from recent surveys conducted has discovered that where split storage tanks have been installed, the tanks have either been isolated, drained down and decommissioned or that one side of the tank has been drained down, isolated and decommissioned. The primary reason for these remedial works is due to the maintenance personnel establishing that the stored volume of 'cold' water is significantly greater than the building demand. Therefore as a precautionary measure, to eliminate risks with stagnant water, and ensure improved water quality within the system, facilities teams have decided to implement these measures.

This paper starts by summarising the current design methodologies for sizing cold water storage tanks and codes of practice, followed by a review of the relevant standards and regulatory requirements with respect to cold water temperatures and the contributing circumstances and risk factors that would impact on water quality within the domestic cold water systems. Finally, potential mitigation measures are presented.

2. BACKGROUND

The first documentation of human society's usage of water came from the Egyptians, approximately 2000BC, where they constructed wells, dams and developed water removal/lifting appliances. This initiated the focus on water storage. Following this, showers, baths and flush toilets were developed and installed in the Minoan Palace of Knossos approximately 1700BC on Crete [2].

Further, the Roman occupation of Britain saw the development of many of today's water system engineering methodologies. Gravity systems in houses used wooden pipes, lead and clay, although this water was predominantly used for washing, livestock and cooking, but not for drinking. Drinking water at this time was only consumed by the poor in society. It was not until after World War 2 that plumbing in the homes of all become more common place [2].

The principle of cold water storage is not a new concept, as noted previously, but the developments in sanitary-ware and building design standards have developed. However, the UK British Standards (BS) and Institute of Plumbers (IoP) guidance currently adopt sizing methods that are based on consumption data dating back to the 1970's & 1980's. However, due to the modern advances in technology, combined with the drive to conserve water (e.g. low flush toilets, low flow devices) it is clear there is a need to obtain current and reliable data on building water consumption to allow building water demand to be more accurately assessed. Without considering the implications of current practices which reduce or limit building water consumption, demand and water tank turnover rates can lead to stagnation of water in domestic installations and result in public health issues.

Whilst, most bacteria are dormant at certain temperatures, they incubate or grow in warmer stagnant water on biofilm (or on a suitable surface) or other media that can support growth. It is difficult to grow biofilm that will support bacterial growth if the water is circulated. Therefore, regular draw off and water movement through the system supported through automated flushing systems or via manual intervention by janitorial or Facilities Management (FM) staff are important to eliminate the risk. Therefore, consideration in the sizing of the DCWST should be a detailed estimation of the amount of water expected to be required by the end users.

Estimating water demand depends on the profile of water usage which is unique to every installation and building type. For example, a difference will exist between a hospital and a school. Water usage profiles will also be unique due to behaviors and the individuality of the end users and their expectations to use water whenever and however they desire.

Bhatia 2012 [15] suggests that an estimated water demand should consider:

1. Climatic influences;
2. Socioeconomic influences;
3. Property size;
4. Recreational or seasonal uses;
5. Metering and pricing schedules;
6. Historical water data sets;
7. Purpose of facility;
8. Conservation practices; and
9. Reliability and security of supply.

This paper will suggest that the daily loads for calculating demands of cold water storage is reviewed in-line with water conservation technologies and techniques currently employed in the industry.

3. BASIC METHODOLOGY

The design of domestic cold water systems should always be carried out in accordance with local Water Bylaws, current design guides and industry good practice. However it is acknowledged that sometimes even with the application of appropriate guidance and good practice the quality of the potable water can be affected by a variety of external influences.

Bhatia 2012 [15] suggests that a potable water system should achieve the following:

1. An adequate volume of water to the most remote appliance during minimum pressure and maximum flow conditions;

2. Provide adequate water pressure to the most remote appliance during minimum pressure and maximum flow conditions;

3. Prevent excessive water velocity during maximum flow conditions;

4. Ensure an adequate flow of water throughout the system to avoid ‘dead legs’ or areas where stagnation and bio-film growth can occur;

5. Maintain water temperatures below HSE guidance levels;

6. Provide clean safe water for users.

The potable water supply will originate from the local water authorities ‘town’ main. The point of connection for a building is normally at the water authority meter located at the site boundary, where it will then be routed to A) potable water storage tanks (pumped system rather than gravity supply) or B) supplied directly to mains water outlets in the building.

From the cold water storage tank, the cold water feed normally serves a cold water booster set which distributes ‘boosted’ cold water around the building to the various cold water outlets and cold water feeds and to the hot water generation plant. Additionally, direct mains water may be distributed throughout a building to appliances or outlets deemed to be ‘potable’ such as drinking fountains, to kitchen taps and tea prep areas; this is deemed industry good practice and as a requirement to satisfy and achieve certain credits through sustainability assessment methods such as BREEAM.

The following from the Association of Plumbing and Heating Contractors [16] highlights the benefits and issues for each water system approach;

INDIRECT COLD WATER SYSTEM ADVANTAGES

- Water can still be supplied to the building if there is an interruption to the mains water supply;
- There may be less system noise as water is under less pressure;
- The system can supply cold water even if the mains water pressure is low.

INDIRECT COLD WATER SYSTEM DISADVANTAGES

- Can be more expensive to install;
- For large buildings, accommodation for water storage can have a significant impact;
- Structural loads need to be considered and the structure designed to accommodate imposed loads;
- Increased risk of bacterial growth.

7. SYSTEM CONSIDERATIONS

A. PUMPING

- Mains water pressure often varies across a 24hour period and from month to month. The pumps are required to achieve a desired pressure at the appliance;
- Potable booster sets are required generally alongside a storage tank;
- Boosted systems may need to be provided with a pressure reducing provision to reduce limit system pressures and account for variances in static head pressure;
- The pump needs an on/off mechanism and expansion tank; to protect the pump during low-flow conditions.

B. STORAGE TANK

The storage tank volume is generally determined by the average probable water demand which is influenced by the number of hours of storage required. Typically tanks are sized to cater for a 12 hours or 24 hours interruption to supply and on the building type served. Typically tanked installations will be fitted with Building Management System (BMS) sensors monitoring both level and temperature.

C. EXPANSION TANK

The expansion tank will have a charged diaphragm that will absorb demand fluctuations to provide a cushioning effect at peak demand and prevent frequent start-stop of the pump sets and minimize water hammer.

DIRECT COLD WATER SYSTEMS ADVANTAGES

- Can be cheaper to install than a storage system;
- Less chance of water growing bacteria;
- Can deal with large demand more easily.

DIRECT COLD WATER SYSTEMS DISADVANTAGES

- If the mains water supply fails there is no emergency backup;
- Potential of not being able to satisfy building water supply demands if the mains water pressure is low;
- Potential noise issues with water being under high pressure and associated increase pipe velocities & frictional losses.

In the UK the Institute of Plumbing (IoP) – Plumbing Engineering Services Design Guide [3], British Standard 6700 [4] or BS EN 806 [5] and CIBSE Guide B [6] are the recognised methods for designing and sizing cold water storage tanks. Whilst in the Health Care sector HTM 04-01 [7] or SHTM04-01 [8] must be referred to.

Whilst not as common as it once was a gravity system with the cold water tank housed at high level is the preference of SHTM04-01, as this system avoids reliance on pumps. Further in the case of where hospital buildings are scattered, the preference is to install several smaller tanks rather than one central water tank tower. SHTM04-01 also recommends that local storage at high level should be able to give four hours supply if installed in a gravity fed system.

8. SIZING METHOD

The industry practice of using the previously quoted guides can result in storage tanks that could be considered to be oversized and as there is evidence to suggest a large number of buildings where cold water tanks have been. The following notes the formula and figures used in determining the storage capacity for various building types.

The volume of stored water is obtained from:

$$\text{Storage volume} = \begin{pmatrix}\text{number of}\\ \text{persons}\end{pmatrix} \text{x} \begin{pmatrix}\text{litres per}\\ \text{person}\end{pmatrix} \text{x} \begin{pmatrix}\text{number of}\\ \text{days'storage}\\ \text{(or \% of 1 days supply)}\end{pmatrix}$$

If the building occupancy is not known, the Health and Safety at Work Act 1974 gives an allowance of 10m^2 per person of working floor area may be used [6].

The following table gives recommendations of water storage quantities.

Type of building **Hospitals**	**Demand (litre) CIBSE Guide B**	**Demand (litre) SHTM04:01**	**Basis of demand**
District general	600	Acute 299-978	Bed
Surgical ward	250	Specialist 319-531	Bed
Medical ward	220	Long stay 180-306	Bed
Schools			
Nursery	15		Pupil
Primary	15		Pupil
Secondary	20		Pupil
Offices			
With canteen	45		Person
Without canteen	40		Person
Hotels			
Budget	135		Bedroom
Travel Inn	150		Bedroom
Sports Facilities			
Swimming pool	20		Person
Field sports	35		Person

Table 1: Water demand per person [6][8]
This list is not exhaustive from the guides. Table A1: SHTM04:01 gives the average water consumption by type and size of hospital.

The author cannot establish how the above demands have been determined or calculated and if any studies have been undertaken to ascertain whether these figures are still relevant taking cognisance of the current drive to minimize water usage.

The sole objective of the period of storage is to cover any interruption of the mains water supply. When the period of storage is not specified by the water supplier, regulations or client requirements, the following percentages may be used.

Type of Building	% of the daily demand
Hospital	50%
Schools	50%
Offices	0-50%
Hotels	50%
Sports Facilities	0-25%

Table 2: Daily water storage demand [3]
This list is not exhaustive from the guide. It should be highlighted that CIBSE Guide B 2014 references the Plumbing Engineering Services Design Guide figures above and does not provide any alternative figures.

9. WATER QUALITY STANDARDS AND REGULATIONS

The most widely known bacteria is the Legionella Pneumophilla which is a member of the family *'Legionellacae'*, that was first discovered in 1976. The micro-organism has been identified as living in a range of building services sources include drinking water, water taps and shower heads, hot water boilers and cooling towers [9].

To offer context to the health issues regarding water quality there are several standards and regulations that are applicable to cold water supply temperature in the UK, these are:

- UK Health and Safety Executives L8: 2013, Approved Code of Practice and Guidance, *'The control of Legionalla Bacteria in Water Systems'* [10].
  This requires that temperatures between 20°C and 45°C are to be avoided.

- UK Water Regulations (WRAS) [11].
  This requires temperatures to be kept below 25°C.

- BS 8580:2010 '*Water Quality – Risk Assessments for Legionella Control'* [12].
  This requires the temperature of a cold water outlet to be below 20°C after the outlet has been opened for 120 seconds.

- CIBSE TM13:2013, '*Minimising the Risk of Legionnaire's disease'* [13].
  This requires the temperature of a cold water outlet to be below 20°C after the outlet has been opened for 120 seconds.

For bacteria such as Legionella to thrive in cold water storage tanks several factors need to be present; these include a suitable temperature and source of nutrients, e.g. sludge, scale algae and other organic matter. The Chartered Institute of Building Services Engineers Technical Memorandum TM13 '*The Control of Legionella'* [13] identifies the following as temperatures for Legionella growth:

- Dormant; 0°C to 20°C:
- Will multiply; 20°C to 45°C:
- Will not multiply and will die in time; 50°C to 70°C:
- Not active; 70°C to 100°C.

The ideal temperature, based on empirical data suggests that the perfect microbial growth and proliferation is 36°C. Also, certain groups of people are known to be more susceptible, for example; men are more open to contract the disease than women, over 45 year olds, smokers, alcoholics, diabetics, immune compromised and those with cancer, respiratory or kidney disease. Therefore the obvious building where infection would prove catastrophic and potentially fatal is a hospital. The Department of Health have the Technical Memorandum HTM 04-01 [7] for their own facilities to ensure a water source hygiene for patients, it states there should be no greater than a 2°C rise between the storage tank and the appliance within 2 minutes. BS 8580:2010 provides detailed guidance on how to conduct a Legionella risk assessment; the risk assessor should however have an in depth understanding of water systems [14].

10. DCWST DESIGN RECOMMENDATIONS

Ideally all storage tanks should comprise two compartments, this will allow for maintenance to be carried out without interrupting the building water supply. Also, depending on the water volume, sectional tanks will typically be installed, usually flanged either externally or internally. Where external flanges are used for construction, these will not require an engineer to enter the tank and permit the tank to drain through one single drain, which therefore avoids entrapment of tank water between the flanges, thereby reducing water stagnation which can lead to bacterial growth [3].

Cold water tanks can be located internally or externally to the building. The ideal location for external tanks is on the highest roof if gravity fed, or if located at ground level would not be subject to flood, excessive heat gains or any other environmental conditions which may materially affect water quality.

Any installer/ designer has a legal obligation to inform the water supplier prior to the commencement of installation work on water systems in order to prevent backflow and potential contamination to the external town main . The backflow contamination level is based on an assessment of the contamination risk from either the water in the cistern or the water/process downstream of the tank.

Contamination by backflow can occur from the use of tanks in domestic or non-domestic buildings. The following categories of risk apply to both property types whilst also covering one-piece tanks, sectional tanks and any other kinds of water holding vessels [11].

The UK Water Regulations Scheme (WRAS) offers guidance on the application of appropriate backflow protection by means of an air gap provided in a tank.

11. FLUID CATEGORIES

1. This is defined as wholesome water. *Example:* Water supplied directly from the mains water supply [11].

2. This is water that would be fluid category 1 but has an aesthetic quality impaired due to a change in temperature, taste, odor or appearance. *Example:* Hot water supplies [11].

3. This is defined as a fluid that presents a marginal health hazard because of the concentration of substances of low toxicity. *Example*: Water in primary circuits and heating systems (with or without additives) in domestic premises [11].

4. This is defined as a fluid that presents a significant health hazard because of the concentration of toxic substances. *Example*: commercial washing machines (excluding those used for laundry contaminated with animal or human fluids or waste) [11].

5. This is a fluid that presents a serious health hazard because of the concentration of pathogenic organisms, radioactive or very toxic substances including fluid which

contains faecal material or other human waste. *Example*: Medical equipment with submerged inlets, a cistern which also receives recycled process water [11].

12. POTENTIAL CAUSES OF DCWST FAILURE

Beattie and Kane 2015 [14] have listed several potential factors in buildings that may contribute to overheating/stagnation of DCWST, these factors include:

- In a new-build there is a standard burial depth for the incoming water mains however sometimes in older buildings incoming mains water pipeline from the site boundary to the cold water tank room can be at a shallower burial depth, as such during a warm day the incoming water could receive heat pickup or may be subject to frost damage during winter;
- A lack of temperature monitoring in the cold water tank, incoming mains and at the extremities of cold water pipe distribution;
- The possibility of over sizing the cold water storage tank;
- Reduced periods of occupancy and demand such as at weekends and holidays. Seasonal variations in the occupancy of the building can result in longer standing times of water in the cold water storage tanks;
- If the plant room where the cold water storage tanks is located and unventilated there may be the potential for cold water storage temperatures to increase when there are periods of low usage;
- Insufficient separation between the heat generating plant and equipment e.g. boilers, hot water storage cylinders and the cold water storage tank room and a lack of appropriate ventilation in the plantroom housing heat generating plant and equipment;
- If the occupancy levels in the building after handover is less than envisaged at design stage a lack of domestic water draw-off due to unoccupied spaces and infrequently used outlets may cause elevated temperatures;
- Ease of access for maintenance;
- Poor maintenance associated with periodic system flushing;
- The use of flexible connections which can harbour biofilm;
- Insufficient consideration of system dead legs;
- The end user not implementing risk assessments and procedures to control the risk of Legionella.

The above factors may not be exhaustive, but may contribute to elevating water temperatures and allow bacteria to grow in any domestic cold water tank installation.

13. POTENTIAL MITIGATION MEASURES

The previous section discussed several factors that may contribute to elevated domestic cold water services temperature and bacterial growth. Beattie & Kane 2015 [14] highlight the following potential mitigation measures that could be considered and adopted where appropriate and also areas where further investigation would be recommended:

- Isolate and drain down one cold water storage tank section if it is a sectional tank as in hospitals. This will improve water turnover-to-demand;

- The addition of chlorine dioxide CL02 dosing system to the domestic water services systems. This is an eco-friendly micro-biocide. This solution will assist in eliminating Legionella in systems but will not address the issue of water temperature. However, it is recognised water temperature is directly related to the growth of microbial bacteria in water supplies, therefore by eliminating the bacteria increased water temperatures may be acceptable;

- Provide a delayed action adjustable height ball valve in the water storage tanks to allow stored volumes to be adjusted if tanks are found to be too large;

- Ensure appropriate controls and sensors are provided for monitoring domestic cold water consumption and cold water temperatures throughout the system;

- Consider reducing cold water storage levels in buildings appropriate to the building type and anticipate demand (reduce from 24hr to 12hr storage);

- Incorporate a ‘soft landings’ approach to help building users and operators adjust to their new facility and help them understand the building and associated systems design intent and operation;

- Include seasonal commissioning in the contract to allow the systems to be adapted to seasonal variations and changes in user need;

- Metering of water consumption has become increasingly frequent. The main objective is for BREEAM credits and actual consumption for bills. Through this metering a lot of data has been recorded which should be used to validate design codes;

- Encourage clients to learn, for post occupancy evaluation, how the system and building are performing. This includes the logging of live data which can be shared with the industry to help inform trends and future updates to standards and guidance:

- Industry review of current standards in relation to the design and sizing of cold water tanks, drawing on the experience of industry professionals and available live data across a wide range of building types and sectors;

- Industry and academic research should investigate the variability of peak consumption over an extended period of time to allow for reassessment of current design codes;

- Data/Knowledge sharing from live in use buildings.

14. SUMMARY

Cold water storage tanks are relatively straightforward appliances, however with ever increasing water efficient low flow devices and building thermal insulation and improved air tightness that result in frequent overheating in cold water systems. The cold water storage tank (and pipework system) needs to be assessed accurately from all aspects prior to its design.

This paper has reviewed the domestic cold water tank with recommendations to reduce system overheating and improve water quality. The paper outlined the history of existing design methodologies and presents supporting guidance and legislation associated with maintaining safe hygienic cold water systems.

The key conclusion for this examination of cold water storage tanks should be to review the sizing guides/methodologies to account for modern practices; this will also require more research data analysis and promotion of knowledge sharing of raw, live consumption data from actual buildings.

15. COMPETING INTERESTS

The issues raised in this paper have accumulated through several resources and in no way reflect any one specific project or AECOM design. The issues and mitigation measures have been compiled through the experience of multiple engineers from many consultancies over several years.

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Water Efficiency Conference 2016

Water Sensitive Design and Renewable Energy: Green Infrastructure as the future path for Flood Resilience, Food Production and Energy Saving

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ABSTRACT
Green Infrastructure (GI) when referring to Stormwater Practices is a set of decentralised stormwater techniques that confer climate adaptation benefits and the provision of better spaces through cleaner water and “environmentally friendly” infrastructure. GI can provide amenity benefits for more sustainable communities on top of the runoff pollutant removal efficiency and runoff control. It also enhances ecosystems by improving biodiversity and also has the potential to reduce carbon and energy consumption in their construction and maintenance. This article presents a pilot study that focuses on understanding the underlying processes of the hydrological behaviour as well as the thermal properties of swales (or linear bioretention systems) since these are some of the most used GI across the world. The potential combination of swales and Ground Source Heat Pumps (GSHP) renewable technology is investigated in this project. The research also studies the potential reuse of the outflow water in swales by undertaking an environmental assessment where water quality and biological parameters are considered in order to establish if the outflow water can be used for agricultural purposes such as crop irrigation. This links with potential end uses in food production and sustainable energy. A comprehensive methodology including field monitoring, laboratory experiments and numerical simulation modelling has been developed. Two full-scale sites have been selected in the UK for their specific characteristics (swales connected to other Sustainable Drainage Systems): Ryton-on-Dunsmore, Coventry, West Midlands; and Hamilton, Leicester, East midlands. The water levels and temperatures of the swales in both sites will be monitored during 12 months. Two different sections of swales (dry and wet) will be studied in the laboratory in order to understand the thermal behaviour of those systems. Numerical simulation through the Hybrid Engineering method will be used to validate the thermal response of the laboratory models. After a few months within this pilot study, the first results have shown a very promising path towards the achievement of the ambitious objective established for the project. The long-term monitoring of the swales both in the laboratory and in the field will provide a rigorous assessment over the next year until the end of the project on the validity of combining GI with renewable energy techniques.

Keywords: Agroecology, Climate Change, Hydraulic, Hidrology, Sustainable Drainage Systems, Stormwater Techniques, Water Engineering.

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1. INTRODUCTION

Climate change is reducing the flood resilience of urban and rural communities across the world [1]. Societies are facing important challenges related to food security, stormwater management, runoff pollution and energy production as three of the main factors influencing human life. Combining water systems with energy production represents one of the big opportunities to face this challenge by ensuring Environmental Sustainability, which is the Goal 7 in the UN Millennium Development Goals and beyond 2015 [1].

Sustainable Drainage Systems (SuDS) or Stormwater Best Management Practices (BMP), and more specifically those defined as Green Infrastructure (GI), provide a wider range of properties to the ones achievable by traditional drainage systems such as piped systems or storage tanks by incorporating a more respectful treatment of the environment and by protecting and enhancing the biodiversity of ecosystems [2,3]. Water quality improvement and runoff attenuation are two of the main characteristics of GI [4,5]. There are, however, several knowledge gaps in the field of GI, identified around the physical understanding of the processes that underpin the hydraulic, hydrological and thermal behaviour of Swales and Rain Gardens when monitored in real-time under real storm events and including climate change effects [6,7]. Moreover, GI has not been fully investigated for all variables, less rarely in the field, with scarce attention to the underlying biology of the biodegradation of organic pollutants [8].

A research project has been developed, with the combined collaborative effort of 4 international universities including the Universities of Cantabria and Oviedo in Spain, North Carolina State University in the USA and Coventry University as the lead and funding institution in the project. The project main aim is to provide flood resilience whilst creating better spaces, more sustainable treatment of the environment and protecting the biodiversity of ecosystems. This will establish the bases for the Pyramid of the Sustainable Management of Water, Food and Energy (Figure 1). Water Sensitive Design will underpin this comprehensive and sustainable approach through the use of GI.

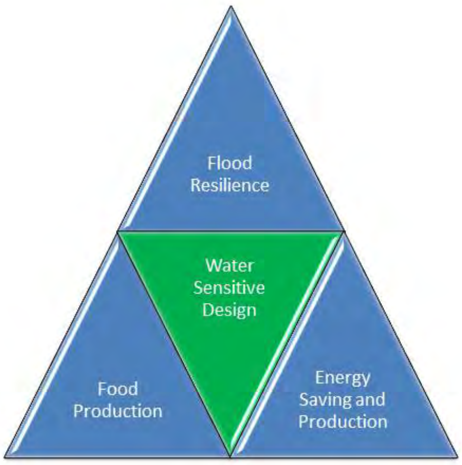

Fig. 1. Pyramid of the Sustainable Management of water, food and energy underpinned by the Water Sensitive Design philosophy through the use of Green Infrastructure

Swales as linear Bioretention systems are at the forefront of the research on GI. However, an important knowledge gap has been identified in the application of the water treated by these systems and their possible combination with renewable energy. This pilot study will deal with the possible applications of the effluent depending on its quality whilst measuring GI hydraulic and hydrological performance in the field under real conditions. Furthermore, a shallow geothermal energy system such as Ground Source Heat Pumps (GSHP) within a swale structure will be studied in the laboratory aiming to provide the proof of concept for the first time in academic research. Specific objectives arise from this main aim as follows:

- To determine the hydraulic and thermal performance of GI in real-time under real and varying conditions in the UK.

- The generation of models of performance of the hydraulic and thermal behaviour of Green Infrastructure as proof of concept for their potential use as part of a geothermal system.
- Validation of the models of performance using the field and laboratory data.
- Estimating the transnational impact of GI, via a comparison with U.S. case studies.
- Determination of water quality, chemical and biological patterns of GI performance. .
- Assessment of the suitability of the water for reuse within Rainwater Harvesting Systems, Urban Agriculture and other non-potable uses.

To achieve these ambitious objectives, the research project has been divided into the following main stages:

- January 2016. Start of the project.
- February 2016-February 2017. Thermal performance experiments at the University of Cantabria and numerical simulation models at the University of Oviedo.
- May 2016. Visit to the North Carolina State University in the U.S.A. and participation on the Seminars related to Green Infrastructure.
- June 2016-June 2017. Field monitoring at the designated sites.
- July 2017. End of the project.

2. METHODOLOGY

The activities that are under development at the moment of this conference are related to the field monitoring of the hydrological and thermal performance of the swales at Ryton Gardens and Hamilton sites in the UK. Also, the laboratory experiments for the analyses of the thermal performance of laboratory model swales have begun. Finally, the numerical modelling simulation is at an early stage of development, having started as per scheduled in the project. Therefore, all the methodologies presented in this conference article will focus specifically on those three areas, giving a brief introduction to the rest of the project related to the analyses of water quality and microbiology as well.

The scientific methods and techniques that will be applied in this research project are divided into three main areas, distinguishing between field monitoring, laboratory experiments and numerical modelling simulations. The experience of the research team will cover the following areas within the project:

- Biological communities [9-11] and their performance in treating organics and tolerance to emerging pollutants [12,13].
- Interactions between SuDS recycled water and the plant species that these systems can effectively irrigate [14].
- Water treatment and the pollutant removal efficiency [15,16].
- Laboratory and field monitoring of hydraulic and hydrological processes [17,18].
- Laboratory and field monitoring of geothermal systems within SuDS [19].
- Numerical modelling simulation (Hybrid Engineering) [20,21].

2.1. Field monitoring

The hydraulic performance of the swales selected is monitored by measuring their water levels and by comparing those with the rainfall data obtained from the UK Met Office for both locations (Table 1) during 12 months. Water levels are registered in real-time under real and varying conditions of rainfall and temperatures during the year in order to highlight the seasonality effects in the drainage systems. Water level monitoring devices are utilised such as the OTT Orpheus Mini which is placed at the point of discharge of the swale in Ryton and at the inlet and outlet points in the site in Hamilton (Table 1). The temperature (fundamental for the purpose of checking the potential benefits of these systems for their use as part of a geothermal energy system) will also be measured in real-time in both locations.

Water quality parameters such as Electric Conductivity (EC), pH, Dissolved Oxygen (DO) and LDO will be measured periodically through the use of a multi-parameter portable meter HACH HQ40d.

Table 1. Field site locations and type of swales investigated in the project

Location	Type of Green Infrastructure
Ryton Gardens, Coventry, West Midlands	**Swale connected to Green Roofs**
Hamilton, Leicester, East Midlands	**Sequence of Swales**

2.2. Laboratory experiments

Laboratory experiments will be divided into 4 main areas of knowledge as per indicated as follows:

- Water quality analyses. Parameters such as Total Suspended Solids (TSS), Total Phosphorous (TP), Nitrate-Nitrite, Ammonia and Biological Oxygen Demand (BOD) will be considered. Chemical oxygen demand (COD) will measured by the dichromate method.
- Microbiological analyses. The microbiological methods will be the analysis of water for total heterotrophs, fungi and *E. coli* (as a proxy for faecal coliforms). There will be an opportunity to identify eukaryotic microbes by morphology using microscopy in order to identify bioindicators for certain substances (e.g. herbicides or heavy metals).
- Thermal properties of the materials used in the GI system. The main objective of this test is to determine the thermal properties of the materials that are part of a swale which will be used as input for numerical models. The equipment that will be used in these Non-Destructive Tests (NDT) is based on the modified transient plane source technique (TCI) described in the ISO/DIS 22007-2.2 [22].
- Thermal performance of GI for its potential application within a Ground Source Heat Pump (GSHP) geothermal device. Several temperature sensors will be embedded within the profile of the GI laboratory models, which will be subjected to varying temperatures to simulate the performance of a shallow geothermal device.

As per indicated before, the last area of this methodology has already started, and therefore, its experimental methods will be explained in more detail as follows. Two types of swales will be explored in this research: dry swales and wet swales. For this first stage of the project, three laboratory models of dry swales were built within polyethylene containers (HDPE) with the experimental set-up showed in Figure 2. Plastic cells of 50 mm depth were placed at the bottom of the containers and covered with a non-woven polypropylene based geotextile for ensuring the correct drainage capacity of the structure. This will also act as a separation layer in order to avoid the scouring of fine particles. Limestone coarse aggregates with a continuous gradation 18-35 mm were used as a sub-base layer (Figure 1).

A 5m length polypropylene flexible pipe and 20 mm diameter was located 50 mm over the bottom of the sub-base layer, forming five loops within the sub-base of aggregates. The minimum distance of the flexible pipe with the containers' walls and between different parts of the pipe itself was 100 mm. Four temperature sensors were placed inside the swale structure, at different heights from the bottom of the container (100, 200, 300 and 400 mm) in order to measure the gradient of temperature within the structure of the swale. The temperature was measured every 30 sec. Two type K thermocouples were placed inside the pipe, at the inlet and at the outlet of the structure (see Figure 2), and connected to a thermometer which measures the temperature of the inflow and outflow water with a frequency of 30 sec. A plastic tank of 5 L capacity was used as a water reservoir and connected to a hydraulic pump of 43W which generated a water flow of 1 L/min inside the pipe looping. An electric resistance was placed inside the water reservoir and used for heating the water when necessary.

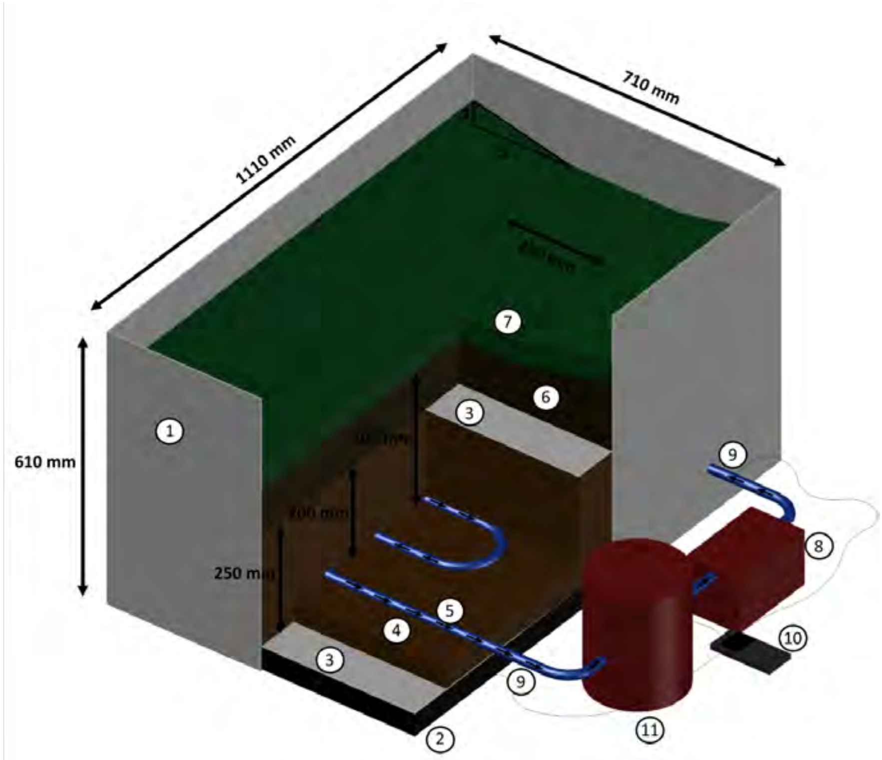

Fig. 2. Scheme of the dry swale structure and the experimental set-up: (1) Polyethilene container; (2) Plastic cells; (3) Non-woven polypropylene based geotextile; (4) Sub-base layer; (5) Flexible pipe; (6) Base layer; (7) Vegetated surface; (8) Hydraulic pump; (9) Thermocouples; (10) Digital thermometer; (11) Water reservoir tank.

Preliminary tests were conducted in which the water in the reservoir was heated until 50ºC and pumped through the pipe. The water was recirculated for 340 min without any further hearting, and the thermal behaviour of the system and the structure was assessed under those conditions. Control tests carried out just for the flexible pipe were also performed in order to assess the influence of the structure of the dry swale in the observed behaviour.

2.3. Numerical Modelling Simulations

The methodology for the numerical simulations is known in the field of engineering simulations and testing as Hybrid Engineering (HE). This methodology joins mathematical methods and experimental tests to solve actual problems in Industrial and Civil Engineering. This method is based upon the use of prototypes in order to validate numerical models that have been developed through the numerical simulations. Firstly, in the initial phases of the HE method applied to a specific research project, simulation is used to define the problem in terms of quality instead of quantity. Then, numerical simulations are used to aid the thinking process, specifying the conceptual design and the architecture of a new development. Numerical simulations simplify the initial decisions and make the process to obtain the prediction of the solution easier. Secondly, prototype tests validate numerical modelling, and by doing so, numerical simulations provide an accurate solution as well as an optimized one. The combination of mathematical models and scale prototype tests provides an accurate and efficient method to solve engineering problems.

Numerical simulations will be divided into two steps as per indicated as follows:

- Numerical Simulation of GI. The thermal performance of GI will be studied in finite element models (FEM) and validated through the experimental results obtained in the thermal performance of GI.
- Design Of Experiments (DOE). This technique will be used to determine the influence of different GI parameters (geometry, thermal properties of the materials used, etc.). The results obtained would allow optimising these systems for its implementation to real scale, adding real value for money to the project.

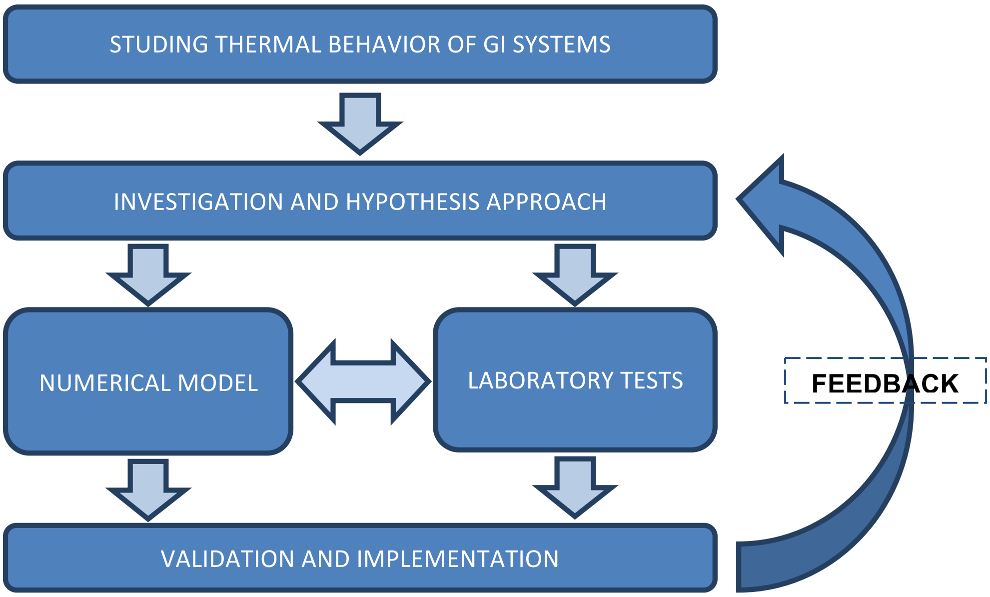

Fig. 3. The Hybrid Engineering (HE) methodology applied for this research project.

3. INITIAL RESULTS AND DISCUSSIONS

The initial results of this research project which started on February 2016 have been mainly based upon the establishment of a rigorous methodology including laboratory and field experiments which sets the bases to obtain the data for the entire monitoring period starting by June 2016 and lasting until June 2017.

3.1. Field monitoring

The first phase of the field monitoring started at the end of June at the first site in Ryton Organic Garden (Table 1) with the installation of the monitoring instrument and the beginning of the readings of the water levels and the temperature at the discharge point of the swale (Figure 5).

Fig. 5. a) Wet-swale in Ryton Gardens, Coventry; b) Detail of the OTT Orpheus Mini water level used to monitor the swale in Ryton Gardens.

The first results indicated a period of heavy rainfalls followed by a dry period where the swale became completely dry. No water was observed (4 cm was the ground level established initially). However, the formation of a thick layer of mud was one of the most interesting findings. Figure 5 pictures one of the periods of moderate water level in the swale (around 12 cm). The maximum level of water in the swale was reached by the end of July (17 cm), coinciding with the lowest average temperature and the highest rainfall events of the period.

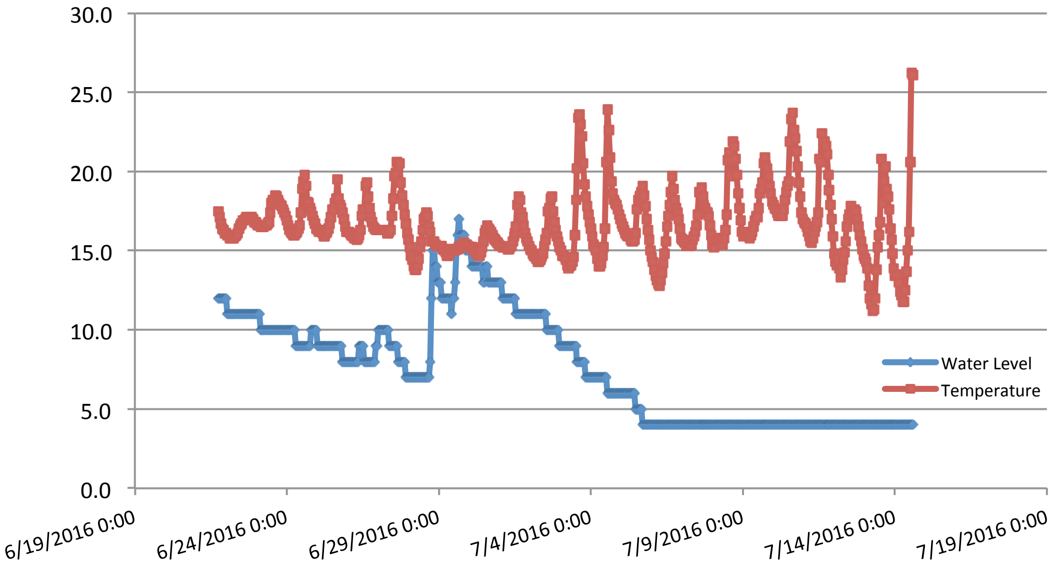

Fig. 6. Initial results of the water level at the discharge point of the swale in cm (blue line and rhombus points) and the temperature inside the swale in ºC (red line and square points) from the 24th June till the 14th July 2016.

As it can be seen in Figure 6, the water levels and the temperatures registered in the swale are quite variable and dependable of the rainfall regimes. Also, the periods when the swale is in dry conditions, the temperatures within the swale are less moderate and more influenced by the atmospheric conditions.

3.2. Laboratory experiments

The installation of the laboratory equipment for the monitoring of the thermal performance of the different layers of the dry swale has been completed as it can be seen in Figure 7.

Fig. 7. Experimental setup of the laboratory simulations on the thermal performance of dry swales.

The results obtained for the initial tests specified in the methodology showed a temperature variation inside the laboratory model that ranged between 0.1 and 2.5 ºC, depending on the nearness of the probes to the pipes (Figure 8). The results obtained are promising, showing more temperature dissipation inside the swale structure in relation to the control tests carried out on the flexible pipes, probably due to some thermal transfer with the sub-base aggregates by induction mechanisms. This result indicates the good performance of the system as heat dissipater despite the increment in the temperature inside the swale.

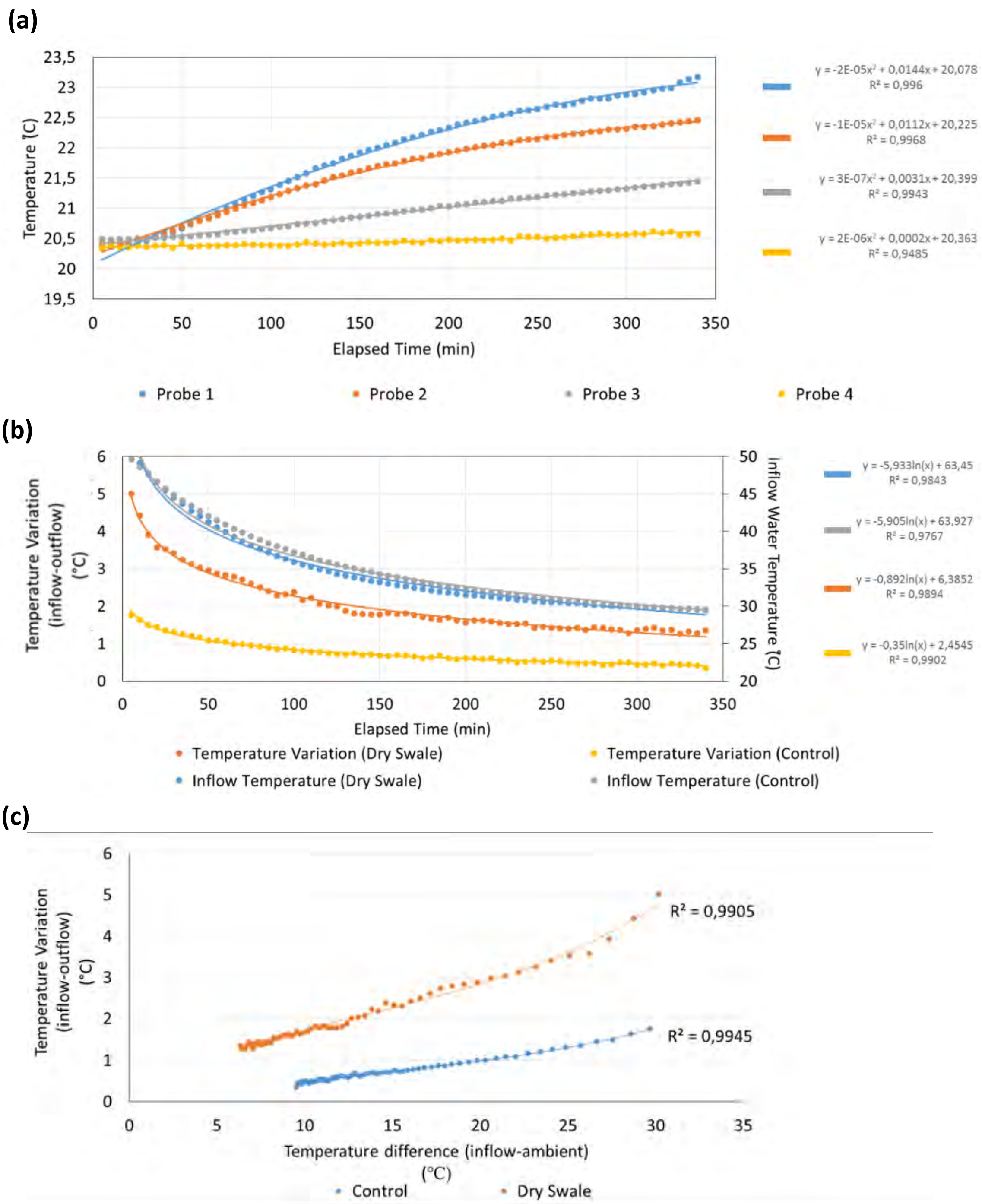

Fig. 7. Preliminary results of the temperature evolution obtained in dry swale structures and control tests: (a) Inside the dry swale structure; and (b) in the circulating water inside the system.

Further experiments at different temperatures (5, 10, 20, 30, 40 and 50ºC) are needed for a better understanding of the thermal behaviour of swale structures under different scenarios of temperatures and water flows inside the system. Rainy and wet conditions will be part of the study as well.

4. PRELIMINARY CONCLUSIONS

As preliminary conclusions obtained so far in the initial stage of the preparation of the pilot study are as follows:

- A combined and new approach to Water Sensitive Design by implementing the suggested "Pyramid of the sustainable management of water, food and energy" which aims to provide a wider benefit by enhancing the variety of ways to face infrastructural challenges such as flood resilience, food production and energy saving.

- A methodology in the laboratory and in the field can be established in order to determine whether a combined system of Green Infrastructure and Renewable Energy works as a proof of concept.
- Initial results in the field and in the laboratory have shown a promising path towards the application of renewable energy in Green Infrastructure.

Research data will be presented at the conference for a range of time covering the initial experiments between mid-June and early September.

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COMPETING INTERESTS

The authors declare no conflict of interest.

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Waste heat recovery from showers: Case study of a university sport facility in the UK

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ABSTRACT

Recovery of waste water heat in the discharge from showers to preheat the incoming cold water has been promoted as a cost effective, energy efficient and low carbon design option. Its ability to reduce carbon emissions is recognised in the domestic Standard Assessment Procedure (SAP) - the energy assessment tool in the UK for demonstrating compliance with the Building Regulation Part L for dwellings. Incentivised by its carbon-cost effectiveness, waste water heat recovery units have been incorporated in the newly constructed Falmer Sports Pavilion at the University of Brighton in the UK. This £2m sports development serving several football fields was completed in August 2015 providing eight first-rate changing and shower rooms for students, staff and external organisations. There are six shower rooms on the ground floor and two shower rooms on the first floor, each fitted with 5 or 6 thermostatically controlled shower units. Inline type of waste water heat recovery units are installed, each consisted of a copper pipe section wound by an external coil of smaller copper pipe through which the cold water is warmed and subsequently supplied to the shower mixers.

This paper reports on the performance evaluation of this waste heat recovery system with the aims to establish the in-situ energy performance and the annual energy and savings. Extracting details from the specification and the schematic diagrams, a heat transfer mathematical model representing the system has been established, which informed the development of the methodology for measuring the in-situ performance of individual and multiple use the showers in each changing room. Using a system thinking modelling technique, a quasi-dynamic simulation computer model was developed. The model incorporated the heat transfer components utilising performance parameters monitored in situ. It also featured the use of probabilistic profiles of daily usage over the whole year. The results indicated that the thermal effectiveness was over 60% with significant potential for energy saving but the overall reduction was largely influenced by the volume of water used. Although the payback periods were long, they could be much reduced through more effective design, correct installation and market competitions.

Keywords: domestic hot water, showers, heat recovery, modelling, energy and cost savings, sport facilities

1. INTRODUCTION

With significant thermal improvements and adoption of low energy lights and appliances, domestic hot water energy consumption is fast becoming the major component of energy expenditure in modern buildings. The main use of hot water in domestic buildings is for the shower/bath which accounts for nearly 21% of the total consumption [1]. Hot water is normally heated by gas or electric boilers which raise the temperature to over 60° and mixed with cold water to a temperature of around 40°C, in the case of use for showers, before the water is used. This low grade heat in the warm water, which normally discharged to the drain, still has a much higher temperature than the incoming cold water, hence, offers a good potential for heat recovery. Among a number of heat recovery options available for designers, in-line pipe heat exchanger (see Figure 1) presents some distinct advantages as they have no moving parts, compact and proclaimed to have higher heat recovery efficiencies.

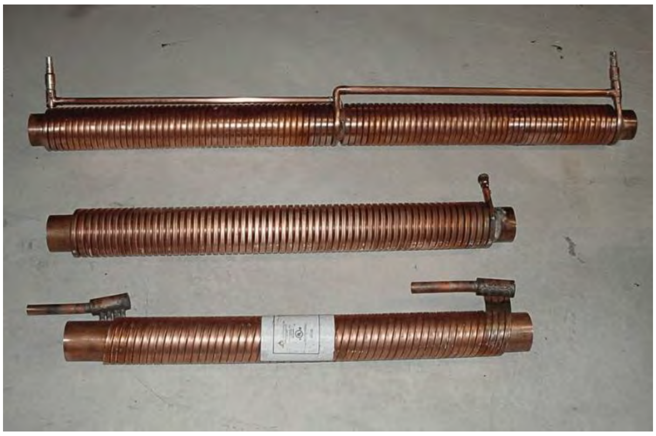

Figure 1 Example tubular design WWHR pipe products [2]

Incentivized by its carbon-cost effectiveness and the recognition in the UK's Standard Assessment Procedure – an energy assessment tool for demonstrating compliance with Part L of the Building Regulations for dwellings [3] - waste water heat recovery units have been incorporated in the newly constructed Falmer Sports Pavilion at the University of Brighton in the UK. This £2m sports development serving several football fields was completed in August 2015 providing eight first-rate changing and shower rooms for students, staff and external organisations. There are six shower rooms on the ground floor and two shower rooms on the first floor, each fitted with 5 and 6 thermostatically controlled shower units. Inline type of waste water heat recovery units were installed, each consisted of a copper pipe section wound by an external coil of smaller copper pipe through which the cold water would be warmed and subsequently supplied to the shower mixers.

This installation provided an opportunity for evaluating the in-situ performance of WWHR, in collaboration of the Estate Department of the university, enabling the collection of data for informed decision making of future adoption of such technology in new or refurbishment projects. The research aims are twofold: firstly to establish the effectiveness of this device in operation; secondly to identify the potential cost and energy savings under different operating conditions. The tasks thus involved developing a methodology for performance measurements on the installations on site; developing a modelling tool for performance evaluation; measuring the in-situ performance and establishing the annual energy and cost savings.

2. METHODOLOGY

Opened in 2015, the Sport Pavilion is a two-storey multi-use facility at the University of Brighton's Falmer campus, see Figure 2. The ground floor features a plant room and changing rooms for the surrounding sports complex. The upper floor features two further changing rooms, four seminar rooms, toilets and first-aid room.

Domestic hot water is produced by a series of grid supplied natural gas boilers. The eight main changing rooms each has a block of five or six showers. Each shower block on the upper floor utilizes a single heat recovery pipe mounted into the vertical PVC-u drainage stack below; the six rooms on the ground floor could not use this configuration so employed two horizontal heat recovery pipes. The configuration of the shower units and the heat recovery pipe for one shower room on the first floor is illustrated in Figure 3.

Fig. 2. Changing room layout

Based on the system schematic configuration, mathematical equations describing the thermal model were established which enabled the identification of key parameters for experimental measurements. Data were collected under different operating profiles to establish the effectiveness of the heat recovery pipe, which were subsequently applied to the simulation model to evaluate the weekly and annual system performance and potential savings.

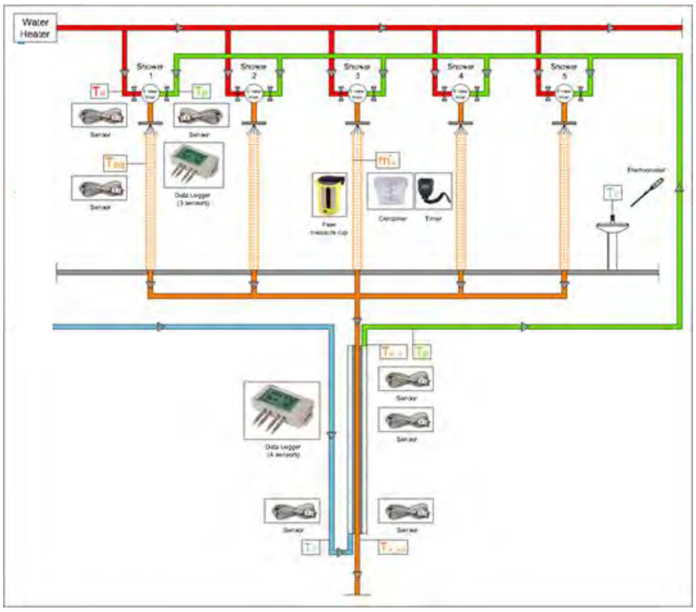

Fig. 3 System configuration and experimental measurements

2.1 Thermal and simulation models

The heat recovery unit is a counter flow heat exchanger, its efficiency can be represented by the term effectiveness ε [4] as:

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}}$$

Where $\dot{Q}_{max}$ is the theoretical maximum heat transfer rate, for counter flow is:

$$\dot{Q}_{max} = C_{min} * (T_{h,in} - T_{c,in})$$

If the effectiveness is known then the thermal power exchanged will be:

$$\dot{Q} = \varepsilon * C_{min} * (T_{h,in} - T_{c,in})$$

$$C_{min} = \min\begin{cases}\dot{m}_c * c_{p,c}\\ \dot{m}_h * c_{p,h}\end{cases}$$

The heat transfer between the hot fluid $\dot{Q}_c$ and the cold fluid $\dot{Q}_h$ are:

$$\dot{Q}_c = \dot{m}_c * c_{p,c} * (T_{c,in} - T_{c,out})$$

$$\dot{Q}_h = \dot{m}_h * c_{p,h} * (T_{h,in} - T_{h,out})$$

At each shower mixer the following mass and energy balance equations are applied:

$$\dot{m}_w = \dot{m}_h + \dot{m}_c$$

$$(\dot{m}_h * T_h) + (\dot{m}_c * T_{p,in}) = (\dot{m}_w * T_{eq})$$

Where:

C_{min} represents the smaller thermal capacity

$\dot{Q}$ *and* $\dot{Q}_{max}$ are the actual and maximum heat transfer rate [W]

$\dot{m}_c, c_{p,c}$ *and* $\dot{m}_h, c_{p,h}$ are mass flow rates [kg/s] and specific heat capacities [J/kg K] of the cold and hot fluids.

T_{eq}, T_h, and $T_{p,in}$ are the temperatures of the water coming out from the shower, hot water and cold water supplies

2.2 Experimental measurements

Parameters identified for the measurement and the corresponding equipment used are shown in Table 1 and illustrated in Figure 3. Experiments are carried out to establish the heat transfer effectiveness of the heat recovery pipe and the results are later applied in the simulation models. As the experiment commenced after the project handover, only parameters accessible for measurements were considered.

Table 1. Parameters in experimental measurements

Parameter	***Unit***
Mixer	
Shower mass water flow rate	kg/s
Shower water temperature	°C
Hot water temperature	°C
Inlet preheated water temperature	°C
Heat recovery pipe	
Pipe heat exchanger	
Inlet drain water temperature	°C
Outlet drain water temperature	°C
Inlet preheated water temperature	°C
Outlet preheated water temperature	°C

2.3 System simulation

To enable annual evaluation and be able to apply the results to other types of buildings and system configurations, a dynamics system simulation software was adopted which allowed quasi-dynamic simulation of operation of shower units. The selected system thinking simulation software STELLA [5], allows dynamic visualization and communicate of complex systems. It has been adopted to evaluate the thermal performance and potential energy savings under different usage profiles. The model building process is realized through the use of "Stocks and Flows and Causal Loop" diagrams [6], as shown in Figure 3, to represent the overall causal relationships existing between parts composing the system. An interactive user friendly interface has been developed in the software which allows effective input-output for case study evaluations as shown on the right hand side of Figure 4.

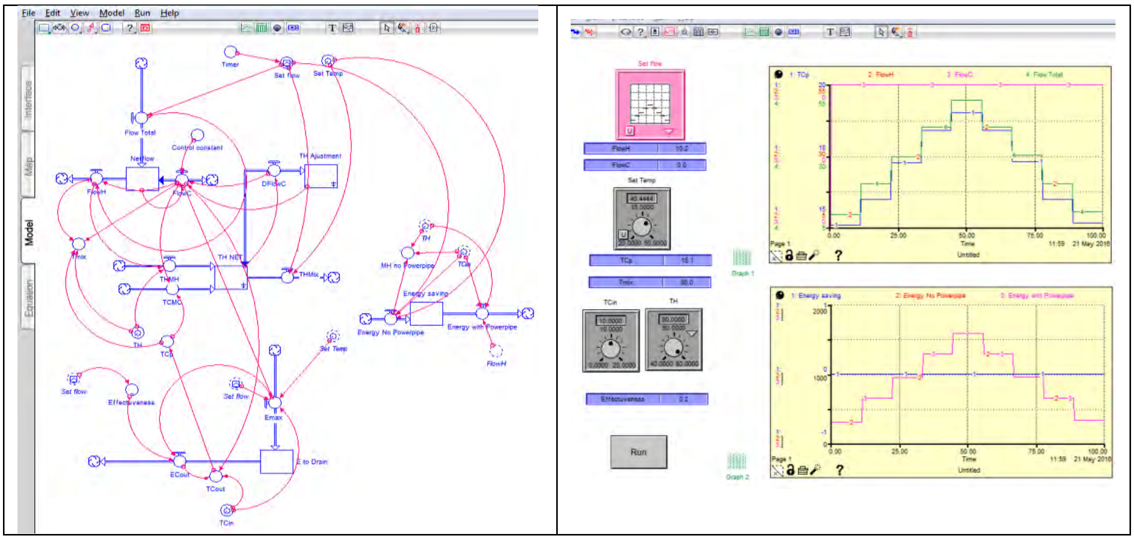

Fig. 4. System model (left) and user interface (right)

Projected user profiles based on estimates from the sport centre were established for evaluating impacts to the annual energy consumptions and financial costs. Firstly the profiles of simultaneous demand of hot water due to number of showers in operation with respect to three group sizes of 10, 15 and 20 users were established, see Figure 4. Secondly four weekly room usage scenarios (see table 2), from light to intense intensities, were devised enabling evaluation of periodic water demand and energy consumptions.

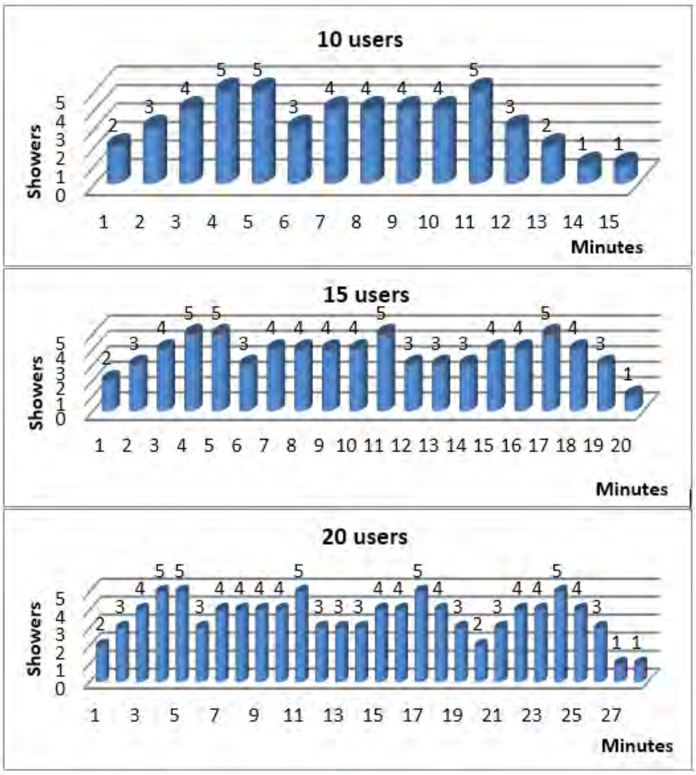

Fig. 4. Showers in use and duration for three groups types

Table 2. Scenarios of usage of different intensities

SCENARIO 1							
2 TEAMS: 1 Football, 1 Rugby (2 Trainings, 1 Match for each)							
	M	T	W	T	F	S	S
1				R-10			
2				R-15			
3							
4							
5		R-10				R-15	
6		R--15				R--15	
7	F--10		F--15		F--20	R--15	
8	F--15		F--10		F--20	R--15	

SCENARIO 2							
3 TEAMS: 2 Football, 1 Rugby (2 Trainings, 1 Match for each)							
	M	T	W	T	F	S	S
1				R-10			
2				R-15			
3	F-15		F-15				
4	F-10		F-10				
5		R-10				R-15	F-20
6		R--15				R--15	F--20
7	F--10		F--15		F--20	R--15	
8	F--15		F--10		F--20	R--15	

SCENARIO 3							
4 TEAMS: 2 Football, 2 Rugby (2 Trainings, 1 Match for each)							
	M	T	W	T	F	S	S
1				R--10	R--10		R--15
2				R--15	R--15		R--15
3	F--15		F--15				R--15
4	F--10		F--10				R--15
5		R--10				R--15	F--20
6		R--15				R--15	F--20
7	F--10	R--15	F--15		F--20	R--15	
8	F--15	R--10	F--10		F--20	R--15	

SCENARIO 4							
6 TEAMS: 3 Football, 3 Rugby (2 Trainings, 1 Match for each)							
	M	T	W	T	F	S	S
1				R--10	R--10	R--15	R--15
2				R--15	R--15	R--15	R--15
3	F--15	R--10	F--15			R--15	R--15
4	F--10	R--15	F--10			R--15	R--15
5	F--15	R--10	F--15		F--20	R--15	F--20
6	F--10	R--15	F--10		F--20	R--15	F--20
7	F--10	R--15	F--15	R--10	F--20	R--15	
8	F--15	R--10	F--10	R--15	F--20	R--15	

Where F represents Football and R for Ruby, the associated number indicates the number of users.

3. RESULTS AND DISCUSSION

Summary results for changing room 8 which represents a typical installation correctly installed with the vertical configuration and counter-flow arrangement are reported. Table 3 shows the flow and temperature values when three shower heads were operating simultaneously. The calculated effectiveness of 0.647 indicates that nearly 65% of the maximum possible recoverable heat can be retrieved to preheat the incoming cold water resulting in temperature rise of nearly 10°C.

Table 3. Indicative parameters and effectiveness

Parameter	***Symbol***	***Value***	***Unit***
No of showers running	--	3	--
Shower water flow rate	$\dot{m}_w$	0.2	kg/s
Hot water flow rate	$\dot{m}_h$	0.11	kg/s
Preheated water flow rate	$\dot{m}_p$	0.085	kg/s
Shower water temperature	T_{eq}	31.6	°C
Hot water temperature	T_h	50.6	°C
Inlet preheated water temperature	T_{p_in}	17.4	°C
Inlet Drain water temperature	T_{w_in}	25.6	°C
Outlet Drain water temperature	T_{w_out}	16.9	°C
Inlet cold water temperature	T_{c_in}	10.4	°C
Outlet preheated water temperature	T_{p_out}	20.3	kW
Effectiveness	ε	0.65	/

Table 4 is the weekly saving based on the assumed scenarios. The weekly savings vary between £40 and £119 are highly dependent on the water usage correspond to the water consumptions in the four scenarios.

Table 4. Weekly savings

	User profile	No. of sessions	Energy Recovered		
			Per session	Weekly	Weekly total
			kWh	kWh	kWh
Scenario 1	1	4	1.99	7.96	39.80
	2	8	2.99	23.88	
	3	2	3.98	7.96	
Scenario 2	1	6	1.99	11.94	57.71
	2	10	2.99	29.85	
	3	4	3.98	15.92	
Scenario 3	1	8	1.99	15.92	79.60
	2	16	2.99	47.76	
	3	4	3.98	15.92	
Scenario 4	1	12	1.99	23.88	119.40
	2	24	2.99	71.64	
	3	6	3.98	23.88	

Table 5 is a simple financial analysis on the potential periods of payback of the scenarios studied. The payback periods of over ten years may be considered as long, but the heat recovery units are maintenance free and replacement is deemed unnecessary over the life of the building. Judging by the actual water flow volumes, there is significant saving if only one recovery pipe was used to serve two change rooms and the pipes were better insulated to minimise the heat loss as indicated by the reduction in temperature of the cold water entering the shower heads.

Table 5 Payback analysis

	Unit	Scenario			
		1	2	3	4
Annual savings @40 weeks/yr	kWh	1592.00	2308.40	3184.00	4776.00
Fuel cost (gas @£0.0166/kWh)	£	26.43	38.32	52.85	79.28
Pay back @£960/unit	Year	36.33	25.05	18.16	12.11
Pay back for 1 unit serving 2 shower rooms	Year	18.16	12.53	9.08	6.05
Cost for return in investment 5 years	£	827.86	768.40	695.73	563.59

4. CONCLUSION

This study has demonstrated the utilization of waste heat recovery technology in a sport facility where a high simultaneous usage of hot water for showers was expected. The results showed that correctly installed pipe heat exchangers exhibited good effectiveness to recovering heat from the waste water. Such devices are certainly cost effective in cases where there is sufficiently high water volume flows. However, with water efficient low flow shower heads the amount of heat can be recovered from the waste water is reduced resulting in the payback periods in excess of 10 years. Nonetheless, this can be significantly reduced if the full capacity of the heat recovery pipe is utilized through combining two discharges from two change rooms and the pipework are better insulated. Long durability and maintenance free are clear benefits to this kind of system. This on-going research will continue to explore the life cycle environmental impact and to develop the simulation model to extend the evaluation of the wider impact on the capacities of heating plants and associated equipment.

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The Water, Energy and Carbon Footprints of Locally Produced Tomato Paste in the UK

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ABSTRACT

Currently, all tomato paste consumed in the UK is imported from other countries. This paper explores the water, energy and carbon implications of this and compares it with a hypothetical case where demand would be locally met. The water, energy and carbon footprints and other environmental impacts are quantified using water footprint and life cycle assessment (LCA) methods for all phases of tomato paste production including cultivation, manufacturing, packaging and transportation within the supply chain. The approach is demonstrated by comparing the impacts of internationally and locally produced tomato paste for consumption in Oxford City. Results indicate that the water footprint is considerably smaller for the local production case as compared with imported tomato paste. However, the energy and carbon footprints of tomato cultivation are quite large in local heated greenhouses although this is partially offset by the energy savings resulting from reduced transportation. This exemplar reveals the benefits of considering simultaneously the impacts of water, energy and carbon footprints on the sustainability assessment of local food production.
Keywords: Environmental impacts, Local food production, Tomato paste, Water footprint.

1. INTRODUCTION

Investigating the water and energy footprints in the supply chain of food products can be particularly important when the food supply chain consists of production and consumption far away from each other. Exploring alternative localised food systems near consumption markets may be considered as a viable option that may potentially reduce negative environmental impacts [1]. For instance, tomato cultivation in the UK is in heated greenhouses as compared with mainly open field-grown or unheated greenhouses in the Mediterranean area. Although energy demand for heating when cultivating Mediterranean field-grown tomatoes is less than for heating greenhouses in the UK, groundwater withdrawals for irrigation of tomatoes in Mediterranean areas can adversely affect water supplies, deplete vulnerable water resources, increase soil salinization and decrease water quality through eutrophication and pesticide contamination in a long-term horizon. Additionally, water abstraction for open-field irrigation requires energy for pumping water from the ground or surface water body and for distribution, while intense cultivation of greenhouse tomatoes typically requires less water and less energy for withdrawals and distribution because water is re-circulated and evapotranspiration is more controlled within greenhouses.

There are a number of methods and tools for evaluation of environmental impacts as well as water, energy and carbon footprints of a product [2-3]. The water footprint of a product is an indicator of direct and indirect freshwater use to produce the product over its full supply chain [4]. Similarly, energy and carbon footprints are the direct and indirect energy used and carbon emission (CO_2) to produce a unit volume/mass of the product. The water used during the cultivation phase of food supply chains usually accounts for the highest proportion of the water footprint of a product [4]. Life Cycle Assessment (LCA) is a common approach for evaluation of the environmental impacts of a product over its life cycle (i.e. 'cradle to grave') [2]. LCA methodologies and tools are regulated by the ISO 14040 for principles and framework and the

ISO 14044 for requirements and guidelines [3]. SimaPro is a commonly used LCA tool for quantifying environmental impacts including the energy and carbon footprints of a product [2]. Numerous LCA studies of food products in the academic literature have been mainly focused on environmental impacts of the cultivation phase [6] while others have been predominantly focused on the manufacturing phase [2 and 5]. However, the LCA analysis of these two phases concurrently with the transportation phase in the food industry has received less attention [3], especially when analysing local food production alternatives. In the specific case of processed tomato products such as tomato paste, the possible scenario for local production is that both cultivation and manufacturing phases are conducted in the same (small) geographical area because of the short shelf-life of fresh tomatoes. This paper aims to explore the implications of locally producing tomato paste in terms of water, energy and carbon footprints as compared to the 'business as usual' scenario: importing this product. To do this, a complete LCA of tomato paste production is undertaken for both the business as usual and localised tomato paste production scenarios, where tomato cultivation and manufacturing phases are conducted locally to meet demands.

2. METHODOLOGY

SimaPro version 7.1.2 is used for modelling the full LCA of tomato paste in four main phases: cultivation, manufacturing, packaging and transport [2]. CROPWAT model is also used as a tool for the calculation of the water demands of crops during cultivation [7]. In the analysed scenarios, it is considered that tomato paste is currently imported from Italy (business as usual), and that this will be replaced with locally produced tomato paste with a 150km radius around Oxford City, UK which has been selected as the case study of the Local Nexus Network (LNN) project [1]. Data for the production phases for imported tomato paste are taken from the study conducted for Emilia Romagna in Italy [3]. Italy is the world's third largest producer of processed tomato products and Emilia Romagna is the biggest producer of processed tomatoes in Italy. LCA inventory data and other assumptions for both modelled cases, imported and locally produced tomato paste, are divided into four phases as outlined below.

The functional unit is a glass jar of single concentrate tomato paste (i.e. 12-14% dry matter) with a net weight of 0.7 kg. The manufacturing of this amount of tomato paste requires 1.39 kg of fresh tomato [3]. Energy, water and greenhouse gas emissions resulted from both resources consumption (i.e. embodied) and system operation for all production phases are analysed. The impacts due to infrastructure life cycle (e.g. depreciation of infrastructure) are not considered in the assessment. The foreground inventory data have been mainly obtained from the interviews conducted in this study for the hypothetical local tomato paste data [1], the Emilia Romagna case in Italy for imported product [3], and literature review for other required data [4-6]. The background life cycle inventory data have been largely sourced from the BUWAL 250, Ecoinvent unit processes and LCA Food DK databases [2].

The first LCA phase is tomato **cultivation** which is based respectively on open field-grown tomatoes in Emilia Romagna and heated greenhouses in the UK. The main activities relevant to the case of open field-grown are seedling production in greenhouses, soil tillage, transplanting, fertilising (nitrogen, phosphorus and potassium), irrigation and pesticide application. The main activities in heated greenhouses include seedling production, transplanting, fertilising (nitrogen, phosphorus), re-circulated irrigation, heating, lighting and traction. Three categories: blue, green and grey water are considered for the water footprints calculated for the cultivation and manufacturing phases [4]. Blue water refers to the volume of water consumption from various sources including surface and underground while green water refers to the rainwater (not runoff) and natural soil moisture consumed.

Manufacturing comprises the second LCA phase and includes a number of activities (e.g. unloading, chopping, blanching, concentrating, filling and packaging). The main raw materials and sources required for the operation of all these activities are electricity, diesel, natural gas and water. The manufacturing phase of the local production case is assumed to have the same activities, and raw and operational materials as the imported Emilia Romagna tomato paste. Also note that electricity from the two cases of Italy and UK have different emissions.

Packaging entails the sourcing, production and end of life of the materials used for packaging tomato paste in the manufacturing phase (i.e. glass bottle, tinplate, label and plastic/cardboard tray/pallet). The end of life scenarios considered here are a specific proportion of packaging waste taken for recycling, incineration (energy recovery) and landfill based on national averages [3].

Transport phase takes into account transport of raw materials and final products by lorry in four stages: agricultural input from local suppliers to farm; transfer of fresh tomato from farm to factory; transportation of packaging materials from local/national suppliers and distributing tomato paste bottles to retailers. In the case of imported tomato paste, it is assumed cultivation and manufacturing are performed in Italy and then imported from Italy to the UK by lorry (i.e. a distance of 1620km) while in the locally produced tomato paste, all phases are conducted in the local area (i.e. 150km).

The methods used to quantify the final product footprints here include Cumulative Energy Demand (CED) for energy footprint [2], CML 2001 for carbon footprint and other environmental impacts [2] and FAO Penman-Monteith [7] and Water Footprint Network (WFN) for Water Footprint (WF) [4]. Note that the FAO Penman-Monteith method is used to estimate blue and green WF and the WFN method is used for estimation of grey WF.

3. RESULTS AND DISCUSSION

Table 1 presents key environmental impacts for the four phases, based on a 0.7 kg glass jar of tomato paste for the two case studies. The energy estimated by the CED method includes both renewable (biomass, water, solar, wind and geothermal) and non-renewable (fossil, nuclear) sources. The carbon impacts in the CML 2001 method are presented as 100-year Global Warming Potential (GWP100). Other impact categories include Photochemical Oxidation Potential (POP), Ozone layer Depletion Potential (ODP), Acidification Potential (AP) and Eutrophication Potential (EP), and the Water Footprint (WF) is also included. Results in Table 1 highlight the areas of concern in terms of negative environmental impacts for both imported and locally produced tomato paste. For example, the water footprint for the local production case is considerably smaller (5 times) than imported tomato paste due to the climate in Oxfordshire. On the other hand, the energy and carbon footprints and some environmental impacts (e.g. AP and EP) are quite large in local greenhouses although this is partially offset by energy savings due to reduced transport. The increased negative environmental impacts of the local production case are linked to the large amounts of energy and associated emissions required to heat greenhouses (i.e. 75% for GWP100).

Table 1. Total environmental impacts for a glass of 0.7kg tomato paste

Impact category	Unit	Production type	Total	Cultivation	Processing	Packaging	Transport
CED	MJ-eq	Imported	13.22	1.45	2.01	4.36	5.41
		LP[1]	46.09	38.21	2.01	4.36	1.51
GWP100	kg CO_2-eq	Imported	0.692	0.064	0.124	0.188	0.317
		LP[1]	3.06	2.66	0.124	0.188	0.089
POP	g C2H4-eq	Imported	0.139	0.013	0.020	0.043	0.063
		LP[1]	0.601	0.518	0.020	0.043	0.020
ODP	g CFC-11-eq	Imported	6.87E-05	6.34E-06	1.39E-05	4.43E-06	4.41E-05
		LP[1]	6.72E-05	3.67E-05	1.39E-05	4.43E-06	1.22E-05
AP	g SO_2-eq	Imported	3.806	0.328	0.353	1.294	1.831
		LP[1]	6.283	4.135	0.353	1.294	0.501
EP	g PO_4-eq	Imported	0.633	0.036	0.042	0.188	0.365
		LP[1]	2.637	2.306	0.042	0.188	0.099
WF	Litres	Imported	104.9	103.6	1.252	-	-
		LP[1]	20.56	19.31	1.252	-	-

[1] locally produced

A comparison of the environmental impacts across the four production phases shows that the cultivation phase is the major contributor (over 50%) of all energy and environmental impacts for the local production case (Fig. 1). However, in the imported case the contribution of the same impact categories for the cultivation phase is relatively small (less than 10%) compared to the environmental impacts of the transportation and packaging phases, which account for between 40% and 60%, and 30% to 40% of the total for most impact categories, respectively.

This analysis also suggests that an environmental bottleneck for local tomato paste production is the heating of greenhouses. Thus, every effort to mitigate this environmental burden should be prioritised if development of this localised production system is to progress. Some examples of such efforts may include the use of waste to produce decentralised energy for example via combined heat and power (CHP) if enough waste and/or biomass is available locally [5]. However, a major constraint, not looked at in this paper, still remains which is the availability of enough suitable land locally to enable cultivation of sufficient tomatoes to satisfy demand.

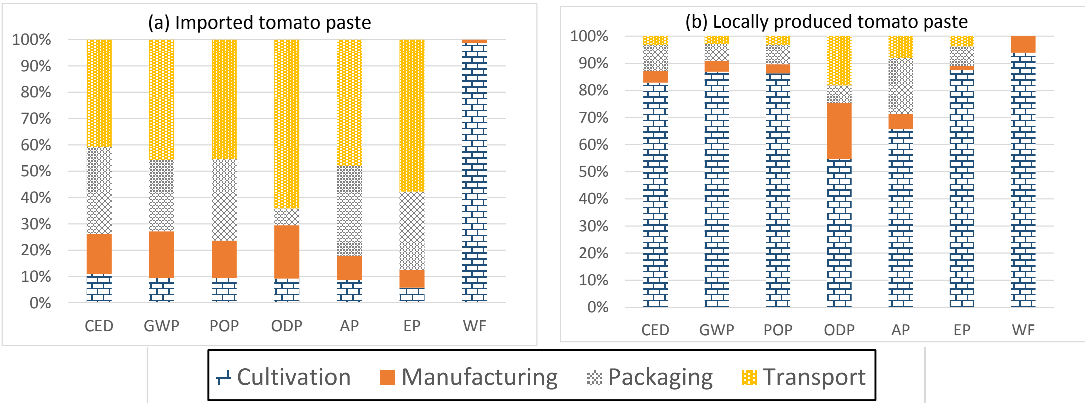

Fig. 1. Break-down of environmental impacts for all production phases

4. CONCLUSION

This paper presented a comparison of water, energy and carbon footprints calculated for locally produced tomato paste in the UK and imported tomato paste from Italy. The analysis suggests that local production of tomato paste in the UK could lead to significant savings in water consumption. However, energy and carbon footprints would increase considerably due to the need to heat an increasing number of greenhouses necessary to meet the demand for locally grown tomatoes. The use of decentralised renewable sources of heating such as CHPs may be considered for further investigation. This case study is a specific example of the water-energy-food nexus and gives a good insight into the interactions between these key resources.

ACKNOWLEDGEMENTS

The work reported is supported by the UK Engineering & Physical Sciences Research Council (EPSRC) project Building sustainable local nexuses of food, energy and water: from smart engineering to shared prosperity (The Local Nexus Network) (EP/M017753/1).

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Water Efficiency Conference 2016

Quantifying Water and Energy Savings Associated With Water Efficiency Retrofits

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ABSTRACT

Aims: To investigate the impact of a water efficiency retrofit programme at a primary school.
Study design: Following a water audit, a range of water efficient fittings were retrofitted to a school.
Place and Duration of Study: Tyseley, Birmingham, UK. April 2015 - May 2016.
Methodology: Water meter data was used to evaluate the pre and post intervention water and on-site energy savings. Options for further water savings by integrating rainwater harvesting systems were also investigated using a time-series analysis approach.
Results: The water efficiency retrofit included upgrades to the WC's, urinals and taps. Monthly water usage reduced by 25% (May 2015 vs. May 2016) generating an estimated annual saving of 220m^3 with a value of £623.
Conclusion: A simple payback period for the intervention was estimated at 3.9 years when the energy cost for hot water savings was also evaluated. Hot water savings reduced the carbon footprint of on-site water use by approximately 381 kgCO_2e. The further retrofit of a RWH was evaluated indicating that further WC and urinal water savings of approximately £735 / annum could potentially be achieved in an average year. Recommendations for additional monitoring systems within the school were proposed to enable estimates to be refined following a further year's monitoring programme.

Keywords: Water Saving, Energy Saving, Rainwater Harvesting, Retrofit.

1. INTRODUCTION

Water demand management (WDM) measures (also referred to as water efficiency measures) enable contemporary residential and commercial developments to be constructed in a manner that reduces the traditional water demand (based on l/p/d) by up to 50% [1][2]. However, the retrofitting of existing premises can be costly, especially where alternative water supply systems such as greywater reuse or rainwater harvesting are incorporated [3]. At a household scale, best practice water efficiency retrofits reported by Essex and Suffolk Water [4] can achieve measured savings of 22l/property/day (8m^3/annum). At a larger scale, commercial retrofits represent an area where water service providers (WSPs) can provide significant savings for their customers. In turn, peak and total water demands on a demand management area (DMA) are reduced, offering benefits to the WSP. In light of the forthcoming market reforms for non-domestic customers, information into the costs and benefits of achievable water efficiency retrofits will become increasingly valuable [5].

1. AIMS

This paper evaluates the water saving and on-site energy saving benefits associated with the delivery of a water efficiency retrofit (WER) at a primary school in Birmingham, UK. The school's water demand was monitored at 15-minute interval resolution. Data from Severn Trent Water's real time data collection platform was available for a period of 4 months prior to, and 10 months following the WER to enable a series of research questions to be investigated:

- RQ1: What was the impact of the WER on the annual water demand at the school?

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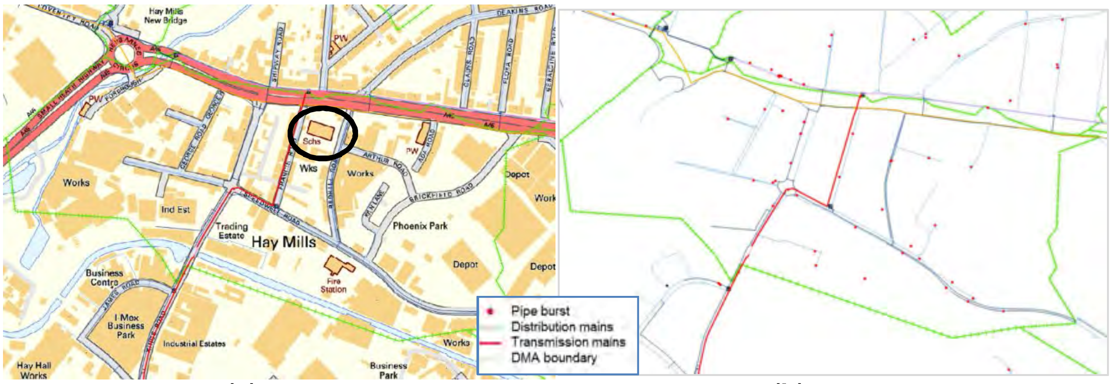
- RQ2: What is the payback period for the water efficiency retrofit?
- RQ3: What was the energy saving associated with reduced hot water demand?
- RQ4: Was leakage identified on site?
- RQ5: Would retrofitting rainwater harvesting provide further savings?
- RQ6: How can monitoring and data collection be improved?

2. METHOD

The school was selected as it is situated within Birmingham's Urban Demonstrator Site and Severn Trent Water is delivering a range of research projects as part of the project [6]. Furthermore, research into best practice for integrated water management is ongoing at the location as part of the EPSRC's TWENTY65 project [7]. Figure 1a shows the location of the school adjacent to the A45. Figure 1b describes historic pipe bursts within the District Metered Area (DMA), where the site is located. The school sits within a handful of terraced streets which are surrounded by industrial users. There are two large industrial consumers in its proximity in the adjacent DMA. Large industrial consumers are known to be sources of pressure transient events that could contribute to degradation of pipes and other assets that are hydraulically associated to these premises (the target school) [8]. Such degradations contribute to formation, development and expansion of cracks on pipes, causing leakage and potential pipe failures.



(a) (b)

Fig. 1 (a) School location (b) historical pipe bursts in the school's DMA

A water audit [9] was conducted on 01/05/2016 which identified the school has 242 students and 22 teachers. Details of the fittings (pre and post WER intervention) reported here are taken from this audit. The water fittings prior to the WER are described in Figure 2. The survey also specified a range of 41 water efficiency upgrades including measures for WCs, urinal controls and taps which were carried out in August 2015 for a cost of approximately £2,800. The report provided a conservative estimate of potential water savings at 17m^3/year with a combined water tariff (£2.83/m^3) saving of £47/annum projected. Comparisons of water demand data from a pre-intervention period were compared with data from the post-intervention period. This enabled discussion and analysis of each research question to be undertaken as described in Section 4.

Current Asset Details			
WC		**TAPS**	
Qty of Male toilets:	7	Qty of Hot taps:	42
Avg size Male Cistern (ltrs):	6.0	Avg Hot flow rate (ltrs/min):	9.0
Qty of Female/Mixed toilets:	23	Qty of Cold taps:	53
Avg size Female Cistern (ltrs):	6.2	Avg Cold flow rate (ltrs/min):	14.4
URINAL		**SHOWERS**	
Qty Uncontrolled Cisterns:	2	Qty Of Wall Mounted:	0
Avg LPM (ltrs/min):	0.1	Avg flow rate:	0.0
Qty Controlled Cisterns:	1	Qty Of Handheld:	2
Avg FPH(flushes/hour):	2.0	Avg flow rate:	12.0

Fig. 2 – Pre-intervention water audit data

4. RESULTS AND DISCUSSION

Processed water meter outputs are included in Appendices A, B and C to support the following section.

RQ1: What was the impact of the WER on the annual water demand at the school?
High resolution (15 minute) metering data was obtained for the mains water meter at the school for the period 01/04/2015 – 10/06/2016. With widely varying monthly water demands (Fig. A-2) and in the absence of a full year of data to analyse, April and May were selected as representative months. Comparisons of water demand pre-intervention (April and May 2015) and post-intervention (April and May 2016) were used to estimate the monthly water demand reduction achieved by the WER measures (Fig. B-1). The water usage reduced by 29% from 70.2m^3 to 49.8m^3 for April and by 25% from 78.1m^3 to 58.6m^3 for May. Figure 3 illustrates the reduction in average daily water demand for April and May 2015 and 2016.

With the seasonal use of the school, high demand variability was observed throughout the year. An estimate of the pre-intervention annual water demand was derived by adding 25% (the lower monthly saving identified) to the observed water use for post-intervention months. Hence, pre-intervention, the school's annual water usage was estimated as 880m^3. Post-intervention, this was estimated as 660m^3 representing a saving of 220m^3 (25%) per annum with a value of £623.

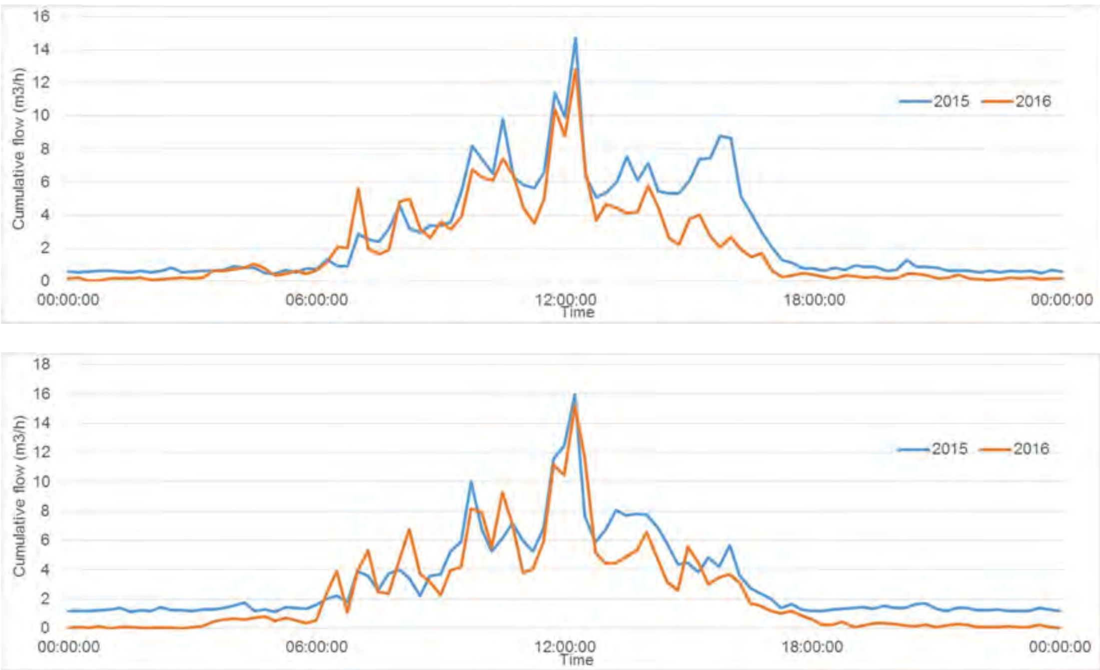


Fig. 3 – Water demand, daily profile, 2015 versus 2016, April (top), May (bottom)

RQ2: What is the payback period for the water efficiency retrofit?

With the capital intervention cost of approximately £2,800 a simple payback period was estimated at 4.5 years.

RQ3: What was the energy saving associated with reduced hot water demand?

The water savings achieved can be broken down into the following upgrade categories: WC; urinal controls; cold taps; and hot taps. Many of the existing WCs were identified as having a low water demand, with only 3 of the 30 WC's warranting upgrades. In contrast, all 3 of the male urinal systems were upgraded to utilise mains powered urinal controllers. The remaining water savings can be attributed to the upgrades at the school's 42 hot, and 53 cold taps. However, no sub-metering data was available to enable a detailed micro-component analysis to be undertaken. Consequently it is not possible to accurately evaluate the reduction in hot water savings. A conservative estimate of hot water savings was established as follows. The upgraded urinal controls and WCs were estimated to contribute no more than 50% (110m^3) of the total water savings. The average flow rates for tap fittings were reduced from 9.0l/min (hot) and 14.4 l/min (cold) to 6 l/min. Assuming all the school's taps were used equally, this suggests a ratio for pre-intervention water demand of 16:9 (cold:hot). This is based on 1) the higher flow rate recorded for the cold taps and 2) the higher proportion of cold taps. Assuming 50% of the water savings were attributed to the tap upgrades, the above ratio suggests 18% of savings could represent hot water savings (39.6m^3). Assuming hot water is heated on site using a 100% efficient gas boiler from 15^{o}C to 60^{o}C a first principles calculation can be undertaken. An annual energy saving has been estimated valued at £86 assuming gas costs 4.16p/kWh [10]. This also represents a carbon dioxide emissions reduction of 381kg/annum (based on 0.184 (kgCO_2e/kWh) [10]. A revised payback period can be estimated taking into account water and energy savings as 3.9 years.

RQ4: Was leakage identified on site?

Night-time flows within DMAs are often used as an indicator for leakage [11]. The school has no overnight accommodation and hence, water usage at night can be attributed to; 1) urinal flushing and 2) leakage. Night-time flows (11pm-6am) in April 2015 totalled 16.0m^3 (0.076m^3/hour). Corresponding night-time flows for April 2016 totalled 6.8m^3 (0.033m^3/hour). Without micro-component data illustrating the configuration and flush rates of the urinal controls, it is not possible to verify if this night-time flow is wholly attributable to urinal flushing or if there may be a low level leak(<0.03m^3/hour) on the customer-side of the meter.

RQ5: Would retrofitting rainwater harvesting provide further savings?

Melville-Shreeve et al. (2016) [6] reported a time series analysis method for evaluating RWH at a site. Utilising this approach a twenty year analysis of water saving efficiency was conducted using a *Central England* rainfall dataset at a daily time-step. It should be noted that this dataset represents an area of the UK with lower annual rainfall volumes than observed at the site (i.e. a conservative estimate is derived). The modelled RWH system was assumed to have a 10m^3 storage capacity, and it was assumed that 50% (800m^2) of the school's roof (1600m^2) could reasonably be routed into the storage tank. An installed cost of £10,000 was estimated. WC and urinal (i.e. rainwater) demand was assumed to comprise 50% of post intervention daily water demand. Hence a daily rainwater demand of 0.9m^3 was modelled (based on average use over 1 year). Figure 4 illustrates a single year's output from the simulation tool. This output represents an average year in which rainwater supplied 79% of WC demand. The chart illustrates periods where rainwater was exhausted (where the blue line reaches the x-axis).

Taking the estimated savings during an average year, and assuming a combined water tariff of £2.83 applies for the lifetime of the installation, the 10m^3 RWH system would save approximately £736 per annum giving a 13.6 year payback period assuming minimal costs for maintenance are necessary (i.e. local caretaker can operate and maintain the system).

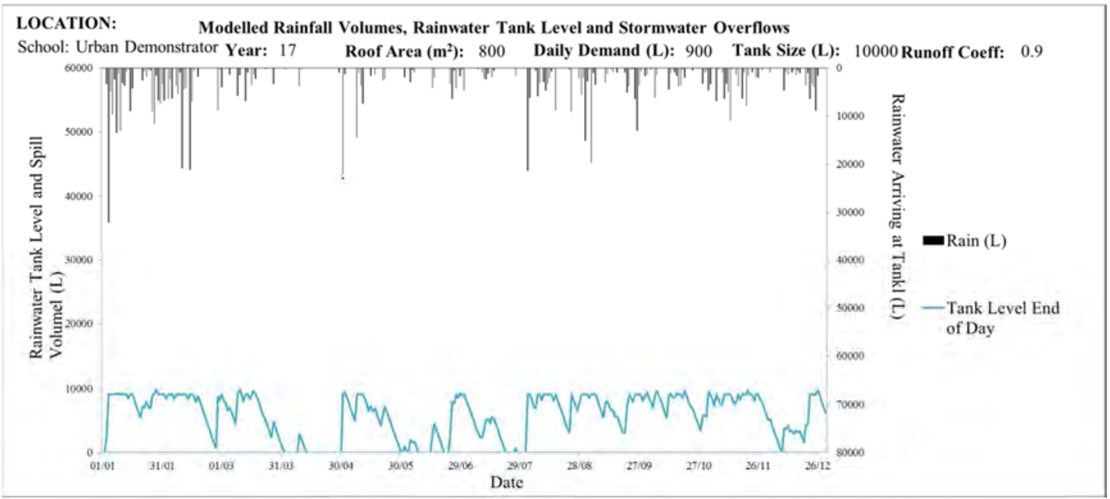


Fig. 4 – Rainwater Harvesting Tank Sizing Output for Average Year

Table 1 describes the max min and average water savings with the RWH system in place over the 20 year rainfall dataset.

Table 1 – Summary Outputs from Rainwater Harvesting Simulation

Annual Rainwater Demand Satisfied Over 20 year Time-Series (m^3)		
Max	289	88%
Mean	260	79%
Min	201	61%

RQ6: How can monitoring and data analysis be improved?
Evidence from this study suggests that the use of a single water meter can enable simple water saving analyses to be conducted. However, results have been presented using a number of assumptions and data interpretations. Refinement with more empirical data would be valuable to increase the confidence of the estimates obtained to date. At residential sites, ultra-high resolution data (<5s/pulse) has been successfully disaggregated to enable end uses to be inferred from the main water meter data [12]. The fitting of additional sub meters (with high resolution data loggers) within the school's plumbing network would enable refinements of the estimates in this report to be undertaken. In turn, that data could be deployed across future interventions at similar schools to provide improved cost benefit estimates (which include hot water savings). Furthermore, disaggregation methods could potentially be developed to provide more information to Severn Trent Water's staff from existing datasets.

The following data acquisition devices are recommended for capturing additional data during a 1 year study to enable further analysis of the interventions to be undertaken with greater confidence:

1) Water meter (and logger) at the boiler's hot water outlet to enable total hot water usage to be identified.
2) Water meter (and logger) on urinal cistern inlets to enable urinal demand profiles to be identified.
3) Water meters (and loggers) within one or more bathrooms to enable the ratio between hot and cold taps to be identified.
4) Rain gauge (and logger) to identify the availability of rainwater to satisfy WC demand.

5. CONCLUSION

A school site was monitored before and after a water efficiency retrofit (WER) intervention upgraded the WC's urinals and taps. The following conclusions were delivered from this study; 1) The WER reduced monthly water demand in April (2015 vs. 2016) by 29% from 70.2m^3 to 49.8m^3 and by 25% from 78.1m^3 to 58.6m^3 for May. 2) At 25% reduction, an annual saving of 220m^3 with a value of £623 was estimated. 3) A simple payback period was estimated at 4.5 years however, this reduced to 3.9 years when the energy cost for hot water savings was also evaluated. 4) Hot water savings reduced the carbon footprint of on-site water use by an estimated 381 kgCO_2e. 5) No significant leakage was identified on site with night-time flows attributable to leakage estimated at <0.03m^3/hour. 6) The further retrofit of a RWH system was evaluated using a time series approach indicating that further WC and urinal water savings of approximately £736 could potentially be achieved in an average year. 7) Recommendations for additional monitoring systems within the school were proposed to enable estimates to be refined following a further year's monitoring programme.

ACHNOWLEDGEMENTS

The study was funded by sponsorship from Severn Trent Water Ltd and the UK Engineering & Physical Sciences Research Council project: TWENTY 65 - Tailored Water Solutions for Positive Impact EP/N010124/1. In addition, support from the STREAM Engineering Doctorate programme enabled the first two authors to work on this paper.

COMPETING INTERESTS

No competing interests were identified during the delivery of this paper.

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APPENDIX A: PROCESSED DATA OUTPUTS

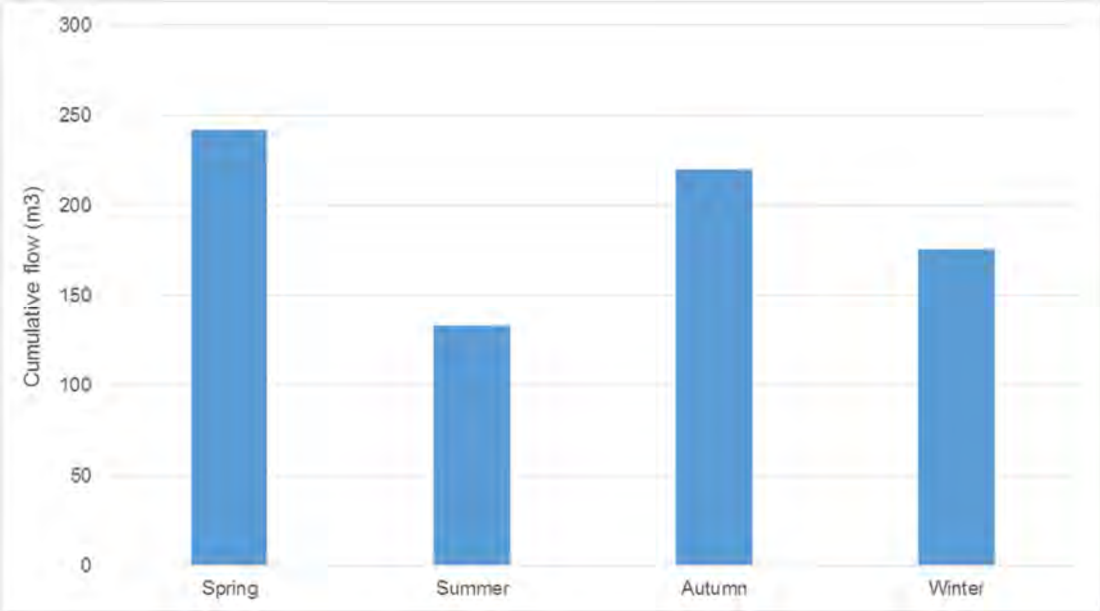

Fig.A-1 Seasonal distribution of water demand (raw pre and post intervention data displayed)

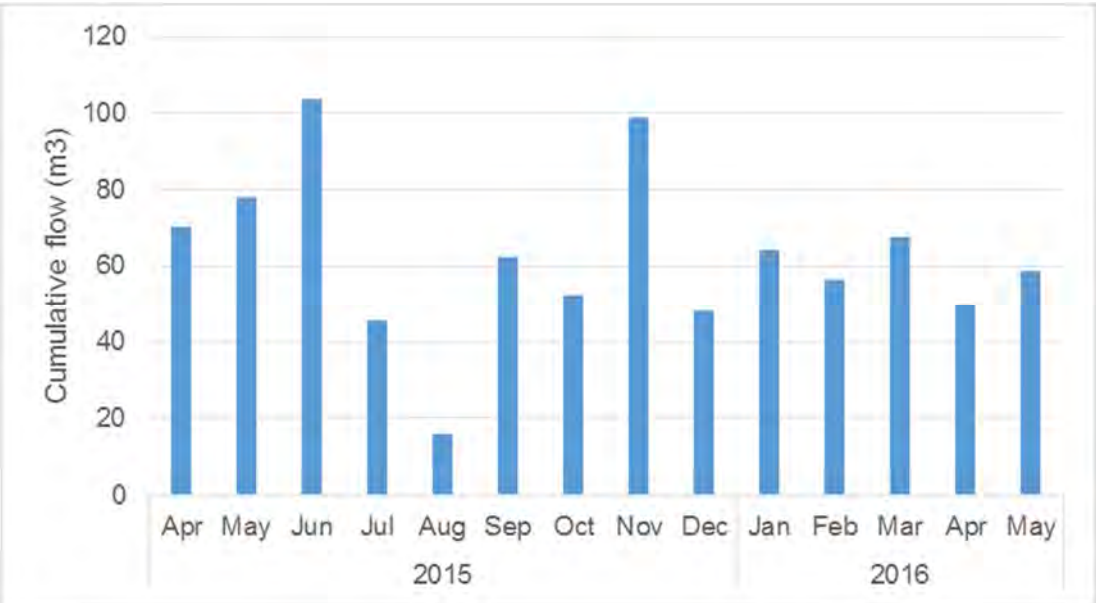

Fig.A-2 Monthly distribution of water demand (raw pre and post intervention data displayed – intervention in August 2015)

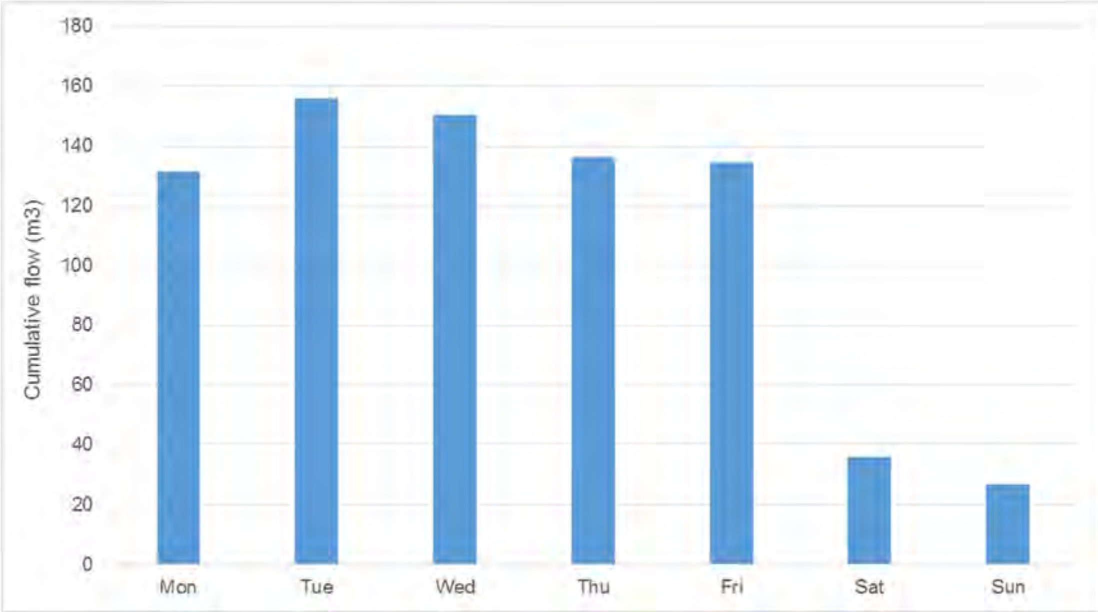

Fig. A-3 Daily Profile of Water Demand, one year of data, April 2015-March 2016 (raw pre and post intervention data displayed)

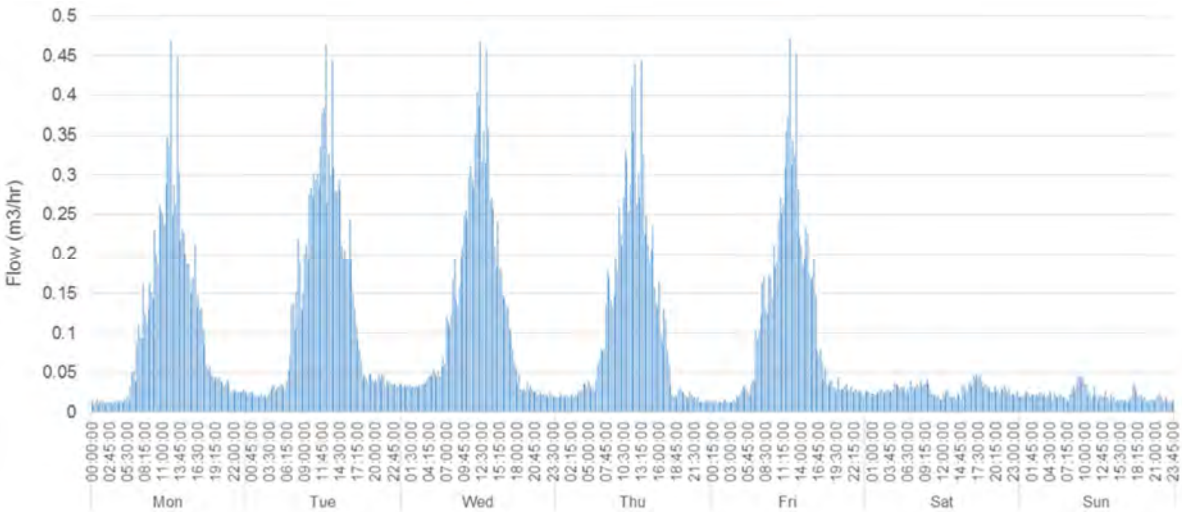

Fig.A-4 Time distribution of average water demand over a week, one year of data, April 2015-March 2016 (pre and post intervention data displayed)

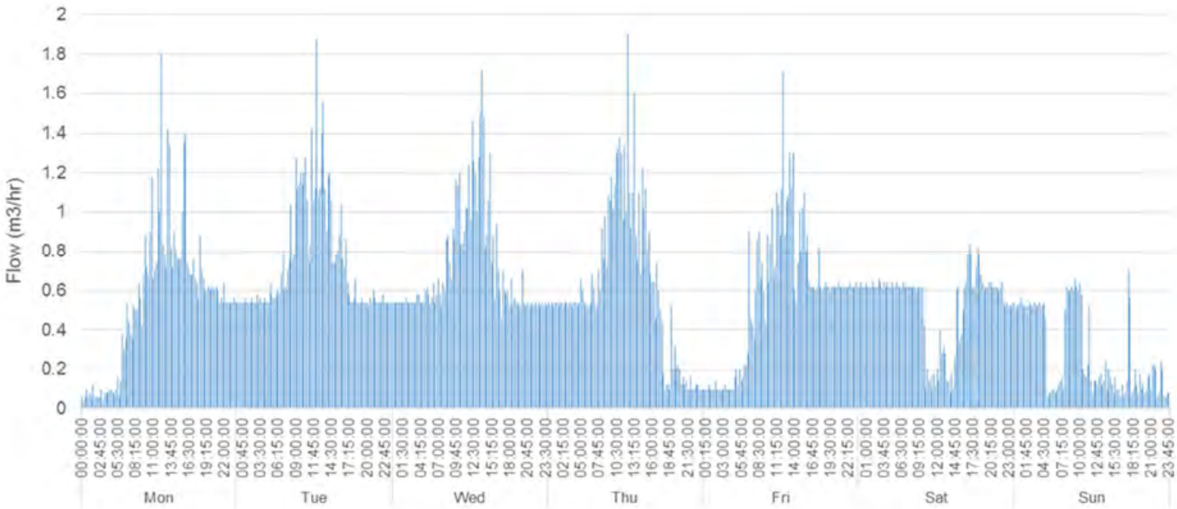

Fig. A-5 Time distribution of maximum water demand over a week (pre and post intervention data displayed)

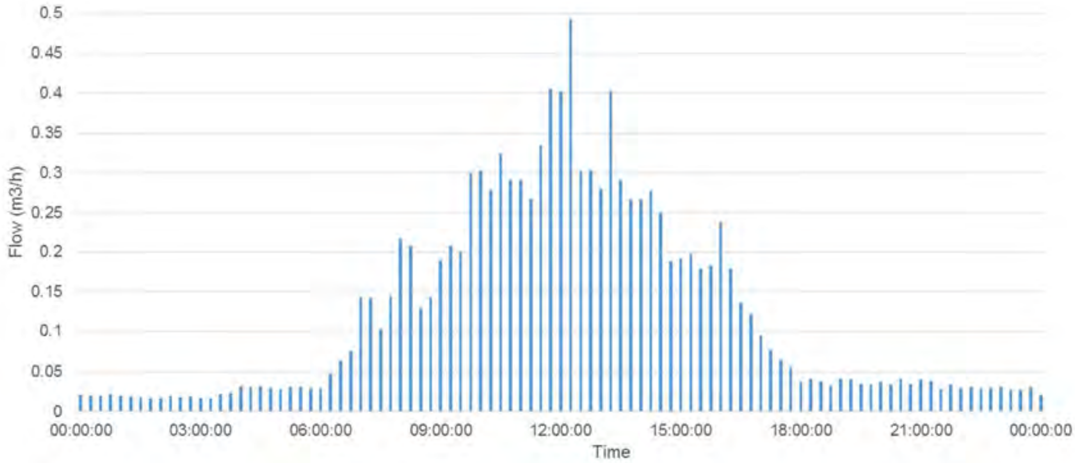

Fig. A-6 Time distribution of average water demand on all Tuesdays in a year (pre and post intervention data displayed)

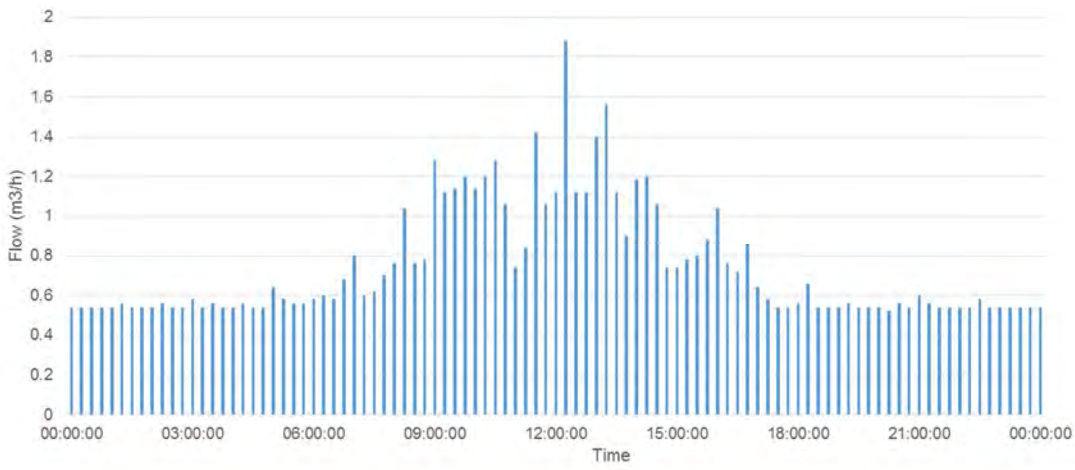

Fig. A-7 Time distribution of maximum flow on Tuesdays (pre and post intervention data displayed)

APPENDIX B – PROCESSED DATA OUTPUTS SHOWING IMPACT OF INTERVENTION

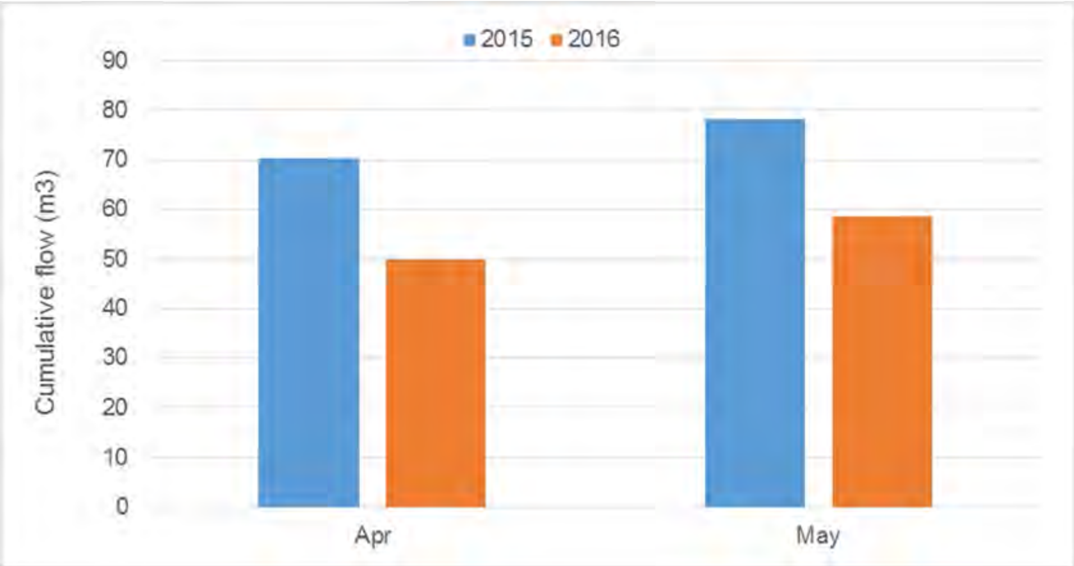

Fig. B-1 Comparison of cumulative water demand in April and May 2015 and 2016

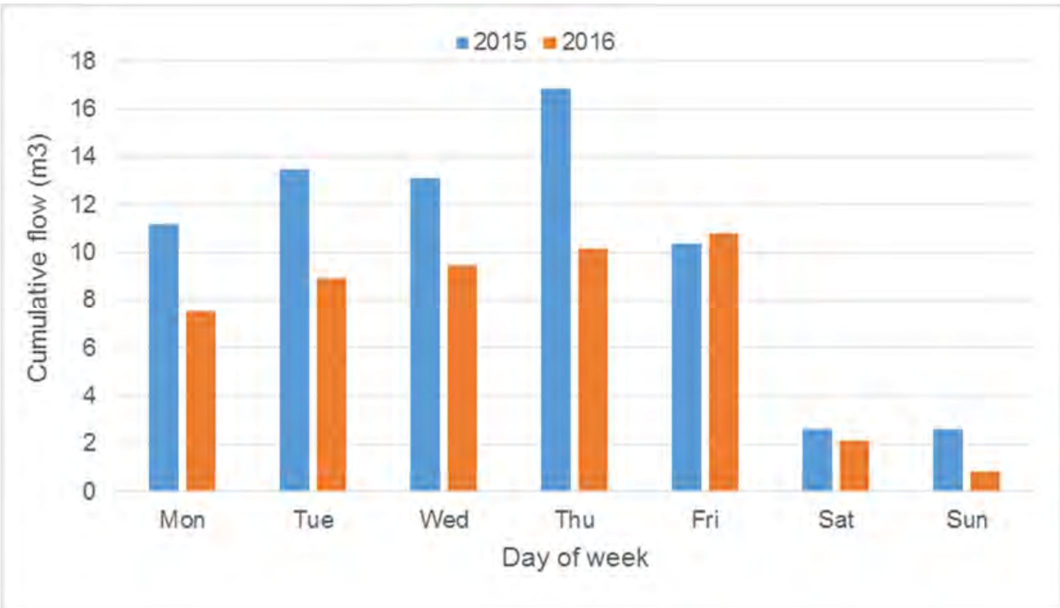

Fig. B-2 Comparison of cumulative water demand in April 2015 and 2016 (daily distribution)

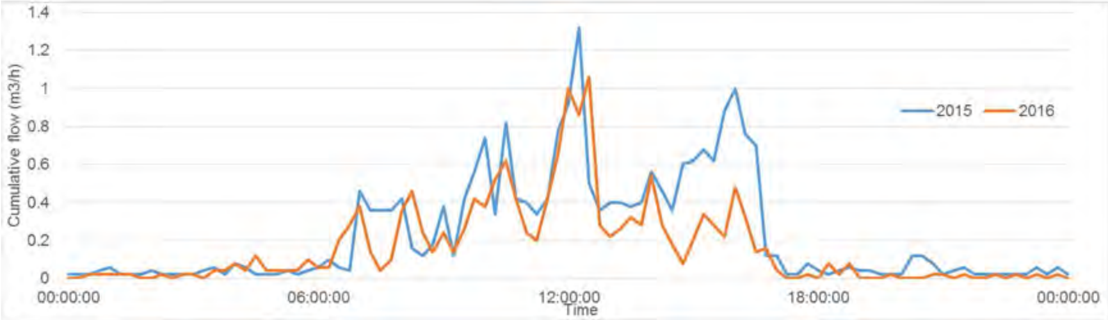

Fig. B-3 Comparison of maximum water demand on a representative Tuesday in April 2015 and 2016

APPENDIX C: ESTIMATING SAVINGS POST INTERVENTION

APPENDIX C: ESTIMATING SAVINGS POST INTERVENTION

	Year 2015 (m3)	Year 2016 (m3)	Saving (m3)	Percent
Monthly (April) comparison	70.35	49.89	20.47	29%
Monthly (May) comparison	78.09	58.63	19.47	25%
Representative Tuesday (based on maximum flow)	5.62	3.91	1.72	31%

Table of water demand reductions as result of intervention

Considering **25% saving** (achieved in May flow comparison before and after intervention), the following profile for pre-intervention was developed by adding 25% of each month's flow to its base flow (post intervention):

Month	Cumulative flow (m3)
Apr	70.21
May	78.09
Jun	103.65
Jul	45.72
Aug	20.03
Sep	78.18
Oct	65.46
Nov	123.53
Dec	60.24
Jan	80.09
Feb	70.56
Mar	84.46

Pre-intervention profile table

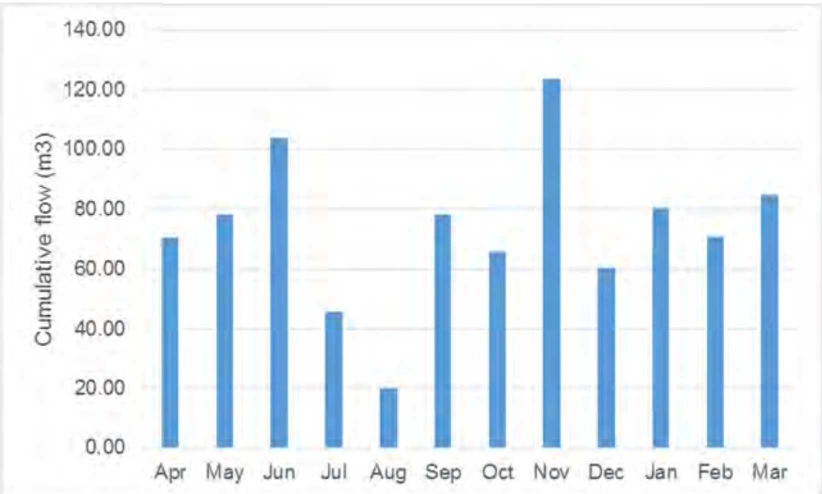

Fig. C-1 Pre-intervention profile chart

Water Efficiency Conference 2016

Integrated water planning - strategies to implement before 2020 and beyond

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ABSTRACT
Climate change and population growth, in particular urban populations, are increasing pressure on water resources and the water environment. The inherent weaknesses of silo based approaches to managing water are already on display. Opportunities to maximise water resources through measures which mitigate flood risk and drainage are far from being realised in the mainstream. Wastewater treatment works continue to treat valuable resources for disposal into the sea. Plans to meet water quality objectives are shoe-horned into plans to manage water resources and supply in the long-term. Better integration between demand management and decentralised water 'supply' options could yield more robust solutions. The need for Integrated Water Management (IWM) and planning has never been more apparent.

The next round of water resources planning and water company business planning is progressing in the UK. Our research question is, "How can we integrate long term water resources, water quality, and flood planning in the UK?". We undertook a targeted literature review of current silo based planning approaches and integrated approaches from the UK, USA, and Australia. We then interviewed expert water planners for their practitioner views on joining up planning. Recommendations for actions within the current round of planning and beyond 2020 are suggested.

Keywords: Integrated water management, planning, WSUD, water resources planning, flood, water cycle

1. INTRODUCTION
This paper addresses the question: *how can we integrate long term water resources, water quality, and flood planning in the UK?* As a concept integrated planning suggests streamlined activities and optimal outputs. Theoretically integrated solutions should be more effective, longer lasting, and cheaper overall than solutions that are designed and implemented considering a narrow set of objectives, or even a single objective. The question posed assumes that this is a shared aspirational vision, but in order to begin answering that question it is necessary to explore whether integration is necessary, and if so to what extent.

The UK population is projected to increase by 9.7 million over the next 25 years (UK Office for National Statistics, 2014), putting extra pressure on all aspects of the water cycle which itself is already revealing its vulnerability to the changing climate. By 2050, 86% of the population of OECD countries will be living in cities (OECD, 2014) and the UK is no different, already 54% of the total population in the UK live in 64 cities (Champion, 2014). Achieving a fully integrated system where all the relevant players fully collaborate to work out the best ways of getting the best outcomes, is a major challenge.

The issue of integrated planning has been recognised in the Water Framework Directive and the Catchment Based Approach (Defra, 2013). However, fragmented water governance and management in the UK has hindered this. Decades of striving for efficiency have moved water management to higher levels of top down 'strategic planning' but increasingly modern

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approaches recognise the benefits of 'decentralising' and managing water at local and micro scales at various points within the water cycle. Interest in integrating water management thus considers both the efficiencies of managing resources (clean and wastewater) and mitigating flood at strategic scales, and the opportunities to enhance this with joined up local action (e.g. partnership working).

In 2011 the Chartered Institute of Water and Environmental Management (CIWEM) produced a briefing report on Integrated Water Management for the UK. This provided an overview of international experience and UK case studies and called for a shared vision (Grant, 2011). A scoping study on Water Sensitive Urban Design (WSUD) identified opportunities to integrate water planning in the UK (CIRIA, 2013). However, so far this has only been taken forward by South West Water (AECOM, 2014) and Yorkshire Water, and only at a policy level, rather than integrating flood risk, water resource, and water quality plans. In 2014 Cambridge University produced *Integrated Water Management Planning Advice* guidance although this was for a specific development rather than strategic planning for water companies (University of Cambridge, 2014). There is clearly a major gulf between interest (speculative and more in-depth) versus actually implementing integrated water management.

This paper explores definitions of Integrated Water Planning and how interpretations differ, the merits of various approaches that are being researched and implemented, the existing system of managing water in the UK, and what shifts may be needed to move towards achieving the outcomes promised by integrated water management. As water resource planners with experience in Australia, North America, and the UK, in this paper we contextualise our own views with international literature on the subject, and diverse perspectives and opinions from a range of current water planning practitioners in the UK.

2. METHODOLOGY

A targeted literature review was undertaken to identify the range of Integrated Water Management approaches that have been developed to date in the UK and internationally. This was based initially on a list of integrated water planning approaches produced for the Water Environment Federation. These included (WERF, 2015):

- Regenerative infrastructure;
- Integrated water resource management;
- Water Sensitive Urban Design;
- Integrated resource planning;
- Integrated regional water management;
- Total water cycle management;
- Integrated water management;
- Whole water; and,
- One Water.

Online resources were used to search peer reviewed and grey literature (google search, google scholar and ScienceDirect) exploring integrated water planning. The Google Trends tool was used to assess the number of searches for these terms between 2004 and 2016 (subsets used to reduce non-water resource returns for "One Water" and "Blue Cities"). Google's Ngram Viewer was used to identify references in books between 1980 and 2008. This review examines how interest levels in integrated water management have changed and how the concept itself is evolving. References to the search terms increased significantly from 1980 providing an appropriate start date for analysis. Keywords without results were removed. This approach builds on the results from a similar study of urban drainage terms, which demonstrated an interesting progression and internationalisation of terms used by the professional community (Fletcher et al., 2015).

Semi-structured interviews were used to fill gaps identified through the literature review specific to the UK planning situation and to identify the range of perspectives of our practitioner peers with different experiences and backgrounds. We requested interviews with 8 water company planners and 1 city planner. Of these five were able to be interviewed in the timeframe available and these cover the South East of England, Midlands of England and Wales. Six questions were put to the planners (Box 1), structuring discussions lasting between 20 to 60 minutes, following which a transcript of notes taken was returned to confirm correct interpretation of comments. The questions were:

1. How would you define integrated water planning?
2. How are you looking to undertake integrated water planning?
3. What are the barriers to integrated water planning?
4. What are the benefits to integrated water planning?
5. How aware are you of UK and International research programmes such as One Water, Water Sensitive Cities, Total Water Cycle Management Approaches, Blue Green Cities etc.?
6. Who should take the lead on integrating water planning in the UK (i.e. Ofwat, Government, Environment Agency, Water Companies, Cities)?

The interview outputs (results) were summarised in tables and coded to identify common themes, conflicting perspectives, and unique insights. It is recognised that these results reflect a small sample of individuals and that these do not necessarily represent the range of views from across the UK water sector. These results give an indication of the range of views on IWP and how different situations affect those views.

3. RESULTS

3.1 Literature review - trends in Integrated Water Planning terminology

The results of the keywords analysis in Google Books, and the terms searched for in Google are shown in Figures 1 and 2 respectively. Over the longer term (Google Books) two of the most interesting trends are the spike in literature referring to 'Integrated Resource Planning' in 1995 (which has since dropped off), and the more sustained increase in references to 'Integrated Water Management' from 1965 to 2008. Use of the term 'Water Sensitive Urban Design' has increased since 1995, however it remains lower than Integrated Water Management and Integrated Catchment Management.

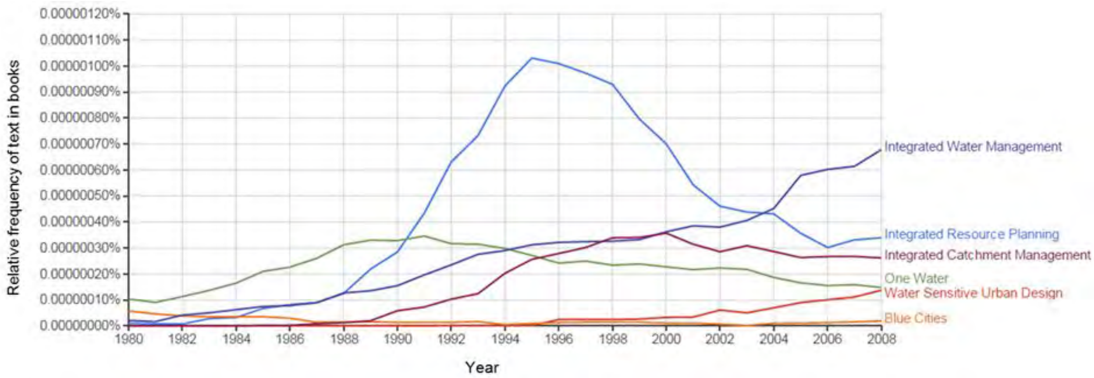

Figure 1. References to integrated water management phrases in Google Books between 1980 and 2008.

Online search is a more recent phenomena and the search history of the four terms was set from 2006 (Figure 2). The most obvious result is that after a peak of interest in the mid 2000s, dominated by searches for Integrated Water Management (blue line), overall the number of searches for these terms declined, and in more recent years no single term has dominated how people have searched on the subject of Integrated water planning. Both of these outcomes suggest that rather than a lack of interest in integrated water management, there has been a proliferation of new terms (and approaches).

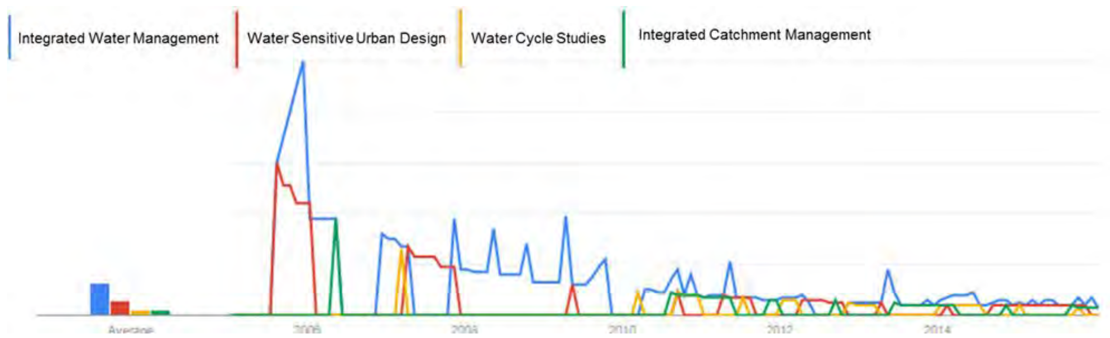

Figure 2. Trends in online searches for IWM terms since 2006

3.2 Literature review – approaches to integrated water planning

<u>3.2.1 Integrated Regional Water Management (IRWM):</u> Four years of drought has revealed the weaknesses in California's water resources and supply system that is fragmented physically, socially, institutionally, and politically. A legacy of senior water rights (historical 'first come first served') makes managing water resources very difficult but in 2002 the Regional Water Management Planning Act (SB 1672) was passed. California voters approved Bond acts which have provided $1.5 billion to support and advance IRWM. The State uses this taxpayer sourced fund to support local scale, collaborative projects. At the heart of the IRWM initiative is the view that water problems are best addressed at local rather than state level. Water retailers, wastewater agencies, stormwater and flood managers, watershed groups, the business community, the agricultural sector, non-profit organisations, and community groups have responded forming local level collectives (Regional Water Management Groups) which in turn have defined (from the 'bottom-up') 48 IRWM regions that cover 87 percent of the state's area and 99 percent of its population (State of California, 2015). At first glance a review of the projects that have received funding suggests that 'integrated' is defined as a collection of individual projects that each tick the boxes of different parts of the water cycle, rather than all projects defining and targeting the multiple water challenges of their local area. The bottom-up nature of projects are local with broad-ranging stakeholder involvement, but in very large watersheds, may simply be dealing with isolated problems, or multiple problems with single dominant causes, e.g. projects to increase water resources (for regional self-reliance which in turn is hoped to improve water quality and reduce conflict over water availability and water rights).

<u>3.2.2 Regenerative Infrastructure (regenerative systems):</u> Most typically regenerative infrastructure is discussed in terms of its role in regenerating places. It has been referred to as identifying the "true essence of a place, exploring its possibilities and unlocking its potential to thrive" (Biohabitats, 2016). Examples in the literature include (decentralised) local measures which individually aim to remedy polluted water (various stormwater management techniques, natural wastewater treatments, Floating Wetlands etc), reduce pressure to abstract from waterbodies (e.g. rainwater harvesting), and enhance the ecological capacity of an area (e.g. green roofs, green streets, urban agriculture etc). WSUD, which has been identified as an IWMP approach in its own right falls under the banner of RI. These examples support the notion that the emphasis of Regenerative Infrastructure is on applying solutions (with multiple functions) restoring watershed functionality that has been lost (e.g. by urbanising a watershed). RI is a concept that aligns closely with biophilic cities and the concept that humans have a love for living systems and need this in our cities, with Singapore often cited as an example (Newman, 2014).

As it stands infrastructure under this banner tends to be more decentralised, and small scale, enabling more innovative systems to be incorporated. The concept appears to be closely related to 'landscape architecture' objectives rather than traditional water services. However, the term has also been applied to the regeneration (maintenance and improvement) of engineered components of the urban water cycle, e.g. upgrading a treatment works (Mitchell, 2014).

3.2.3 Integrated Water Resources Management: The Global Water Partnership has defines this as "a process which promotes the coordinated development and management of water, land and related resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (Global Water Partnership, 2000). In this respect, IWRM is not a technique. It is an overall management philosophy with guiding principles designed to enable agreed understanding of what IWRM aims to achieve, and its scope is the global water environment. This is at the broadest end of the scale, in comparison to site specific techniques and local/city approaches, e.g. WSUD. The GWP approach to IWRM is embodied within a defined framework that explicitly targets institutional integration and management to create 'enabling' environments.

3.2.4 Total Water Cycle Management (and Water Cycle Studies): Conditions in Queensland Australia, have driven the State to legislate requirements on Local Government to implement 'Total Water Cycle Management' over 20 year planning horizons (combining water infrastructure and land-use planning). The approach explicitly requires system-thinking approaches. The focus is on how the water cycle functions, rather than on how the various authorities and water uses function. The aspiration is that TWCM will identify specific solutions that may not otherwise be identified by component based water management, e.g. "The idea of a sewer mining plant was investigated after Kogarah City Council developed a Total Water Cycle Management Strategy and found that water reclamation would be the most sustainable way of reducing potable water use". Guidance prepared by the State highlights the role of more specific water management techniques, such as WSUD and sustainable urban water management to "assist the land development industry and government make the transition towards smarter water management" (Water by Design, 2010).

3.2.5 One Water: This term was developed through a research effort sponsored by the Water Environment Research Foundation, Water Research Foundation, and Water Research Australia. It was led by the Institute for Sustainable Futures at the University of Technology Sydney, the Center for Neighborhood Technology in Chicago, and ForEvaSolutions in Pittsburgh. The project recognises the inertia of dominant and siloed institutions and its research objective was to identify how to successfully transition to integrated 'institutional' planning (i.e. to overcome the impact of regulatory patchworks and fragmented responsibilities and priorities). By examining case studies where water, wastewater, and stormwater managers have actively adopted integrated approaches the One Water project focuses on identifying causes and realistic strategies to overcome the barriers and remove fragmentation – to realise the benefits. In this way it falls into the same category as Integrated Water Resource Management, focusing on the institutional barriers to integrated water management (WERF, 2015).

3.2.6 Blue Green Cities: A focus on reducing flood risk and incidents of flooding reflects that this is a UK based programme, initiated against a backdrop of severe flood incidents overshadowing the less frequent drought longer-term risk of water shortages. The overall aim is to "to recreate a naturally-oriented water cycle while contributing to the amenity of the city by bringing water management and green infrastructure together". This project is about improving techniques on the ground – rather than institutional management and paradigm change and the Blue-Green Cities team has spent the last three years creating methodologies and frameworks, conducting field and lab work, testing novel techniques, and developing models to evaluate the multiple flood risk benefits of Blue-Green Cities. In 2015 focussed their research on Newcastle, UK, assessing and evaluating the multiple benefits of different flood risk management strategies in the urban core of the Ouseburn catchment. Outcomes are intended to generate data and information to inform community members, land-owners, decision-makers and other relevant stakeholders of the multiple benefits that Blue-Green strategies can provide. Early adopters include the Plymouth Green Infrastructure Project, Counters Creek in London, and the Glasgow and Clyde Valley Green Network Partnership already implementing innovative solutions and new technology for flood risk management in urban environments (Blue Green Cities ESPRC, 2016).

3.2.7 Water Sensitive Urban Design: Water Sensitive Urban Design (WSUD) was first used as a term in Western Australia then in the state of Victoria in the 1990s. Most early applications focussed on stormwater management and it has been led by the urban drainage community initially. The key objectives have predominantly been around urban drainage and water quality as well as delivering added values while reducing development costs (Fletcher et al., 2015). However, the application of WSUD in cities such as Melbourne has been broader in terms of water recycling and addressing groundwater flooding for example (City of Melbourne, 2015). In scoping the potential for this approach in the UK a report by CIRIA developed a broader definition of “a holistic design process that strives to establish greater harmony between water and communities”. This includes connecting the water cycle across aspects of water supply, wastewater, runoff and flood management. No specific barriers are identified in the UK, however there is regulatory fragmentation (CIRIA, 2013). WSUD is seen as the process while Water Sensitive Cities is the outcome in programmes such as the International Water Association’s work on cities of the future. Research from Australia has identified key factors for transition to water sensitive cities. The North West Cambridge development represents an example of this approach being applied in the UK at a development scale (Wilson, 2016).

3.2.8 Blue Cities: A report published in Canada in 2014 developed the concept of “Blue Cities” based on interviews with 17 subject matter experts and thought leaders. The report goes into detail about the financial responsibility, rate setting, and innovative service delivery. A business case approach is also outlined. The vision for a water sustainable city includes (Blue Economy Initiative, 2014):

- Water is visible - blue and green landscapes;
- A culture of conservation exists - smaller use of energy, resources, water and land use footprints; and,
- Shared responsibility - citizens are engaged and motivated.

3.2.9 Fourth Generation of Water Infrastructure: This approach was developed by the Institute for Sustainable Futures at the University of Technology Sydney (White and Turner, 2014). The first generation of urban water provision can be seen as unmanaged, the second centralised, the third is a transition towards environmental protection, the fourth is an emerging approach in the 21st century. This includes integrated service provision, customer service, planned and managed distributed wastewater treatment and reuse, advanced water efficiency, distributed stormwater capture and management. The fourth generation seeks to reduce financial and environmental costs and invests in treatment over transport and enables participatory decision making (White, 2010).

3.2.10 Integrated Resources Planning: Integrated Resources Planning (IRP) is a way of ensuring efficient and sustainable management of water, energy and other resources. This approach develops a supply-demand balance, identifies a suite of options to reduce demand or increase supply, and is an open and participatory approach to identifying the least cost options to meet service needs. IRP can integrate centralised and decentralised supply options, conservation measures and conflicts across economic, social and environmental objectives. Although supply-demand is the core area of this approach it can consider wastewater objectives across the whole water cycle and impacts of options on wastewater and stormwater systems (Institute for Sustainable Futures, 2011). An example of an integrated water management application of IRP was for the Upper Blue Mountains Wastewater Strategy in Sydney. The approach analysed the costs and benefits of demand measures on proposals to upgrade the sewerage collection system. A range of water efficiency options were modelled from rebates for front loading washing machines to water efficiency audits. This found that for a AUD $1.83m investment AUD $2.04m of benefits would arise primarily from reduced capacity required in sewage treatment plants and reduced septic pumpout and transport costs (Howe and White, 1999).

3.2.11 Integrated Water Cycle Management: Integrated Water Cycle Management is an approach that is being applied in Melbourne, Australia (Yarra Valley Water et al., 2013), and also in the Southern Water region of the UK (Hoyle, 2015). It can be defined as a multidisciplinary and multi-objective approach, used to promote the sustainable use of all available water in ways that best deliver multiple community objectives. This was applied in Melbourne with aims to reduce pressure on drinking water supplies, reduce stormwater runoff and discharge/ Nitrate pollution into Port Phillip Bay, and reduce groundwater depletion. A traditional option, a recycled water option, and several "integrated" options sets were evaluated using multi-criteria analysis. If cost is the only criteria used then the option of centralised wastewater recycling was best, however with environmental benefits considered a more integrated approach including stormwater harvesting and decentralised solutions scored higher.

3.3 Interview results

Interviewees were asked to define integrated water planning. Shared themes included a holistic view of different functions linked to integrated asset planning, integrated water cycle management, and catchment management. Wider pressures in the environment were discussed and how collaborative and synergistic solutions can deliver multiple objectives and efficiency. Scale of planning was raised as being important and also that approaches need to be climatically and culturally relevant.

However, there were varied responses regarding how they are currently looking to undertake integrated water planning. Two of the companies have integrated their water resources and wastewater/ flood planning teams as part of regulatory requirements to split wholesale and retail elements of the business. This has enabled them to consider water reuse options in more detail and to start bringing together data streams to consider multiple objectives in their cost-benefit analyses. One of the companies has identified two water framework directive catchments in which to trial an integrated water cycle approach based on experience in Australia and North America. All companies also mentioned their catchment management teams and programmes as starting to move towards integrated approaches through partnership working.

A major barrier discussed by most of the companies was the fragmented nature of current water planning. This was largely due to the framework where companies are regulated separately to others in the catchment, regulation is in silos with ring fenced funding, and responsibility for flooding is split between organisations. The move to retail and upstream competition was seen as having the potential to fragment planning further. There is a need for different expertise that can bridge the gap between silos and this presents an organisational challenge with the large amount of time and effort already required for existing plans. Integrated water planning can be seen as conceptual and academic, whilst there is a need for more scientific evidence around the costs and benefits of this approach in the UK. Integrated planning will also be information heavy and there is a shortage of IT capability. Finally, integrated water planning is currently a voluntary approach and this limits progress.

Optimising planning to progress options that deliver multiple benefits was a theme across all the interviews. The approach should help systems become more resilient to stress and improve benefits for the environment, customers, companies and their investors. By identifying and demonstrating the trade-offs between parts of the water cycle across local and strategic scales the overall costs would be cheaper. Several examples were given by one company on the flood attenuation benefits or reservoir management and real time abstraction monitoring. With a privatised industry (excluding Dwr Cymru Welsh Water and Scottish Water) it is important that investors recognise the benefits and one company is actively piloting more integrated approaches to support this.

Awareness of UK and international research programmes varied across the interviewees. Some had a greater knowledge of Integrated Regional Water Management approaches from California and Australia. The city based water approaches such as Blue-Green cities are not seen as particularly visible in the UK or "One Water". One company referred to the trade press such as the Chartered Institute of Water and Environmental Management as a source of information on this and that the research and development teams may know more than the planners. The interviewee responses reflect individual awareness, not necessarily awareness or views from the wider company. It was suggested that there are many of these approaches being discussed and that they are quite conceptual, transient, and academic. There is a need to "jump the gap between aspiration and implementation".

There was a split between interviewees as to whether Government or water companies should take the lead on integrated water planning. Government was seen as having an overarching role and at the least required to facilitate integration. The current approach of River Basin Management Planning was seen as top down versus the bottom-up model applied in California. In this case the regulators identify the issues and provide funding while the bottom-up solutions come from the community. An integrated approach was thought to be easier for a company with coverage across a whole region compared with the many small companies in the South East of England. One water company believes that it makes sense for the water company to lead as it can own its own challenges compared with the regulator-response model that drives silo based responses.

3.4 Discussion

The literature review and interview results provide some insights to begin answering our research question: how can we integrate long term water resources, water quality, and flood planning in the UK? This builds on previous research by CIWEM and CIRIA on integrated water management and water sensitive urban design in the UK. However, a key difference is that this paper focusses on the strategic scale of planning and regulatory framework that exists for water companies in terms of water resources management plans and the five yearly business planning process.

There is an increasing trend (in the references within books) to a more diverse range of concepts although trends are less clear trend in the search term results. The literature review suggests there is a wide variation in what integrated water planning means to different people, organisations, and locations. This variation is manifest in the concepts that have been developed and the level to which these are integrated across the whole water cycle. The scale of application varies from site developments to neighbourhoods, cities, and regional utilities. Although they aim for integration many approaches have core (siloed) drivers such as water resources in Integrated Resource Planning and urban drainage in Water Sensitive Urban Design. The outcomes of these approaches are limited by the fact that water is typically (and mistakenly) considered somehow separate and secondary to priorities of economic growth and housing. A 2012 survey of 90 cities globally observed that the key challenges reported were transport, jobs, population growth, housing, and finance (LSE Cities, 2012). However, the critical role of well-managed water in sustaining resilient cities is recognised in the need to make business cases for better water management in Blue Cities and Water Sensitive Urban Design. At a more strategic planning level this supports the need for taking a wider economic view of the costs and benefits of more integrated water planning options.

The interviewees suggested that many of the approaches to integrated water management developed to date are too conceptual and academic. There was also relatively low awareness of the range of approaches in the international literature. Fragmentation of water management is a key issue. Previous research by CIRIA on WSUD in the UK also supports this with respondents suggesting water isn't considered a high enough priority in planning and urban design (CIRIA, 2013). There was support for this approach in delivering multiple benefits for the environment, customers, water companies and their investors.

Many of the current approaches to integrated water management exist in the grey literature rather than peer reviewed journals. Due to the space available in this paper the literature review was limited to an overview of the key concepts rather than presenting a full analysis and comparison of these. The sample of five interviewees of the twenty four water companies provides some useful insights but limits the generalisations that can be made. Other studies such as the CIRIA research on WSUD had a sample size of ten but this was expanded through use of a questionnaire. Further research should be undertaken using a questionnaire of water company plannings, R&D/ innovation leads, city planners and regulators on the next steps for integrated water planning. More pilots of integrated planning options and portfolios are needed for the 2020 period review in order to support a more integrated planning approach for 2024.

In the short-term (i.e. to 2020) there are opportunities to integrate planning within water companies and several are trialling this in key catchments. In the longer term there is a need for Government to facilitate a more fully integrated planning framework, either through regulation or supporting voluntary approaches in catchments that are under more pressure. A key outcome of this could be a reduction in the number of 'water management' related plans, potentially moving towards One Plan (Figure 3). This brings in multiple objectives, joined up datasets and stakeholders to identify a single optimal investment plan for water companies and society.

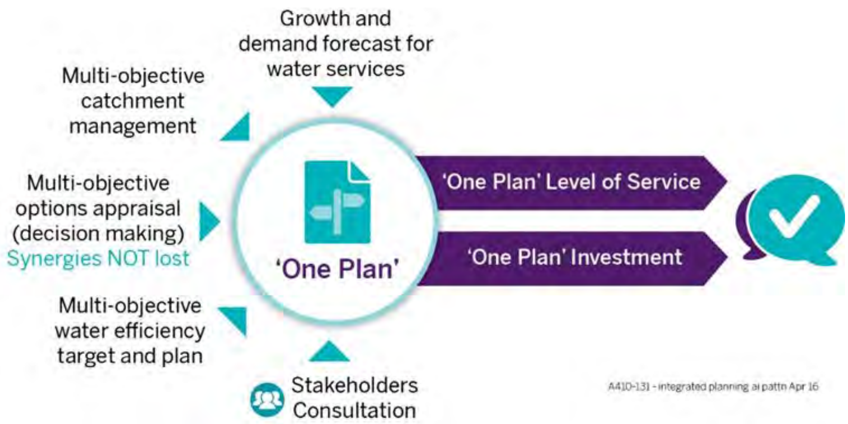

Figure 3. Multiple objectives and outputs from a single plan

Many water companies are already engaging in urban demonstrator programmes. These should be extended to ensure their outputs are also suitable for strategic planning. In Australia the use of liveability indicators is helping to drive more integrated water management (Water Services Association of Australia, 2016).

4. Conclusion

In the short term we may see benefits from tweaking the existing system and undertaking more integrated planning in catchments that are most vulnerable to climate change and population growth. There is a wide variation in the definition and terminology around integrated water management and this has been increasing since the 1980s. The interviewees suggest that the concepts are often too academic and conceptual and the multiple terminologies applied may add to confusion around how to effectively move from aspiration to implementation. Beyond the current UK price review period (up to 2020) we should utilise evidence from pilot studies to support Government in developing a more integrated planning approach. Future research following this paper is intended to include a wider questionnaire to understand views on integrated water planning and looking to apply some of the approaches in the literature to key catchments in the UK.

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Water Efficiency Conference 2016

To use or not to use enough water in Travellers' sites? What does the new planning framework do about water uses and misconceptions?

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ABSTRACT

During the last few years the author had the opportunity to work in partnership with international researchers in order to investigate on case law issues often affecting negatively the outcome of planning applications for Gypsy and Traveller sites in the UK and other European countries. These research activities took place during a two-year European funded project with the title Wor(l)ds which Exclude (WE). The author and her team in the UK had carried out visits to various sites; reports and recommendations have been written in relation to the latest developments in the planning framework which also regulates the construction of pitches for Gypsy and Traveller users in its special supplement. Some changes emerged after Law Court hearings and relevant decisions referring to accommodation arrangements for Gypsy and Traveller Communities. Although these arrangements were often established after consultation between local authorities and communities involved, rejections of planning applications were often based upon strong disagreements amongst members of local communities and neighborhoods in proximity of proposed new pitches. According to Gypsy and Traveller culture toilets, showers and kitchens should not be integral parts of their mobile homes and caravans; all these facilities should be grouped mainly in blocks of facilities (or blocks of facility rooms) according to the size of the site. Because of certain local petitions though opposing the size and view of caravans and facilities inside the pitches, the facilities' blocks do not provide enough space and equipment for water uses and drainage. The researchers had the opportunity to visit some sites providing facilities and accommodation and interviewed the inhabitants of the sites. It was also found that often rejections of extensions to planning applications of previously approved temporary sites for Gypsy and Traveller people, when challenged to the law courts, were hardly successful mainly because of planning inspectors and local residents' preconceptions on these groups' unsanitariness (not enough use of water) or, strange enough, because of overflows and waste of water during so-called extremely dirty works, such as recycling processes in pitches. In reality, the European Law Courts often found that rejections occurred because of local communities' misconception on water uses in services attached to the accommodation pitches. The main question should be what the title of this paper is asking, so that the groups interested could get swift and competent answers. The research findings in the UK were compared with solutions and findings in other partner European countries participating in the WE project and an interactive website was created for ongoing discussions and dissemination of best practice activities and projects.

Keywords: Gypsy and Traveller sites; water and drainage facilities; temporary planning applications; misconceptions on health hazards.

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1. INTRODUCTION AND BACKGROUND

From January 2013 to December 2014, as a principal researcher, the author worked and investigated for a European Grundtvig Justice 12 funded programme with the title 'Wor(l)ds which Exclude'; this research project brought together experts and researchers from eight European countries working on frameworks related to housing and planning applications by Gypsy and Traveller Communities. The entire programme of this project's activities and dissemination incorporated international mobility meetings, writing up of national reports [1], chapters for books [2], an ethnographic documentary film per participant country [3] and one book containing recommendations on planning law changes to state central governments in all participant countries, including the UK [4]. The author collaborated and was supported by the International Centre of Guidance Studies (iCeGS) at the University of Derby. The dissemination of materials produced by the author and her colleagues during this project is still taking place in the UK and abroad; presentations in conferences and symposia as well as lobbying of politicians in key policy making roles are enduring in the researchers' agenda. Since 2015, the author has been invited twice by Prof. Katalin Forray, Institute of Romology, University of Pécs, Hungary, to give papers at symposia related to Gypsy, Roma and Traveller youth issues and again policies and frameworks have been scrutinised further and discussed. During the 'Wor(l)ds which Exclude' project, linguistics and meanings in official documents or informal public discussions were identified and further debates began. Infamous words, such as "sedentary", "dirty scroungers", "menace" or "filthy parasites" denote the trends of misconception in today's society on health and squalor conditions in Gypsy and Traveller sites, which are still considered a public hazard, whenever these could be found in proximity either to urban areas or in the Green Belt [5].

Most misapprehensions about Gypsy and Traveller communities' attitudes, culture and lifestyle began when legislation and planning frameworks dictated what Gypsy and Traveller people lifestyle should be according to the policy makers who obviously did not have the background of a Gypsy or a Traveller person. There has been a lot of pressure from Gypsy Liaison Groups in all regions in the UK and Travellers' movements and associations to promote changes to the definition of being a Gypsy and a Traveller as ethic groups, not just a 'gypsy' or a 'traveller' as terms which declare only an individual's status. All planning applications for sites containing pitches and appropriate facilities are mainly rejected on the basis that people are classified as non Gypsy or Traveller by planning laws, thus, not allowed to have their home according to their own culture. Rejections of planning applications and extensions of previously approved ones do not only have a negative impact to Gypsy and Traveller reputation, but also they can get their health and well-being at high risk. Pretty often awkward reports from some local authorities declare that expansion of pitches could eventually create over abstraction to water resources in some areas. Therefore they are unfavourable to new applications:

> According to the Catchment Abstraction Management Strategies for these four river catchments existing water resource availability in the District is either over abstracted which means abstraction is causing unacceptable damage to the environment at low flows, over licensed which means current actual abstraction is such that no water is available at low flows, or has 'no water available' which means that no water is available for further licensing at low flows. [6]

If Gypsy and Travellers are refused to get a proper home and facilities in a site, they are inclined to live in illegal encampments which are often close to hazards, such as along the side of high traffic road, in flooded grasslands and remote areas far away from vital electricity, gas and water supplies. Often the conditions are such that soiled water runs on the surface of the sites and no sewers for drainage are available at a close distance at all; that means other local residents nearby could easily talk very negatively about what appears to them to be a norm for Gypsy and Traveller everyday life: to be 'filthy' and 'dirty'. These data were often found and described in case law reviews and discussed against rejections. One researcher in the UK team was often tasked by Derbyshire Gypsy Liaison Group (DGLG) to study and analyse specific cases talking about hazards from lack of drains and insufficient water supplies. All these elements were discussed against criteria and planning frameworks' regulations during moderation and court hearings; reviews of rejections were defended by barristers and planning consultants in DGLG. The UK team had chosen a lengthy and at the end successful review and outcome case study for their documentary inserted in the WE website, which mainly dealt with the construction and size of their facilities block. However in August 2014 (when the filming took place) and during the researchers' visits in some Gypsy and Travellers fairs in Staffordshire the lack of drainage and/or water supply was very evident.

A year later, in August 2015, the government announced big changes to Gypsy and Traveller planning guidance, called Planning Policy for Traveller Sites (PPTS). The definition of Gypsy or Traveller for Planning is now:

> 1. For the purposes of this planning policy "gypsies and travellers" means:
> Persons of nomadic habit of life whatever their race or origin, including such persons who on grounds only of their own or their family's or dependants' educational or health needs or old age have ceased to travel temporarily, but excluding members of an organised group of travelling showpeople or circus people travelling together as such.
> 2. In determining whether persons are "gypsies and travellers" for the purposes of this planning policy, consideration should be given to the following issues amongst other relevant matters:
> a) whether they previously led a nomadic habit of life
> b) the reasons for ceasing their nomadic habit of life
> c) whether there is an intention of living a nomadic habit of life in the future, and if so, how soon and in what circumstances. [7]

When PPTS refers to 'persons of a nomadic habit of life' it means travelling for an economic purpose. All Gypsy and Traveller groups had already opposed these changes in 2014, but the government did not listen. So, discrimination and prejudices about some people's status are still ongoing and, on the top of this, no real regulations can establish the real rights of these ethnic groups on public utility supplies, because of their 'temporary' residency in several places during the year.

2. METHODOLOGY AND DISCUSSION

Whether regions and city councils should be able and willing to provide suitable sites for pitches and facilities is still unclear, although the legislation affirms that councils should do their best to have provision of adequate sites. However Planning Policy for Traveller Sites (PPTS) remains a separate document, but still related to the National Planning Policy Framework.

In Policy H: Determining planning applications for traveller sites in *Planning policy for traveller sites*, we find:

> When considering applications, local planning authorities should attach weight to the following matters:
> a) effective use of previously developed (brownfield), untidy or derelict land
> b) sites being well planned or soft landscaped in such a way as to positively enhance the environment and increase its openness
> c) promoting opportunities for healthy lifestyles, such as ensuring adequate landscaping and play areas for children
> d) not enclosing a site with so much hard landscaping, high walls or fences, that the impression may be given that the site and its occupants are deliberately isolated from the rest of the community. [8]

The terms and language used in this document show clearly the existence of fixed ideas in policy making, such as, for example, Gypsy and Traveller people should be brought back to 'order' by transforming untidy and derelict land into children' playground green sanctuaries, by 'promoting healthy lifestyles' via 'landscaping' and by avoiding high walls to show intentions of being sociable. During our investigation we found out though that, local residents and neighbors wanted high fences to hide Gypsy and Traveller sites; they said that these high walls should hide filthy yards, pipes and open drains. During our visits with Silvia Paggi, French film producer, to Gypsy sites and pitches in Derbyshire and Staffordshire, we discovered right the opposite as you can see in Fig. 1 below. The Gypsy Romani residents of that site had self-built a facility block required for three residing families providing kitchen and dining space, plus two toilets (one internal and one external) and two shower rooms. They had installed a boiler for heating and washing and they had separated grey water which was used for the plants in their garden. No signs of ugly views, and therefore, no need to hide anything. But, their neighbours had insisted for a high wall to be constructed around the site, otherwise, they were threatening to do a petition against them in order to be evicted. The residents inside the site were not happy at all and they are still confined in their site. They had mentioned that, by harvesting rainwater they should be able to cultivate vegetables and have fresh food. But, their neighbors were against this and also against a small playground for the children inside the courtyard.

Fig. 1. The facilities building in Johanna's house – Photo credits ©: Silvia Paggi. Available: http://weproject.unice.fr/photo-gallery/johannas-house

In the last few years, several councils in the UK started carrying out specific Sustainability Appraisal and Strategic Environmental Assessment Scoping Reports before deciding on Gypsy and Traveller site allocations, which were often contested from other local residents. The appeals won by Gypsy and Traveller communities against planning application rejections have been always fiercely challenged by local campaigners, usually flagging up problems with facilities which include kitchens, toilets, showers and drainage efficiency.

The analysis and evaluation of materials and case studies during the international European project Wor(l)ds which Exclude had some impact to changes to planning laws; the project endorsed equal opportunities for accommodation and/or social housing for Gypsy and Travellers in Europe. Before these changes, prejudices about the uses of water were common in all countries and in some extreme cases, local authorities could dictate how much water should be used not only in accommodation pitches, but also at the nearest schools in which Gypsy and local community children attend classes. Children coming from Gypsy and Traveller sites were obliged to have one more shower at school before going to class. Water metering was checking regularly how much water was used by considering that, indication of low use was to be an indication of dirtiness and perhaps of a high risk of spreading diseases in schools and pitches. On the other hand, water meters in pitches did not allow high uses of water in order to avoid having Gypsy people using their pitches for jobs, such as recycling. There was no will to improve drainage and no will to move pitches outside flooded areas.

3. CONCLUSION

Now the definition of Gypsy and Traveller changed slightly, but the misconceptions of the people are still the same. At the same time there is still a lot to be done about water uses and water management; there should be no temporary sites solution. Permanent accommodation arrangements with a view towards increases of population inside and outside pitches should be considered and also detailed grids of utility supplies and services should be on place to enable each local authority to respond promptly to future expansions' stresses by adopting real sustainable solutions. 'To use or not to use enough water in Travellers' sites' should not be the case; awareness on uses and waste of water is evident in these ethnic groups' attitudes. Laws and planning frameworks should make this clear inside their text; regulations should provide the same guidance for all members of the local communities at all times.

ACKNOWLEDGEMENTS

The author should like to thank all her colleagues in the project Wor(l)ds which Exclude (2012-2014); they have provided and are still providing materials and support for further and ongoing investigation on energy and water efficiency in Gypsy, Traveller and Roma accommodation by regularly updating the web site which has been created intentionally for this project.

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Water Efficiency Conference 2016

Co-watering the grassroots: combining community participation and social entrepreneurship to share roof runoff

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ABSTRACT

This extended abstract shares a firsthand narrative of a pilot project using a co-productive participatory approach led by a social enterprise to share roof runoff between different properties. Conceptually, the project was simple to formalize and initially received wide industry support. Facilitated by an 'expert' in the field and with start-up funding secured, the technical aspects of the initiative were potentially straight forward. Engagement with a community group to initiate a pilot project was also straight forward, entailing a conversation about growing plants on an allotment without a mains water connection and an enthusiasm to use roof runoff from nearby houses. However, in the co-production of the pilot invisible technical and organisational complexities were made visible. For example, land ownership and management issues meant that the actor-network concerned expanded to include a number of unanticipated organisations, applications and fees. The dynamics of these tensions are summarised, demonstrating that the interplay between the organisational and technical aspects resulted in difficulties in practice. Though not unresolvable, they significantly delayed the completion of the pilot, absorbed a substantial amount of energy from the actors involved and impeded the collection of empirical data through which to evaluate the project concept.

Keywords: complexity, co-production, participatory, rainwater harvesting, social enterprise

1. INTRODUCTION

Socio-technical approaches to urban water governance and management are recognised as key to transitioning the sector to a more resilient and sustainable future [1] [2]. Participatory methodologies are also increasing in profile in a sector that is moving beyond engagement methods such as consumer challenge groups and online surveys, to consider the role of wider citizen perspectives and service innovation within future water provision [3] [4]. There is room for top-down and bottom-up approaches, including social enterprise, in utility sectors as shown through the example of community energy initiatives [5]. Additionally, the rise of local food movements and urban agriculture [5], as well as the continuation of traditional allotment use, generates a growing demand for water that may need to be met through alternative water supply systems, particularly for the latter, which has experienced increases in mains water charges by local authorities (LA) in recent years. However, whilst bottom-up approaches to water infrastructure and services and in particular for decentralized systems such as rainwater harvesting, are visible in countries such as Mexico (project Isla Urbana) [6] [7] and India (project Aakash Ganga) [8], such initiatives are yet to emerge in the UK. Through the use of a firsthand narrative in relation to a pilot project for a rainwater-orientated participatory social enterprise ('RainShare'), this paper aims to elucidate some of the potential reasons behind the apparent lack of progress in this area.

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2. METHOD

To develop the conceptual stages of the runoff sharing enterprise and initiate the participative aspects, a pilot project was established (‘the pilot’), funded by a specialist social enterprise funding organisation. The pilot enabled experiential learning and co-creation to form the foundation of the enterprise from the very beginning. In the interests of anonymity regarding the community groups and organisations embedded in the pilot, generic descriptive names are utilized herein, rather than their actual names and names and locations are omitted from all Figures. In early 2015, conversations were held with several residents near and users of an allotment site illustrated in Figure 1.

Fig. 1. The pilot project allotments, adjacent row of houses and Highways adopted footpath situated between the two

The topic of conversation was water resources available to and used by the allotment holders (AH) to water their plants/crops (‘plants’). It transpired that there was no mains water on site; the option had been explored but was too expensive to install. Consequently, the AH were very water conscious and were already innovatively managing water by: (i) bringing it with them from home in watering cans; (ii) capturing and storing small amounts of runoff on site via tiny improvised catchment areas (<0.5m^3) and containers; (iii) growing plants that required minimum watering between rainfall events: and (iv) occasionally pumping water from a water butt located at a nearby house through a hose to a water butt on site. Despite these interventions, the AH had a desire to improve their water availability to enable them to better cope with longer dry spells and increase the range of plants they could grow. Conversations turned to how a runoff sharing scheme could be developed based on the existing intervention outlined in (iv) above, but on a more permanent basis. This would potentially be able to provide both a source of non-potable water and also to reduce the discharge of roof runoff to the local sewer (to help maintain capacity/reduce risk of surcharge/flooding).

After some further discussions and technical evaluation of the supply-demand balance of the site, it was decided to proceed with a pilot project to connect the downpipes from one of the houses adjacent to the allotments via some additional pipework to a storage tank (1m^3) situated on the allotment site – essentially a rainwater harvesting (RWH) system distributed across two different properties. The main unknown risk identified oriented around a footpath running at the back of the houses and between them and the allotments (Figure 1). To enable the roof runoff to be conveyed most efficiently and automatically to the storage tank, a conduit with a small bore pipe required installation under the footpath. Consequently, its status as being Highways adopted or not became a primary concern for the pilot. This is discussed further in the Results and Discussion section.

By following and reflecting on each stage of the pilot’s development, the conceptual and theoretically ideal process for sharing roof runoff was co-created and is illustrated in Figure 2. Through further reflexive observation in the form of a firsthand narrative (which thus reflects the author’s perspectives and biases), the next section describes and discusses how the theoretical process was made real and some of the obstacles it experienced along the way.

To enable the organisational-institutional aspects to be further explored, an actor-network diagram was constructed (Figure 2) and a social network analysis (SNA) initiated (work in progress, therefore not covered in this extended abstract).

3. RESULTS AND DISCUSSION

Invisible technical and organisational complexities were made visible in the co-production of the pilot project and attempted expansion of the social enterprise to other urban agriculture projects, as well as other applications such as community RWH to provide watering water for green infrastructure. The temporal and spatial dynamics of these issues are described in detail in this section and are summarised in Table 1. Despite the landlord and residents of the ‘contributor’ property being ready and willing, initially complications arose due to a complex land ownership and management structure relating to the land on which the allotments (the ‘beneficiary’ property) are situated, as the main storage tank for the harvested rainwater was to be located on allotment land. The land ownership and management structure was being negotiated when the pilot commenced, but the implications of potential outcomes were not fully appreciated by the social enterprise or the community group at the time. The main issue was waiting for a decision to be made as to who could approve the installation of the tank on the allotment land.

As the top-half of the actor-network shown in Figure 2 illustrates, the Land Owner and land management organisation (Community Trust) were not the same entity and in addition to this neither organisation managed the allotments (this was undertaken by the Allotment Association) – involvement of these organisations were unanticipated in the original feasibility assessment undertaken. Though some of the individuals concerned were involved with multiple organisations, they were not necessarily responsible for contract negotiation or decision making and therefore both communication and decisions took time to be exchanged and completed, respectively. Due to the uncertainty of the proposed pilot scheme being accepted or not by one or all of the organisations, but not wanting to see the pilot fail due to these complexities, it was decided to persevere and delay installation of the distributed RWH system until they were resolved.

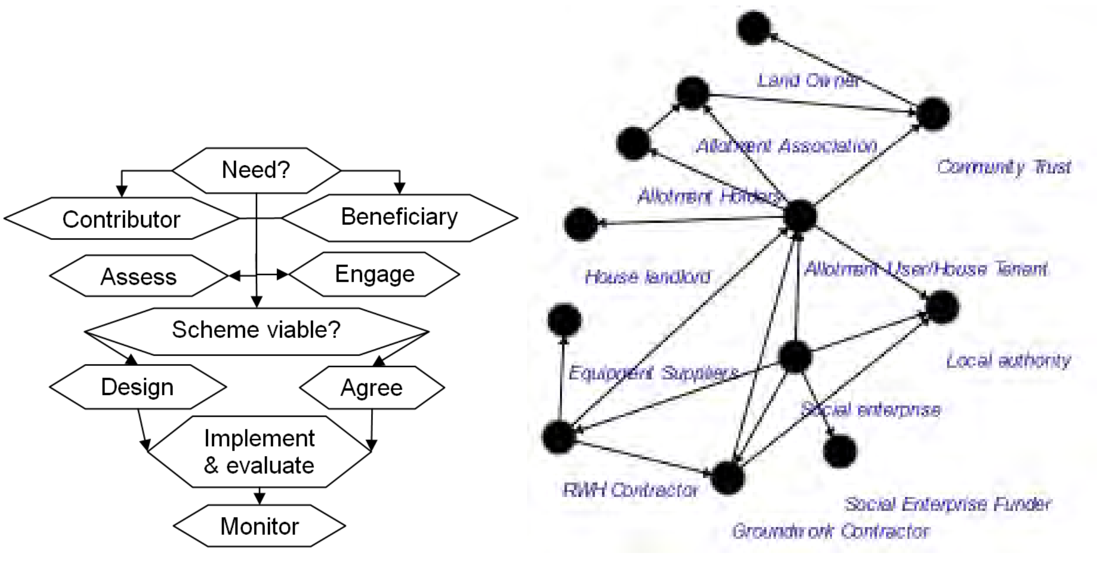

Fig. 2. Flowchart summarising the conceptual project selection process and the actor-network associated with the roof runoff sharing pilot project

Whilst waiting for the land ownership and management complexities to be resolved, attention turned to the status of the narrow footpath mentioned in the previous section and shown in Figure 1. The need for installation of a small conduit beneath the footpath necessitated establishing whether or not it was Highways adopted and therefore effectively the property of the Local Authority. Submission of an enquiry to the Land Charges team at the LA confirmed it was adopted and as the lower half of the actor-network in Figure 2 shows, the number of organisations involved in the pilot increased further. This was primarily due to the requirement of the New Roads and Street Works Act (1991), which required submitting a Section 50 licence application to conduct work. Additionally, contractors working on Highways adopted roads or paths need to be streetworks accredited and have a Street Works Qualification Register (SWQR) card for both the operative(s) and the supervisor, which must be included in the Section 50 application. Time was spent searching for a SWQR accredited contractor that would accept such a small contract and eventually one was appointed. Negotiations were made with the contractor regarding the cost of the conduit installation, as a limited budget was available and therefore financial issues had to be regularly monitored. The contractor began to liaise with the main RWH system contractor, the residents of the contributor property and the LA regarding the Section 50 licence application.

Table 1. Timeline of activity relating to issue resolution for the pilot project

Timing	Activity	Timing	Activity
Apr *2015*	Initial discussions	Dec *2015*	Received missing form
May	Assessments & engagement	Jan *2016*	Search for contractor
July	Actor/footpath issues	Feb	Contractor appointed
Aug	Land negotiations finalised	Mar	Notice of additional fees
Sept	Footpath confirmed as Highways	Apr	Fee issue resolved
Nov	S50 forms received – 1 missing	June	Full installation completed

The LA declared that an expensive Temporary Traffic Regulation Notice (TTRN) would be required to close the footpath, despite it being a dead end and located on a spur of a crescent by some bollards that effectively made it a no through road. After assistance from a local councillor and the contractor, total fees were negotiated to a level that meant the installation could go ahead. During mid-June 2016 the installation of extra piping, water butts, diverter valves, the under footpath duct, intermediate bulk container (IBC – main storage tank) took place, much to the delight of all involved. Consequently, from initiation to implementation took just over a year. The co-creative relationship between the community and social enterprise has undoubtedly benefitted from collaborative resolution of the issues and invaluable experiential learning gained. However, the extended timescale has delayed the collection and evaluation of performance data. Consequently, demonstrating the concept of runoff sharing to the wider water industry is delayed, limiting current opportunities for wider implementation.

4. CONCLUSION

Co-production between a social enterprise and community group of an innovative initiative to share roof runoff demonstrated complex dynamics, which were explored using an actor-network approach. The interplay between the organisational and technical aspects resulted in difficulties in practice, which although not unresolvable, delayed significantly the completion of the pilot project and the growth of the enterprise. Such difficulties included high fees and delays resulting from land ownership complexities and local authority processes, as well as impeded project evaluation. Further research work will expand the SNA, undertake a project evaluation (performance and practice – data on usage and narratives on if and how allotment holder's activities have changed) and exchange insights with other international community-based water projects.

ACKNOWLEDGEMENTS & COMPETING INTERESTS

Thanks go to the family of actors involved in the pilot project, as well as to UnLtd who provided funding in the form of a 'Do It' award. UnLtd had no involvement in the study design, collection and analysis of data or in the writing of this manuscript. The author drives the social enterprise discussed in this paper, but takes a reflexive researcher perspective and there are no competing interests relating to this work.

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Water Efficiency Conference 2016

The challenges of availability and safe access to adequate quantity of clean water in rural refugee settings: A case study in Nakivale and Oruchinga refugee settlements, Uganda.

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ABSTRACT

This paper explores the constraints of water supply in rural refugee settings as a fundamental prerequisite to life, health and dignity using Nakivale and Oruchinga Refugee Settlements in the Republic of Uganda as case studies. Contextualised within basic human rights, the paper will assess access to safe, clean water for drinking, cooking and personal hygiene in the camps, and will also investigate existing coping mechanisms, as well as factors that impact the response of host governments and humanitarian organisations to water supply needs.

Despite both settlements being sited near Lake Nakivale and the Oruchinga Wetlands, refugees still face shortages of adequate quantities of safe, clean water for basic household consumption, as well as uses such as irrigation of crops and livestock watering. The study also assesses the influence of water scarcity on livelihood initiatives and human security, and the ability of water scarcity to hinder the implementation of refugee self-reliance with the potential for intercommunity friction. The paper concludes with recommendations on how best to provide a safe and adequate quantity of clean water to rural refugee households through (1) the use of appropriate technology; (2) beneficiary empowerment and; (3) enhancement of existing local knowledge on rainwater harvesting, treatment and water source management.

Key words: Availability, accessibility, quantity, quality, refugee, settlement, Water.

1. INTRODUCTION

Whether in peace or crisis, water remains an essential commodity, a prerequisite to life, health and human dignity (Oxfam, 2011). During crises, there may not be sufficient and adequate water available for human survival - drinking, domestic and personal hygiene - (Sphere, 2011) however, water supply shortages are often attributed to a combination of factors. These factors could involve both physical and social factors, such as the geological structure of the location, or simply the dynamic nature of refugee influx that surpasses the host country's capability (e.g. limited financial, infrastructure and human resources) to provide adequate water supplies. Water access is often tested by certain realities, particularly in situations where the majority of refugee camps and settlements are located in remote rural and arid areas (McDonald et al, 2008).

Nakivale and Oruchinga Refugee Settlements in Uganda are typical of camps situated in challenging environments. Despite both settlements being located in the vicinity of Lake Nakivale and the Oruchinga Wetlands, refugees still face shortages of adequate quantities of safe, clean water for household consumption, irrigation of crops and livestock watering (On-site Nzamisi, 2015). During the dry season (May to August/September), water supplies are obviously scarce, but this hinders resident's initiatives that promote self-reliance, as well as having the potential to generate intercommunity friction leading to security problems (On-site UNHCR, 2015).

Using case studies, this paper therefore has two aims:

1. To investigate residents' coping mechanisms in accessing water supply, in particular the management of water facilities including rainwater harvesting.

2. To assess the vulnerability of women and children in particular, to the threat of water shortages, and their consequent use of unclean water (UNICEF, 2015).

3. METHODOLOGY

Located in South-West Uganda in the district of Isingiro (Figure 1), Nakivale and Oruchinga Refugee Settlements were established in the late 1950s to accommodate refugees and asylum seekers fleeing tribal conflicts in Rwanda (OPM/UNHCR, 2011). In 1960, Nakivale was officially recognised as a refugee settlement (UG Gazette no 19) and Oruchinga in 1961 (UG Gazette 1433). Since then both settlements have been receiving refugees and people of concern on a regular basis. Initially, the majority of refugees were of Rwandan and Burundian origin. However, in the last two decades, armed conflicts in neighbouring Democratic Republic of the Congo (DRC) and South Sudan have resulted in a refugee populations increasing hence putting pressure on the Government of Uganda's capacity to respond to the basic needs of settlement residents. Although some improvement in water access has been reported in both settlements, the constant influx of refugees has challenged the ability of boreholes and water points to supply sufficient water, making water availability and access inadequate in some areas (OPM/UNHCR/WFP, 2014; AU, 2009).

Fieldwork was carried out at both refugee camps during the dry and wet seasons: 30 days in July 2014 and 15 days in November 2016 in Nakivale; and 15 days in July 2015 in Oruchinga. Qualitative data were obtained from a combination of transect walks, observations, ethnographic and participatory approaches whilst quantitative data were obtained from a medium scale assessment of water supply in 176 households in Nakivale and 20 households in Oruchinga. The disparity in the number of households accessed between the two settlements was due to settlement size in terms of area and population, as shown in Table 1.

Table1: Settlements details

	Population	Size	Number of zones	Number of villages
Nakivale Refugee Settlement	95,633	185 km^2	3	79
Oruchinga Refugee Settlement	6,068	8 km^2		15

(Source: OPM/GovUganda, 2015)

Fig 1 Location of Nakivale and Oruchinga Refugee Settlements, Uganda (circled in red)

http://www.unhcr.org/pages/49e483c06.html

In each of the assessed zones and villages, a range of qualitative and quantitative research techniques were applied - unstructured and semi-structured interviews, focus group discussions, transect walks and observations. Interview respondents were drawn from a combination of refugees and non-refugee populace. Non-refugee respondents included members of the host community, representatives from the Uganda Government, regional and on-site representatives from United Nations High Commission for Refugee (UNHCR), national and international NGOs operating in both refugee settlements. Existing water sources and specific linkages between a safe and clean water supply, consumption and socio-economic impact on refugee were assessed. Water quality, treatment, taste, use, and water point management including rain water harvesting were also investigated.

3. RESULTS

3.1 Sources of water

Table 2 shows that Nakivale is mainly dependant on the Lake and on rainwater harvesting for its supplies of water, whereas the much smaller settlement at Oruchinga uses springs, shallow wells and hand dug wells to access water. These sources are insufficient as the settlement population continues to grow.

Table 2: Water availability

		Nakivale Refugee Settlement	Oruchinga Refugee Settlement
Water Sources	Surface	Lake Nakivale	1 protected spring (Rurongo)
	Boreholes		4
	Shallow wells		9 (8 hand dug + 1 drilled)
	Rain water harvesting	3 shallow dams (Kabazaana)	
Water quality	Treatment plants	3 (Base Camp, Misiera & Kabazaana)	
Distribution	Hand pumps	50	
	Water taps	318	
	Trucking	During the dry seasons, water trucking supplies water to refugees and public institutions (schools and health centres)	
	Rainwater	Mini hand-dug pools of harvested rainwater	

3.2 Water usage and access

The successful implementation of the Sphere minimum recommended water supply standards (see Table 3) is often challenged by factors such as unpredictable weather patterns, settlement users physiology, food type, social and cultural norms. Table 3 also shows water use in both camps as of November 2015 compared with the Sphere minimum standards, and shows that at times, these standards are met. However, interactions with interviewees, observations and transect walks found fluctuations of water supply towards the lower volumes shown in Table 3, therefore stretching availability and access to water. Water shortages were attributed by 79% of refugee farmers in Nakivale and 17 farmers in Oruchinga to the continuous influx of new refugees and former refugees from neighbouring countries. Members of the host community and their farm animals were also mentioned as equal users of water facilities.

Table 3: Water use in Nakivale and Oruchinga Settlements

Minimum Water Standards (Sphere project, 2011)	Nakivale Refugee Settlement	Oruchinga Refugee Settlement
Total basic water needs: 7.5–15 l/h/d • Survival needs – water intake (drinking and food): 2.5–3 l/h/d • Basic hygiene practices: 2–6 l/h/d • Basic cooking: 3- 6 l/h/d	11.6 l/h/d	16.1 l/h/d

(OPM/UNHCR, 2015)

Water is distributed by means of tanks to public institutions such as schools, health centres and offices and to households, but only during the dry season. Rainwater harvesting is carried out during the wet season. For general household use such as drinking and cooking, water is fetched using 25l supplied containers, very often carried for longer than the recommended minimum distance of 200m. Children use hand crafted wooden bicycles to transport water from the water point to the household. Domestic washing up and livestock watering are generally carried out at water points particularly where rainwater has been harvested.

3.3 Water quality

There is significant concern over high levels of water turbidity and iron content in most refugee settlements in Uganda. In Nakivale and Oruchinga settlements, on-site American Refugee Council (ARC) records confirmed by the OPM/UNHCR 2015 Joint Assessment, suggest that boreholes have water hardness and high contents of elements such as calcium, magnesium, iron fluoride and manganese. In comparison with World Health Organisation standards, water hardness presents no risks to human health; however, 100% of interviewed respondents in both settlements reported that the water tasted unpleasant.

4. DISCUSSION

A significant gap was found between water supply and demand in Nakivale and Oruchinga settlements. The suggested gap is due to the increase in refugee population exceeding the national capacity and existing water sources. The host country's limited financial resources, the deep aquifer and unpredictable rainfall are all major constraints that hinder any effort to address water supply response, and illustrate the challenges facing on-site agencies in both settlements (On-site UNHCR, 2015; ARC, 2015).

For Nakivale specifically, the main issue of concern is the dependency on the only available main water source, Lake Nakivale. A combination of human activity (e.g. encroachment by farmers and animal grazing of the wetlands) and the settlement's growing population (95,633 inhabitants) has led to a dramatic deterioration in Lake Nakivale (Nzamisi 2015). As a result, there is water rationing and long queues at water points. In order to establish a balance between water supply and demand that meets the Sphere (2011) recommended minimum standards, alternative water sources and extra financial support will be required.

Water treatment and conservation at household level remains a significant concern in terms of water quality. Although the World Health Organisation (WHO) considers water treatment using chemical and water hardness harmless for consumers, 95% of interviewees found the taste of the water unpleasant. This represents an ultimate risk of less water intake and consumption of untreated water leading to the likelihood of waterborne diseases.

There are also issues around random timings to unlock water points leading to long queues; long distances (500≥ metres) from water points to the nearest household results in women and children having to carry heavy loads for long distances. This represents a safety hazard (e.g. unreported rape and abduction) for women and young girls, whilst also having an impact on children's education and quality time. Current water management in both refugee settlements require improvements/adjustment, particularly in terms of water point opening hours and queuing time. The promotion of appropriate technology by supporting local knowledge is important. For instance enhancing the performance of locally appropriate technology such as the handcrafted wooden bicycles could help alleviate the burden of women and children carrying heavy containers and at the same time allow children to enjoy childhood. Closing water points at 17h00, after which the circulation of people around the settlement is less, could contribution to the reduction of unreported abuses.

Rainwater harvesting using shallow hand dug dams, such as those located in Kabazaana, (Rubondo village, Nakivale Refugee Settlement) offers a valuable alternative to surface water and borehole sources. However, they can pose a threat to human health particularly when refugees and members of the host community use untreated rainwater for domestic needs such as bathing, cooking and washing kitchen utensils, laundry and livestock watering. Humans sharing water facilities with animals (including wild animals) presents the potential for diseases, such as tuberculosis, to be transmitted from animals to humans, particularly in situations where farm animals are not under regular veterinary care (Davies, 2010; WHO, 2011).

5. CONCLUSION AND RECOMMENDATIONS

From the results and discussions on the challenges posed of water availability and access in Nakivale and Oruchinga Refugee Settlements, further in-depth exploration of mechanisms that could improve and/or develop new means of water access and equity are needed. This could be achieved through (1) the use of appropriate technology; (2) beneficiary empowerment and; (3) enhancement of existing local knowledge on rainwater harvesting, water treatment and water resource management

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Design of an Energy Performance Contract: City of Jackson Case Study

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ABSTRACT

The typical Energy Performance Contract (EPC) can be a very cost effective method by which energy/ utility companies (UCs) may perform significant upgrades to their infrastructure, in order to reduce operating costs or energy consumption, which may otherwise be cost prohibitive. In the typical EPC structure, an Energy Services Company (ESCO) performs an audit of existing infrastructure or energy consumption and identifies what improvements are required to reduce energy costs and increase savings for the UC. Annual guaranteed "savings" are then predicted by the ESCO and are contingent upon the UC's implementation of the required improvements. These savings, in turn, pay for the upgrades. The key to success lies with identifying and quantifying the upgrades required, as well as determining the appropriate measurement and verification methods for their successful implementation. This paper presents one EPC used by the City of Jackson Department of Public Works (COJ) for water and sewer upgrades to demonstrate some of the key factors which led to an unsuccessful EPC delivery. In this case, a nontraditional EPC was utilized which beneficially favored the ESCO, rather than COJ. Contract evaluation will be discussed, including a quantitative evaluation of EPC viability, contract setup, and measurement and verification methodologies used. Critical factors which ultimately determine EPC success, as well as lessons learned, are identified and will be discussed in detail.

Keywords: Energy Performance Contract, Energy Services Company, Guaranteed Savings

1. INTRODUCTION

Energy Performance Contracts (EPCs) began to gain popularity in the mid-1980s to the mid-1990s as energy efficiency became more of a household term. Prior to that time Energy Service Companies (ESCOs) predominantly were subcontracted by utility companies or authorities (UCs) to provide energy conservation services to their customers. Most of the work was centered on residential home audits of energy consumption and conservation activities, as well as providing manpower to the UCs. However, in the mid-1980s and beyond, UCs were beginning to respond to more environmental regulation and energy efficiency mandates which forced ESCOs to adapt to the changing marketplace. They began to fine tune energy consumption measurement, energy efficiency methodologies and energy demand savings. With this shift in the mid-1990s, the International Performance Measurement and Verification Protocol (IPMVP), which standardized how efficiency savings were defined and measured, was born. This was the foundation the ESCOs needed which ultimately led to the fast growth of many ESCOs from the mid-1990s to the mid-2000s. Today, ESCOs partner with UCs on multi-million dollar projects, without whom, many large Energy (or Utility) Capital Improvement Program (CIP) projects could not be financed.

As utility infrastructure and equipment become outdated or faulty, water consumption and operations and maintenance costs rise. Typically, an ESCO is hired using a qualification based selection process to perform an Investment-Grade Audit (IGA). During this audit, the ESCO determines baseline utility consumption and/or condition of existing infrastructure. The baseline consumption typically includes reasonable growth in use and price. From the

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assessment and as a means to modernize the infrastructure and replace failing equipment, the ESCO identifies what improvements, typically termed Facility Improvement Measures (FIMs), are required to reduce utility costs and increase savings for the UC.

The ESCO determines what the predicted utility (or energy) savings will be, either in terms of actual consumption and/or in monetary terms, as an estimate of annual savings the UC will see should the FIMs be performed. Predicted savings are typically based on the ESCO's past experience with similar projects given the particular technology or methodology they propose to use. This should be considered the best case outcome. In order to mitigate some of the risk associated with providing the UC with the best possible outcome, the ESCO will convert the predicted savings to "guaranteed" savings, which are also annual savings but are typically some percentage of the predicted savings. The guaranteed savings will in turn pay for the upgrades if the UC contracts with the ESCO to perform the work. Obviously, the UC would like the savings to be as high as possible so the ESCO must balance achievable guarantees against competitiveness. The guaranteed savings are translated to the UC as part of the IGA report which is then the basis of a subsequent performance contract.

At this point the UC will review the proposal to determine if it will proceed with the recommendations and, if so, negotiate with the ESCO to perform the work in the performance contract. The contract will describe the terms, such as length of construction, guarantee period, and payment schedule. The ESCO becomes a one-stop shop by acting as both project manager and contractor for the duration of the project. The ESCO finances the work up front and is then paid by the public utility with the savings it incurs. In this way, payments to the ESCO never surpass the UC's operating costs. The term of the contract is calculated by dividing the total project cost by the guaranteed annual savings. If the savings are not as much as the ESCO guaranteed in the contract, he is required to pay the public utility the difference. On the contrary, if the savings are more than what the ESCO guaranteed, the public utility may keep the difference or split the difference with the ESCO depending on the contract terms. Once the contract term is over, the public utility is allowed to retain all of the savings. The general sequence of events is outlined in Fig. 1 and can obviously be stopped if the EPC project is determined not to be feasible:

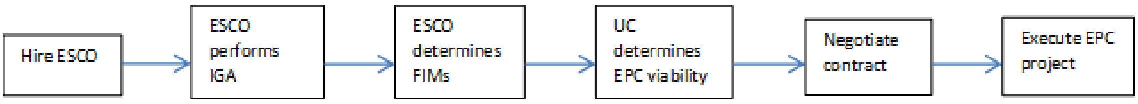

Fig. 1. Energy Performance Contract Project Process

For this project, a case study approach was chosen to highlight the use of an EPC in one particular instance. A case study can generally be defined as an in-depth investigation of one specific situation or account over an extended period of time rather than a traditional broad survey of many accounts or experiments over a short duration. In this way, a thorough understanding of one particular situation can be obtained and the findings generalized and applied to other, similar situations. In the current paper, the case study approach describes what happened during the planning and execution of the EPC and then explains why the EPC was unsuccessful for COJ. In order to illustrate this conclusion, a thorough literature review and quantitative evaluation, by recreating a cash-flow analysis scenario similar to that which would have been conducted by COJ and the ESCO at the time of the EPC contract, were performed. The outcome of this analysis resulted in the development of a list of lessons learned that can be utilized by COJ, or other organizations, in the planning and execution of future EPCs.

2. THE EPC BETWEEN CITY OF JACKSON AND SIEMENS

In the period between 2010 and 2012, COJ faced significant problems with its water and sewer infrastructure. An exceptionally cold winter caused more than 150 water main breaks across the city and at the same time, COJ was cited for multiple violations of the Clean Water Act by discharging almost three billion gallons of raw sewage into the Pearl River, an extremely important wetlands habitat supporting various plant and animal species across Mississippi and Louisiana. As part of the settlement for the violations, COJ was required to create and implement a comprehensive and time-sensitive improvement plan for its water and sewer infrastructure. Financially, this was the largest project that COJ had ever undertaken ($91M) and they had to negotiate a contract very quickly in order to meet the settlement obligations. To accomplish this, COJ contracted with Siemens (the ESCO) to perform an IGA of the current state of the COJ Department of Public Works (DPW) sewer and water treatment system, as well as its water distribution system. It was determined that upgrades and/or repairs were required at two water treatment plants and within the sewer collection system. It was also determined through sampling that the aging water meters within the water distribution system averaged less than 90% accuracy and warranted replacement with new, electronic, water meters. COJ again contracted with Siemens to perform the installation of approximately 65,000 new remote-read water meters, perform upgrades at two water treatment plants and perform repairs/replacements of its aging sanitary sewer collection system for a total of approximately $91M, with more than 50% of the budget going to water meter and billing system upgrades. Thirty percent of the budget was for the water treatment plants and sewer line repairs/upgrades and remainder for mobilization, PMO costs, etc. The construction phase duration was projected to last 2.5 years; the savings guaranteed by the ESCO was $123M; and the guarantee period was determined to be 15 years beginning upon construction completion.

The EPC between COJ and Siemens was hastened due to the significant problems with COJ's water and sewer infrastructure which resulted in a rather atypical contract and project. First, Siemens negotiated upfront monthly project payments by COJ during the construction phase, before 99% of the projected savings were anticipated. In addition, the payments were higher in the beginning of construction and gradually decreased over the construction phase (57% paid in Year 1, 40% paid in Year 2, and 3% paid in the last 6 months). To date, this had been the largest contract (in dollars) that COJ ever undertook, and financing the project before the projected savings were realized forced COJ to issue $90M in bonds in order to make the upfront payments. In addition to the construction payments, COJ was required to pay Siemens for executing a Performance Assurance Services Program (PASP) which included Siemens' annual inspection and report of the facility improvement measures, and measurement and verification and/or accuracy testing of water meters. PASP payments were to be paid quarterly for 15 years following construction completion. Contractually, if COJ defaulted on PASP payments, Siemens would be deemed to have met its performance guarantee obligations for all remaining annual periods without verification. PASP payments totaled $4.5M.
Based on the annual guaranteed savings and PASP reports prepared by Siemens, it would be determined if the guarantee was met. If it was met or exceeded, COJ maintained the full benefit. If a shortfall was confirmed, Siemens was required to pay COJ the difference between the guaranteed and actual savings reported. The contract further stated that shortfall payment to COJ, based on Siemens' calculation of the annual realized savings, was the sole remedy for any savings shortfalls.

Siemens' contract guaranteed savings in four areas for COJ: small water meter installations; large water meter installations; operational savings due to the installed meters being remote read, resulting in less manual meter reading, disconnects and restorations; and deferred maintenance of the two water treatment plants and sewer system. Of these four savings areas, only small meter installation was contractually subject to annual measurement and verification (M&V) of the newly installed meters. This equates to approximately $43M of the $123M guaranteed savings. The remaining $80M was stipulated to occur (i.e. without verification). The new large meters, for instance, which accounted for $15M of guaranteed savings, were assumed to be more accurate than the existing meters they replaced. Additionally, a further assumption was made that the existing meters were reading *lower* usage rates than the new meters would. No M&V of large meters was specified in the contract.

3. PROJECT EVALUATION AND ANALYSIS

Several factors inherent to the typical EPC lead to project success. These include: the ESCO determines, via an IGA, the upgrades which the UC should perform. A proper study is performed to determine project feasibility. The ESCO and UC negotiate a contract to perform the required upgrades which includes: qualified staff within the ESCO and UC to properly negotiate the contract, guaranteed savings upon performing the upgrades that can be

measured and verified, payment schedule which coincides with the verified savings, proper installation of the upgrades is performed and verified, and an annual M&V program that determines actual savings to the UC by the ESCO. The COJ EPC contract, however, shows many issues that do not conform to these best practices.
A detailed discussion of these items is presented below.

3.1 EPC Viability Discussion

To better understand the project's viability in terms of a quantitative evaluation, a financial analysis was performed to evaluate project feasibility. All of the known project expenditures, including construction and PASP payments to Siemens, as well as annual savings guaranteed to COJ by Siemens, were considered, resulting in a cash flow analysis. Four types of benefits in the project are savings from small meters, savings from large meters, deferred maintenance, and avoided operation costs due to remotely reading meters. It should be noted that as COJ is a public utility, taxes were not a consideration in this analysis. Also, FCF does not take into account debt or financing. It is only the cash that a company generates which is available for future expenditures or opportunities, such as expansions, enhancements or other projects.

COJ financed the project by issuing $90M in bonds. Annual interest paid on the bonds was 3.5% with maturity at the end of the guarantee period at Year 18, at which point, the entire principal amount plus the capitalized interest payments during the construction period will be paid in full. The result is shown in Fig 2. It is interesting to observe that total benefit of the project is slightly smaller than the life-cycle cost. Please note that the benefits cover all possible benefits in addition to guaranteed savings from small meters in the contract. The viability highly depends upon the continuous operation after the EPC contract. Assuming a perpetual annuity after the contract, the present value of such benefit tops $68 million, which makes the project a viable one. However, the project is not a typical performance based contract. EPC payments were made to Siemens for the construction project upfront in the construction phase before 99% of the savings were realized. Payments made in the near-term are not necessarily equally offset by savings made in the future, even though those savings could be greater than the upfront payments, due to inflation and time value of money. Had the savings been realized prior to paying Siemens for the construction activities, a different result would have been returned. Using annual payments of approximately $1M - $3.5M within the 15 year guarantee period (not to exceed the guaranteed savings for that year) totaling the approximately $91M construction cost, a positive NPV would have been returned.

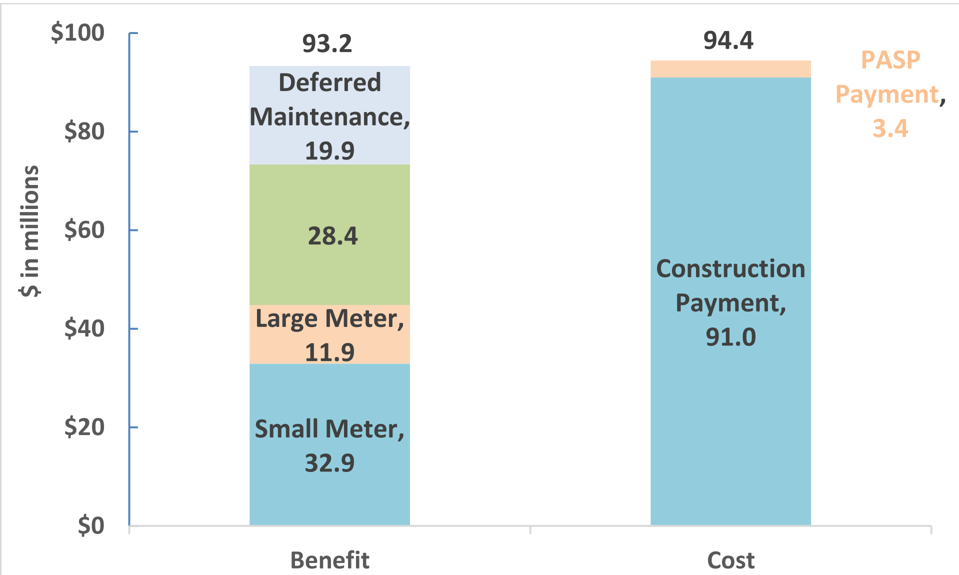

Fig 2. Project Costs and Benefits

As the project uses public finance, financial cost has not been included but would be borne by the COJ. A closer look at the financing structure shows that interest to be paid to bondholders is considerably more than the savings minus the construction cost. Such issue endangers the viability of the contract if excluding residual benefits after the EPC contract. While using the residual benefit approach described above in determining project feasibility NPV analysis is a logical and easy alternative; however, the upfront construction payments to Siemens vs. spreading the payments over the guarantee period is not so easy to rectify. A typical performance contract construction cost is financed by the contractor to be paid for out of the savings or benefits realized by the Utility on the backend. If guaranteed savings aren't realized, the contractor must pay the difference. In this case, the timing of the construction payments to Siemens was mandated by the contract. And, in addition to the construction payments, the contract also required maintenance (PASP) payments be made to Siemens during the guarantee period. In order to spread the construction payments across the guarantee phase, the contract itself between Siemens and COJ would require modification.

3.2 Contract Setup

There are several key observations and issues relating to the contract that put COJ at a disadvantage and ultimately led to an unsuccessful EPC delivery. This included Siemens requiring upfront construction payments before the guaranteed savings were realized. The construction was completely paid for before the guarantee period (where almost all of the savings were to occur) even began. Without the savings for funding, COJ was forced to issue bonds to pay for the project, putting them in debt before the project began. The bonds, in turn, must be paid back to the bondholders with interest, another financial disadvantage for COJ. Once construction was complete, during the 15-year performance guarantee period, COJ was also responsible for PASP payments to Siemens in addition to the construction payments. PASP paid for Siemens to perform an annual analysis and report of the guaranteed savings to ensure that there was no shortfall. Some very important benefits to Siemens lie here. First, Siemens included only one actual item to be tested in the contract, small remote read meters. All other improvements made were stipulated or assumed to be improvements over the pre-upgrade condition. These will be discussed further in the M&V section. The most important part of this scenario is that only a small portion of the contracted upgrades, $43M of the $123M guaranteed savings, were contractually verifiable through actual testing. It was assumed that the remaining upgrades produced the guaranteed savings whether they actually did or did not, significantly skewing to prospect of a savings shortfall away from Siemens. Second, the shortfall payment by Siemens was contractually the sole remedy COJ had for financial compensation due to any savings disparity. And if COJ defaulted on any PASP payment, Siemens was deemed to have fulfilled its performance guarantee obligation for the rest of the savings guarantee period. This put COJ at a huge financial disadvantage without much recourse for project failure.

3.3 Measurement and Verification

The basis of an EPC is that some agreed upon amount of upgrades (by the ESCO and UC) are required which will produce a predetermined amount of savings to the UC with verifiable and measureable results. This means that installation of the upgrades (construction) should be verified (i.e. inspected) for specified/working materials and equipment as well as measured (i.e. tested) to ensure that the savings guaranteed were actually accomplished.

At the time of this EPC, COJ was under scrutiny and legally required to quickly rectify significant CWA violations. The construction, which consisted of upgrades to two large WTPs, repairs or replacement of many faulty sewer mains, and installation of 65,000 new meters, required significant oversight to ensure proper installation of all new upgrades. Add the fact that this was the largest contract COJ had ever undertaken to an accelerated contract negotiation and award, and COJ was at a disadvantage both through lack of sufficient inspection capability and contractually. Verification of installed equipment became even more of an issue when only one of the four savings areas guaranteed by Siemens (small meter installation) was contractually subject to measurement (approximately 35% of the guaranteed savings). This was further compounded by the fact that only a small percentage of those small meters were part of the testing program, with the rest of the upgrades, including large meter installation, assumed to provide savings without testing. This meant it was absolutely imperative that COJ have sufficient oversight during meter installation, in particular. Otherwise, there is no recourse if the meters were improperly installed as the savings are still assumed to be realized. For instance, after a significant portion of the meter installations were complete, several of the meters were found to be the wrong type (reading gallons instead of cubic feet) causing unusually high water bills for users. That should have been caught before installation. Much of the QA required to ensure the projected savings were met was left to Siemens to essentially “police” itself.

The remaining three areas of guaranteed savings (large meter installation, operational savings and deferred maintenance) were stipulated to occur regardless of whether any actual savings could be demonstrated. Deferred maintenance savings, which relates to the sewer main repairs and WTP upgrades, could arguably be assumed based on craftsmanship and the warranties of the materials used; however, this accounts for slightly more than 20% of the guaranteed savings. The new large meters were assumed to be more accurate than the existing large meters. A further assumption was made that the existing large meters were reading lower usage rates than the new meters would, thus, replacing the meters is assumed to result in increased revenue. No M&V of savings for large meters (nearly 15% of the guaranteed savings), a very easily tested item, is specified in the contract.

The final task, which accounts for a significant portion of the guaranteed savings (over 30%), lies within the operational upgrades. Operational savings are assumed to result from the installation of the new water meters. There are two major flaws with the determination of savings. First, the savings are predicated on COJ having to take some type of action. Since the new meters are remote read, it is assumed that the following would occur:

- Manual meter reading and data entry is eliminated, resulting in decreased staff.
- Fewer meter re-reads and meter locates due to greater accuracy, fewer reading errors and elimination of manually finding difficult to locate meters, resulting in decreased staff.
- Manual service shut-offs and restorations is eliminated, resulting in decreased staff.
- Reduced staff results in elimination of staff vehicles and their associated maintenance and fuel costs.

To realize the savings, COJ has to eliminate staff and their vehicles, which is no small task, particularly within government organizations. Typically, when one task or function is eliminated, employees are retained and given other job responsibilities. Although less employees may be required for meter reading, the “savings” associated with eliminating their salaries is likely to result in simply moving that cost to a new functional area.

The second flaw in the operational savings is that it is based on assumed and unverified costs of current operations, meaning that is was assumed by the ESCO that a certain number of meters were read in a day by a certain number of readers, and so on. Any or all of the operations cost assumptions that are incorrect, then the flaw is carried on to the operational guaranteed savings. If, for instance, the original estimation was predicated on 15 meter readers and COJ actually only used 10, or on 40 meters being read by a reader in a day and each reader actually read 50, then the guaranteed savings associated with de-staffing will have also been significantly overestimated.

PASP payments by COJ during the guarantee period were required in order for Siemens to perform annual savings M&V and ultimately to produce a report quantifying the savings COJ realized during that year. If three of the four upgrade tasks were stipulated without requiring M&V, which amounts to 65% of the guaranteed savings, and only a small percentage of the small meters installed were being tested, it begs the question, for what exactly the $4.5M PASP payments were to pay?

4. LESSONS LEARNED

After the evaluation of the Siemens/COJ EPC was performed, several lessons learned were determined that can be used to reduce risk to COJ (or any UC) and improve the success of subsequent EPC projects. These include:

- In future EPC projects, the traditional EPC payment schedule should be implemented. The ESCO should finance the project and be paid by the UC with its realized savings. It is not unusual for larger projects to have some upfront payment to the ESCO to minimize a portion of its risk; however, only a partial payment should be considered until anticipated savings are realized.
- The UC needs to fully understand PASP (Performance Assurance Services Program) payments, should they be included in future contracts. It is devised to be a method of compensation for performing measurement and verification of the upgrades which are to provide a savings benefit, as well as producing a report of the findings. This is an acceptable charge if the upgrades are actually tested. In the case of the current EPC, a large majority of the savings were stipulated. If they are assumed and not tested and verified, then what the PASP payments actually pay for becomes questionable. Also in the current contract, the PASP payments were required for the guaranteed savings benefit. If the payments were stopped, then the contract indicated the ESCO was deemed to have successfully achieved its savings guarantees without verification. A full understanding of the PASP scope, deliverable and payments verbiage in the contract is essential.
- Test the testable tasks. The UC requires a firm understanding of the implications of stipulated vs. measured and verified tasks. Although in the case of this EPC, stipulated tasks were problematic, they certainly should not be deemed negative in all cases. They just must be used appropriately, understood and agreed upon. It seems relatively obvious but, testable items should be tested and not stipulated. The large meters in the current EPC had assumed efficiencies associated with them but without testing and comparison to the previous meters, it is unknown how much benefit they really had. This could have been easily verified. If it can be easily tested, it should be.
- If a task is to be stipulated, it requires a verified baseline. In this case, the ESCO assumed how much the UC's operating costs were, including personnel utilized, daily tasks performed, equipment used, etc. These assumptions were not verified by either the ESCO or UC. If any of these assumptions were overestimated, then so would be the savings. Without baseline verification, it is possible that savings may not have even been achievable based on the assumptions.
- Savings should not have been based on tasks that the UC must perform, as done in this EPC. It is unreasonable to base savings on employee layoffs. Savings should come from the upgrades that are performed and should not include unreasonable tasks that the UC must perform to be realized. If some savings are based on actions required of the UC, the actions must be reasonably achievable, the utility must fully understand the actions required, as well as their implications, and the utility must agree upon them.
- The UC should understand and require proper recourse for deficiencies. In the current contract, recourse was only through the shortfall payments based on the ESCO's annual performance reports. If all or most of the savings are stipulated (particularly without proper baseline verification), then the utility essentially has no actual recourse. The contract must include proper bases for savings to ensure proper recourse for shortfalls.
- The UC must allocate sufficient time and resources to the EPC project, particularly in contract negotiation and execution; project management; and construction (QC) oversight. Ideally, the UC's legal department should be part of the contract review and negotiation process along with a project team knowledgeable on EPC. If the utility does not have enough of these personnel available, it should subcontract them. It's imperative to understand a contract, particularly one of the current EPC's magnitude and complexity. Full-time, knowledgeable project management is required during the project execution phase to monitor scope, schedule and budget. Lastly, proper field inspection is imperative. With 65,000 meters to install, 2 WTPs to upgrade and various sewer lines to repair in the current contract, many crews would have been necessary to complete construction within the contract time. Inevitably, several field inspectors would have been necessary to verify successful completion of the work. For instance, the ESCO' annual report did not address either verified, successful meter installation or large meter testing, so the UC would require an aggressive and sophisticated quality control process in order to ensure their savings were realized. This requires sufficient staff to oversee the work.

EPC should still be deemed a good way to perform and finance large energy or utility CIP projects that would likely not have a viable financing alternative; however, the UCs need to be well-versed on EPC and its contractual language and language to understand exactly to what they are agreeing. They, too, must have sufficient staffing to ensure that the proper facility improvements are verified and tested so that the benefits they are paying for are not only achievable, but also actually realized.

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Analysis and implementation of sustainable drainage practices under Spain's oceanic climate conditions

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ABSTRACT

Since 2003, up to 15 different research projects have been undertaken in the north of Spain to assess the application and usefulness of Sustainable Urban Drainage Systems (SuDS) under the oceanic climate conditions that define this part of the country. These projects encompassed the study of all the facets related to sustainable drainage techniques, such as harvesting systems, in situ rainwater treatment, energy exploitation and strategic planning, with emphasis on the design and installation of pervious pavement structures (PPS). The research on which these projects are based has been supported over the years by the testing of both experimental sites and lab specimens in terms of water quality and quantity. This paper describes the SuDS-related experience under Spain's oceanic climate conditions by providing an overview of the most relevant research projects that has been developed across regions located in the north of the country so far and the main scientific publications to which they have led.
Keywords: Filter drains; Hydrocarbons; Pervious pavement structures; Sustainable Urban Drainage Systems; Water management.

1. INTRODUCTION

According to the Köppen Climate Classification for the Iberian Península [1], the north of Spain completely belongs to a type C climate, which corresponds to temperate climates. In particular, the regions of Basque Country, Asturias, Cantabria and Galicia are the most representative areas of the subgroup Cfb, also known as oceanic climate, which is characterised by having temperate summers and cool winters, with a not very broad range of temperatures and moist conditions all year round. San Sebastián, Oviedo, Santander and Pontevedra, which are some of the most important cities in the four regions aforementioned, have average annual values of precipitation (mm per year) of approximately 1,700, 1,000, 1,200 and 1,700, respectively. As a result of these considerations, this climate zone is subject to an almost continuous state of high demands in terms of drainage, which supports the interest in the application and analysis of the impact of Sustainable Drainage Systems (SuDS) on these regions.

The SuDS-related research conducted in the north of Spain throughout these years has been based on the testing of both experimental and laboratory SuDS' samples in terms of water quantity and quality. The activity in this field has traditionally been focused on the analysis of pervious pavement structures (PPS) as the most comprehensive type of SuDS, including the study of their behaviour from different perspectives, such as rainwater harvesting, in situ rainwater treatment, energy exploitation and strategic planning. This research overviews the most relevant SuDS-related projects carried out under Spain's oceanic climate conditions so far and the main outcomes derived from them.

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2. OVERVIEW OF SUDS-RELATED RESEARCH IN NORTHERN SPAIN

The Construction Technology Applied Research Group (GITECO) at University of Cantabria was the entity that led the first Spanish SuDS-related research project in 2003. Since then, up to 15 different public and private projects related to the analysis and implementation of sustainable drainage practices have been successfully developed across Spain's oceanic climate zones. Table 1 provides a summary of the most relevant research projects conducted in northern Spain regions from 2003 to the current date.

Table 1. Overview of the SuDS-related research projects developed in northern Spain

Year	Title	Aims
2003	Development of new hydrocarbon biodegrading pavement structures (FIDICA) [2-6, 17, 18]	- Development of new pervious pavement structures using recycled aggregates. - Analysis of biofilm growth in the PPS through the study of the geotextile layer.
2006	Development of new catchment, pre-treatment & in situ treatment systems for hydrocarbon contaminated water coming from urban runoff in parking lots with impervious pavements (TRAPI) [7, 8]	- Design of a device to be placed in sewer systems for catchment and treatment of runoff containing hydrocarbons from impervious surfaces. - Analysis of the hydraulic and depuration behaviour of the designed device at real-scale conditions.
2006	Design, research & instrumentation of parking lots built with pervious pavements capable of degrading hydrocarbons [9, 10]	- Design of 45 parking bays based on the combination of 5 different permeable surfaces and 3 different geotextiles. - Monitoring of water quantity and quality parameters in the outflow of the parking bays.
2007	Design & monitoring of sustainable drainage linear systems [11]	- Testing of three drainage stretches in the roadside of a parking area: a swale, a filter drain and a concrete ditch. - Monitoring of water quality parameters in the outflow of the three drainage linear systems.
2009	Design, control & monitoring of pervious pavements built with slag and steel waste [12]	- Instrumentation of eight parking bays built using different pervious surfaces and a sub-base of BOF-Slag aggregates. - Monitoring of water quality parameters in the outflow of the parking lots.
2010	Development of catchment and store rainwater systems, using porous pavements in parking lots, for non-potable use with geothermal low enthalpy energy (VEA) [13-16]	- Analysis of the rainwater harvesting capacity of permeable pavement systems. - Development of water storage systems to be used for non-potable uses or with geothermal purposes.
2013	Hydrological rehabilitation of urban road infrastructures (RHIVU) [18-20]	- Mechanical and hydrological analysis of different permeable pavement materials. - Design of a spatial decision support system to rehabilitate urban roads through sustainable drainage practices.

These research projects have been mainly targeted to address the behaviour of different types of SuDS in terms of both water quantity and quality, with emphasis on the analysis of PPS as the most complete sustainable drainage system. Both aspects have been approached from several perspectives, including the analysis of different layer configurations and materials. The outputs derived from these projects also include the design and evaluation of novel devices for water collection and treatment in impervious area, whereas the latest research trend focuses on the development of hydrological models and decision-making tools to assess the response of SuDS in terms of sustainability and resilience.

3. RESULTS AND DISCUSSION

The SuDS-related research in northern Spain was started by members of GITECO, who conducted a literature review of the state of sustainable drainage systems at that time. As a result, a paper was released a few years later [2] in which the concept Sustainable Urban Drainage Systems was introduced in Spain under the same acronym: SuDS (Sistemas Urbanos de Drenaje Sostenible).
The need for devices to test pervious pavements resulted in the creation of the Cantabrian Fixed (CF) Infiltrometer [3] and the Cantabrian Portable Infiltrometer [4], whose aim was to assess the infiltration rate of different pervious surfaces in laboratory and field conditions, respectively. Castro et al. (2007) [5] inferred that Interlocking Concrete Pavers having longer and narrower gaps behaved better than those with shorter and wider gaps, whereas the amount and size of the particles filling the gaps was proved to influence the infiltration capacity of the PPS.
The hydrocarbons removal capacity of PPS was analysed in Bayon et al. (2015) [6] through the study of the geotextile layer as a support for the growth of biofilm. The results suggested that thickness was the main factor contributing to the generation of biomass, whilst the exposure of geotextiles to a microbial community resulted in an increase of their mechanical response in comparison with situations without inoculated biological activity in which the effect of oil or atmosphere was uncontrolled.
The design of the SCPT (System for Collection, Pre-treatment and Treatment) prototype provided a device to be installed in impervious park areas to manage polluted runoff. Fernández-Barrera et al. (2010) [7] pointed to the inflow and the number of geotextiles layers in the SCPT as the factors that most influenced the efficiency of the device in removing pollutants. Rodriguez-Hernandez et al. (2010) [8] showed that the SCPT was capable of reducing pollution rates up to 90% for both Total Suspended Solids (TSS) and Total Petroleum Hydrocarbons (TPH). As a conclusion, the hydraulic conductivity of geotextiles was found to be not relevant for the behaviour of the SCPT.
Gomez-Ullate et al. (2011a) [9] proved that the impact of surface is greater than that of geotextile on the infiltration capacity of PPS and highlighted the usefulness of this drainage system to store water. They also clustered surfaces into open (pavers), closed (continuous) and green (grids) according to their infiltration behaviour. After one year of storage, Gomez-Ullate et al. (2011b) [10] demonstrated that water quality within the parking lots was enough as to be used for irrigation purposes, according to Spanish law.
Andrés-Valeri et al. (2014) [11] compared the pollutant removal efficiency of two sustainable drainage linear systems such as a swale and a filter drain with a conventional concrete ditch. The results showed that water quality in the outflow of the sustainable systems was significantly better than in the concrete ditch, with reduction rates close to 70% in both TSS and Turbidity in both SuDS.

Andrés-Valeri et al. (2013) [12] analysed the influence of Basic Oxygen Furnace slag (BOF-slag) sub-bases and surface types on PPS and found that the outflow water could be reused for residential, industrial, recreational and agricultural purposes, despite the high pH and EC values recorded. The analyses derived from this research also yielded significant correlations between climate and parameters such as pH, Electrical Conductivity (EC), TSS and Turbidity.

Sañudo-Fontaneda et al. (2013, 2014a, 2014b) [13-15] and del Castillo-García et al. (2013) [16] compared the hydraulic and geothermal performance of several permeable pavements for their use as a combined rainwater harvesting and sustainable energy technique. All the permeable pavements showed great infiltration and storage capacity. The combination of a porous asphalt surface and a limestone gravel sub-base provided the best insulation from the ambient air conditions, while interlocked concrete block pavement surface and plastic cell sub-base dissipated the heat better than the other systems.

Rodriguez-Hernandez et al. (2016) [17] analysed the impact of the surface and sub-base type on the long-term hydrological performance of different PPS. The type of aggregate in the sub-base layer was found to influence the storm water retention capacity of PPS, whilst continuous surfaces proved to be better than pavers in terms of runoff attenuation, and vice versa regarding clogging effects. Jato-Espino et al. (2014) [19] presented a multi-criteria decision-making model based on the combination of the AHP and MIVES methods to select PPS according to the three pillars of sustainability. The results showed that continuous pavements outperformed paver-based systems due to their better economic and social performance. In Rodriguez-Hernandez et al. (2016) [18] the ravelling resistance of porous asphalt mixtures made with different binder types and affected by water and hydrocarbon as aging agents was studied. They concluded that polymer modified bituminous binder provided the best response in these terms, with a good ravelling resistance for all the tested conditions. Jato-Espino et al. (2016) [20] performed several GIS-based stormwater simulations to test the potential of PPS and green roofs for attenuating flooding in an urban catchment located in San Sebastián. The results proved that PPS reached the best ratio between volume reduction and required area, although green roofs also demonstrated their capability to avoid sewer floods and surcharges.

Future SuDS-related research under Spain's oceanic climate conditions will focus on the study of these systems as a tool to improve urban resilience and make cities adaptable to Climate Change demands, including the study of the following specific topics: porous concrete pavements, hydrologic/hydraulic simulations, decision-making tools and risk analyses.

4. CONCLUSION

This paper overviews the main projects and results achieved through the research conducted in the north of Spain in relation to the analysis and implementation of sustainable drainage practices, the study of which has great interest in these areas due to the persistently moist climate conditions to which they are subject. The SuDS-related research undertaken across Spain's oceanic climate zones has resulted in 16 different projects, which led to 26 JCR journal papers, 2 books, 35 conference presentations, 5 doctoral theses and 2 patents.

SuDS-based research in these regions has been mainly focused on the analysis of PPS in terms of both their water storage capacity and their influence on water quality. Other systems such as swales and filter drains have been analysed from a similar perspective, whereas alternative approaches for water collection and treatment such as the SCPT device were also designed and assessed. The last research lines have been oriented to the development of GIS-based stormwater simulation models and decision support tools to improve urban water management, two topics which will be further studied in the future, along with porous concrete, flood risk analyses and Climate Change modelling.

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Conceptualising the hydrology of tropical wetlands to aid habitat management in northern Zambia

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ABSTRACT

Climate change and human population increase may potentially negatively impact river systems and associated biodiversity and ecosystem services related benefits in sub-Saharan tropical countries. Kasanka National Park, Zambia, provides valuable freshwater habitats for rare species and valuable income to local communities through ecotourism. A hydrological study was carried out (2006-2008) utilising tracers to investigate hydrological pathways, and potential threats to the freshwater habitats. Spatial and temporal variability in terms of hydrological tracers was seen across the park, with varying importance of rainfall inputs to different habitats, and dependent upon preceding wet season levels of precipitation. The findings should be developed further to aid management of habitats and water resources from both a nature conservation and sustainable human livelihood perspective.

Keywords: Biodiversity; dambo; ecosystem services; freshwater; hydrochemistry

1. INTRODUCTION

Factors including climate change and population growth are expected to put increased pressure on water resources in some sub-Saharan regions, potentially threatening drinking water and agricultural irrigation supplies (e.g. [1,2]). Other factors including high stream densities, inter-seasonal discharge fluctuation, and extensive floodplains often result in high biodiversity in tropical river systems (e.g. [3,4,5]). However, ecosystem services provided by tropical rivers and associated habitats have received little attention to date but are important for livelihood support [6,7], and can provide income generation via ecotourism for poor communities [8]. Conservation is essential to protect these benefits [9], but an integrated catchment management approach is needed based on an informed scientific understanding [10].

Zambia is home to the headwaters of the Zambezi and Congo rivers, and their numerous tributaries and associated extensive wetlands [7]. It is a poor, lower-middle income country, which also has the highest predicted human population growth in the world [11]. Hence, the need to monitor and protect Zambian rivers is pressing, although recent work by the authors [5,12] represents the first systematic baseline river surveys conducted in the country.

Previous process-based hydrological investigations in the region have focused on “dambos” (seasonally saturated wetlands) which often form important seasonal headwaters of river

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systems in southern Africa (e.g. [13,14]). Aspects of groundwater recharge and flow are also generally understudied and uncertain [13,1]. Hydrochemical and isotopic tracers have proven utility in hydrological up-scaling studies, when combined with appropriate hydrometric data [15]. Different solutes can ascertain the provenance of hydrological sources which sustain rivers and wetlands [16], whilst stable isotopes of H and O can be used to infer the timing and mixing of major water fluxes [17,18]. This approach (of which this study represents an early stage of development) can be used as a basis for conceptualization of system function, and in turn, for developing predictive models to aid management decisions.

The study was carried out in the 470 km^2 Kasanka National Park (KNP), on the Central African Plateau in Zambia (Fig. 1). KNP is considered particularly important for its varied freshwater habitats [19], and a seasonal influx of up to 10 million straw-coloured fruitbats (*Eidolon helvum*) (e.g. [20,21]). It is also important for high densities of puku antelope (*Kobus vardonii*), and a visible population of the semi-aquatic sitatunga antelope (*Tregelaphus spekei*) [19]. KNP supports significant ecotourism which benefits local communities within one of the poorest districts of Zambia. Perceived threats include reduced precipitation and flooding, illegal burning, and increased farming in headwater dambos. The park has an elevation between 1200-1286 m [19], an underlying granitic geology with sandy, low fertility soils. Long term average precipitation is approx. 1200 mm yr^{-1} [20], and max. daytime temperatures average 27°c to 38°c [19].

Work was undertaken using hydrometric and tracer methods to provide a baseline assessment of hydrological functioning, to understand the temporal and spatial variability of precipitation, and examine mechanisms of groundwater and wetland recharge and the relative importance of hydrological processes to the main river corridors.

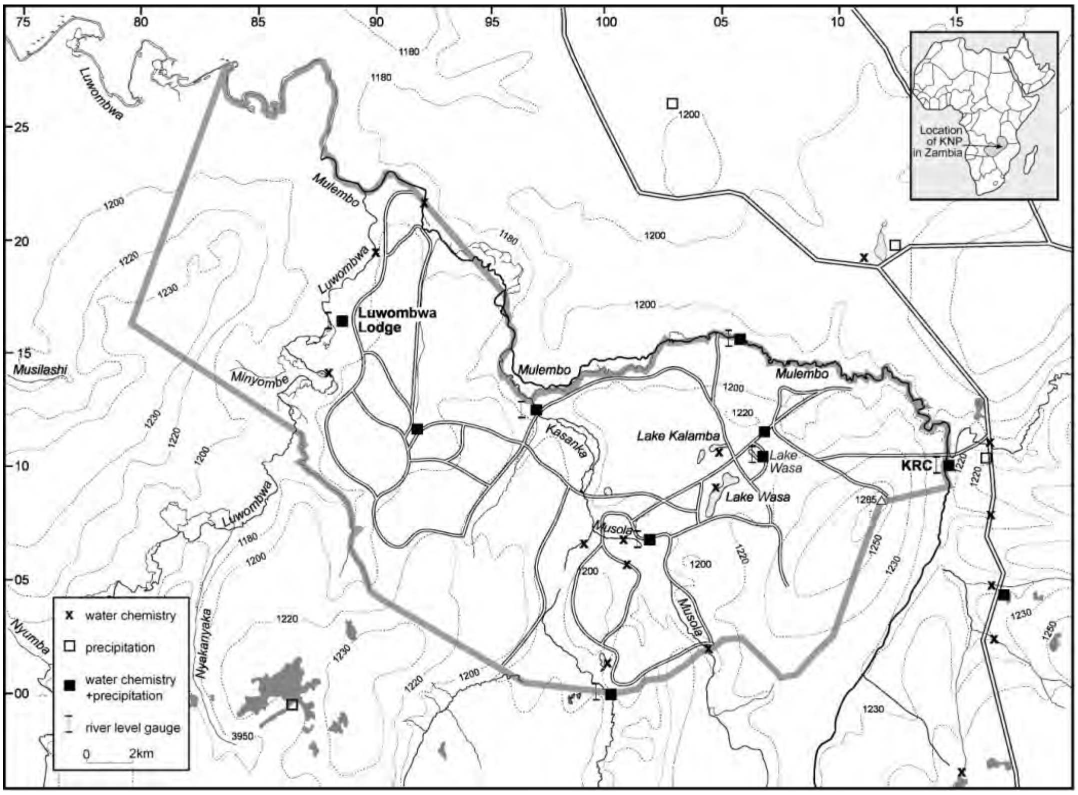

Fig. 1. Map of Kasanka National Park showing sample locations. (Park boundary indicated by solid grey line), and location of Zambia in Southern Africa; KRC = Kasanka Research Centre (© Crown copyright Ordnance Survey. All rights reserved).

2. METHODOLOGY

Precipitation was recorded at 0800hrs each day from 2005 to 2008 at locations in KNP (Fig. 1) using 100mm graduated gauges. Hourly air temperature in the shade was recorded from 1st October 2006 at Kasanka Research Centre (Fig. 1) using a -20°C to 50°C thermometer.

Water sampling was conducted May 2005 to January 2008 at locations shown in Fig. 1. Sampling during the 2005/6 wet season (and until late May 2006) was carried out at approximately two weekly intervals. The frequency of sampling was then reduced to approximately six weekly and four weekly intervals during subsequent dry and wet seasons respectively.

pH and electrical conductivity (EC) were measured, to aid physic-chemical differentiation of samples, using portable Hanna meters, or occasionally, immediately on return to the lab using a Jenway desktop meter. Where sites were easily accessible, measurements were taken from a depth of approximately 10cm; otherwise samples were drawn using a collecting bucket.

Gran alkalinity [22] was measured as adapted by McCartney and Neal [15] for sub-Saharan dambos as a measure of end-member contribution to water-bodies, with higher values generally indicative of longer water residence within soils and aquifers. 60ml LDPE sample bottles were filled and sealed at each site (to minimise carbon dioxide degassing, which increases pH). Samples were filtered through Whatman GF/C filter papers, and alkalinity was determined by acidimetric titration over pH range 3.0 to 4.5 using a Jenway desktop meter. For oxygen isotopes, which can act as a conservative tracer of water source, 5ml glass vials were filled and sealed at each sample point (to exclude evaporative loss), and samples were analysed at the Scottish Universities Environmental Research Centre (SUERC).

3. RESULTS AND DISCUSSION

Table 1 summarises the hydrochemical variability across all river, lake and groundwater sites sampled between September 2005 and November 2007 (Figure 1), with the maximum annual precipitation measured being more than double the minimum. Rivers had the widest range for pH, whilst groundwaters had the lowest values. Mean EC was lowest for rivers, but overall ranges were high for rivers, lakes and groundwaters. The same pattern was observed for alkalinity, but lakes had the lowest maximum vales measured (around two-thirds of the maximum value recorded river). Rivers and lakes had similar mean oxygen isotope signatures, though rivers tended to remain less enriched with δO18, whilst lakes were far more seasonally variable, probably due to dry season preferential evaporation of δO16 [17].

Table 1. Summary of main climatic and hydrochemical variables in KNP and KGMA for sampling period September 2005 to November 2007. (†Temperature values for January to December 2007 at Kasanka Research Centre (KRC): see Fig. 1).

Variable	Mean	Minimum	Maximum
Annual Precipitation (mm)	1438	754	1884
Monthly mean temperature (°c) †	22.2	17.9	25
pH			
Rivers	7.21	5.38	8.90
Lakes	6.91	5.84	8.36
Groundwaters	6.58	5.06	8.09
EC (µS cm^3 s^{-1})			
Rivers	95	3	535
Lakes	131	6	500

Groundwaters	136	5	539
Alkalinity (µEq l^{-1})			
Rivers	1187	33	5844
Lakes	1609	168	3943
Groundwaters	1516	70	5323
Oxygen Isotope Ratio ($\delta^{16}O$: $\delta^{18}O$)			
Rivers	-5.5	-8.6	-5.2
Lakes	-0.1	-8.6	6.7
Groundwaters	-5.6	-9.5	-0.4

Sampling has shown that a number of the surface water-bodies in KNP are highly responsive to precipitation, and that water levels may take 1 or more years to recover following a year with below-average precipitation. For example, Lake Wasa I, a seasonal dambo (see Figure 1), was very responsive to local precipitation: 2005/6 precipitation at Wasa Camp was below the regional average, and a minimum lake level of 60cm was recorded at the end of the 2006 dry season. Lake level showed a rapid and sustained response to above average precipitation in the subsequent two wet seasons (Fig. 2).

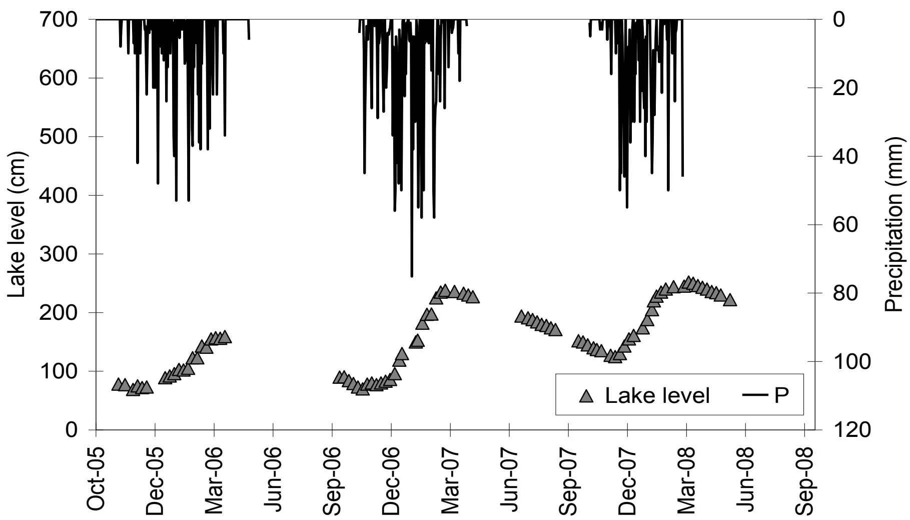

Fig. 2. Daily precipitation at Wasa Camp and Wasa 1 lake level

Figure 3 provides an example of the application of δ16O:δ18O ratios as a possible tracer of water source and movement. To Summarise:

- Values for $\delta^{18}O$ remained consistently depleted for all of the main river sites, in contrast to lake sites (Table 1).
- For the Luwombwa River (Fig. 3), the general trend between May and November 2005 was an enrichment of $\delta^{18}O$, most likely due to selective evaporation and uptake of the lighter $\delta^{16}O$ isotope [17].
- Following a wet season with below-average precipitation (2005/6) there was an evident strong influence of precipitation on the main Luwombwa river channel: the depletion and re-enrichment with $\delta^{18}O$ shown in the precipitation was mirrored, with a lag of several weeks, by river δ16O:δ18O ratios. The influence of precipitation appeared less pronounced during the May-November 2006 dry season.
- Differences in isotopic values between the upstream (Yewe) site and the two downstream sites were observed in May 2006 (Fig. 3), with downstream values similar to those for the groundwater sample (approx. 30 m. from the 'Lodge' main river site), indicating that connectivity between groundwater and rivers is likely to be both seasonally variable, and spatially variable over small scales.

- Small-scale spatial and temporal variability in flow connectivity between various waterbodies should therefore be considered in the context of protecting biodiversity and associated ecosystem services [23] from potential anthropogenic impacts such as abstraction for farming and industrial intensification [11].

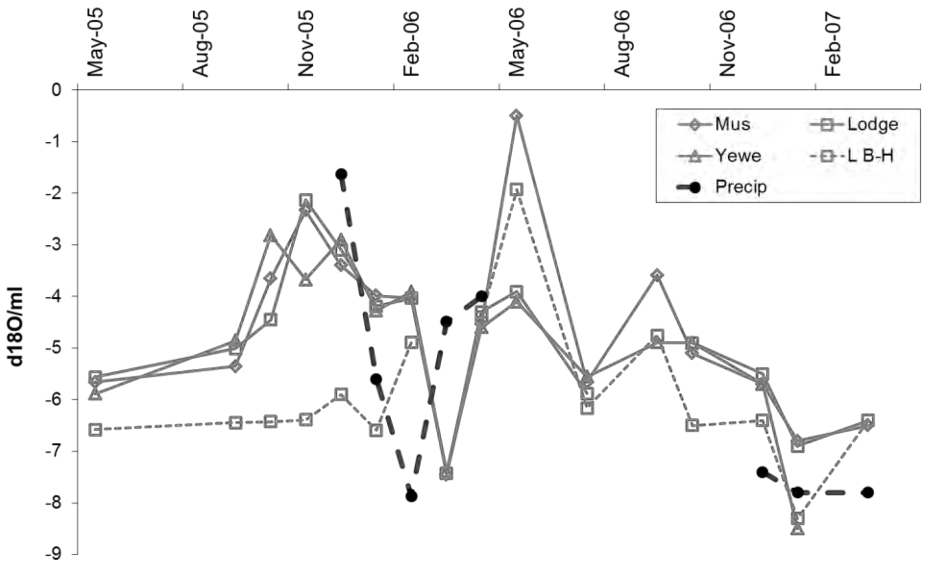

Fig. 3. River δ18O values from sites along the Luwombwa River and from ground water (L B-H) and precipitation (Precip: from KRC) samples (see Fig. 1 for locations).

4. CONCLUSION

This study has provided a first attempt at understanding hydrological processes within a little studied region of sub-Saharan Africa, and has concluded that the processes are spatially and temporally complex even over short distances, and to a large degree are precipitation-driven during dryer periods. Whilst hydrochemical variability exists between different waterbody types, connectivity also exists between them. Successful management of freshwater resources and associated habitats within KNP (and the wider region) therefore needs to utilise information about current climatic conditions, along with information from the years immediately preceding, whilst recognising that local factors (e.g. geology) may control connectivity. Further work should provide discharge estimates to be calculated. In conjunction with hydroclimatic monitoring this might allow useful end member mixing analysis, and provide insight into potential impacts of climate change and anthropogenic pressures.

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COMPETING INTERESTS

No competing interests.

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Technical-financial evaluation of rainwater harvesting systems in commercial buildings – Case studies from Sonae Sierra in Portugal and Brazil

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ABSTRACT

Water is an essential and increasingly scarce resource that should be preserved. The evolution of human population and communities has contributed to the global decrease of potable water availability and the reduction of its consumption is now compulsory. Rainwater harvesting systems (RWHS) are emerging as a viable alternative source for water consumption in non-potable uses. The present study aims to contribute to the promotion of water efficiency, focusing on the application of rainwater harvesting systems to commercial buildings, and comprises three stages: i) development of a technical evaluation tool to aid the design of RWHS and support their financial evaluation; ii) validation of the tool using operational data from an existing RWHS installed at Colombo Shopping Center, in Lisbon, Portugal; and iii) comparison of the performance and financial feasibility of hypothetical RWHS in two existing commercial buildings. Complementarily, a parametric analysis was carried out for Colombo Shopping Center, namely to assess the impact of precipitation and consumption data. The technical tool was applied to two Sonae Sierra's shopping centers, one in Portugal and one in Brazil. The installation of a 200m^3 tank is advised for the first case-study, allowing non-potable water savings of 60% but a payback period of about 19 years. In the Brazilian shopping the implementation of a 100 to 400 m^3 tank leads to non-potable savings between 20 and 50% but a smaller payback period, under two years, due to the relatively low investment costs and high water fees.

Keywords: Rainwater harvesting systems, Commercial buildings, Technical evaluation tool, Technical-financial feasibility, Case studies.

1. INTRODUCTION

Several contemporary phenomena contribute to water scarcity, namely contamination of water resources, such as seawater and groundwater, increased consumption of potable water, rapid growth of the world population and climate change (e.g., [1]). Numerous studies refer alternative measures to address this problem (e.g., [2]). Regarding water consumption, those alternatives include more efficient devices, greywater recycling systems and rainwater harvesting systems implementation, among others.

In countries such as Australia, China, South Korea, Syria, Holland, Germany, the UK and Portugal, it is estimated that water consumption in residential buildings can vary from 120 to 200 liters/habitant.day [3-8], leading to an average value of 150 liters/habitant.day. In some countries, an increase in water consumption is even expected, e.g. Australia expects a 33-58% increase of domestic water consumption by 2031 [9]. However, not all residential water uses require potable water, such as toilet flushes and laundry machines that represent about 50% of the domestic water consumption [3, 5-7]. In commercial buildings, that percentage may even achieve 75% [10].

Rainwater harvesting systems (RWHS) have been implemented in countries such as Australia, Brazil and Japan, providing significant water savings, e.g. [11]. These systems generally comprise a catchment area, a device that deflects the first portion of the water collected (first flush), a filter, a storage tank, an overflow unit, a supply system and a distribution network. The first flush rejection intends to avoid excessive contamination of stored water by diverting the most polluted waters and, depending on the water quality and end use, there can be complementary treatment schemes.

RWHS can be installed in new or existing building, and its design essentially consists in determining the storage tank volume which leads to greater water savings and smallest payback period. This can be made using various design methods that might be classified as empirical or analytical. Empirical methods include the Brazilian, German, English and Australian practical methods and rely on variables such as precipitation, catchment area and water consumption to determine tank capacity through regression based relations. Analytical methods explore the interaction between the system and the consumption pattern. The Balance Equations Method in particular estimates the systems efficiency through daily analyses.

The present work addresses the implementation of RWHS in commercial buildings. This type of building is usually characterized by large catchment areas and significant water consumptions in non-potable uses, such as cooling towers, irrigation, fountains, cleaning services, toilets, among others, enhancing the potential for rainwater use.

A technical evaluation tool is presented to aid the design of RWHS and support their financial evaluation. The proposed tool is validated using operational data from an existing RWHS installed at Colombo Shopping Center, in Lisbon, Portugal. A parametric analysis is performed for this case study to validate the influence of each input in the final performance of the RWHS. After validation, the proposed methodology is applied to two existing commercial buildings to estimate performance and financial feasibility of future RWHS. Two different locations, Portugal and Brazil, are selected, in order to attest different performances depending mainly on initial and maintenance costs as well as water fees, quite diverse for different locations.

2. METHODOLOGY

2.1 Technical evaluation

The Balance Equations Method (or simulation method) was chosen to evaluate the technical performance of a hypothetic rainwater harvesting system. A technical evaluation tool was developed in Matlab in order to test simultaneously the system performance for several alternatives of consumption pattern, catchment area and tank size.

The analyses were performed on a daily basis with the following inputs: (i) local precipitation; (ii) catchment area; (iii) runoff coefficient; (iv) first flush (v) total water consumption; and (vi) daily consumption of water for non-potable uses. Following previous studies [12, 13], the daily precipitation data series used has at least 10 years of records. A variety of precipitation data sources were used, including weather stations in different locations and with records from different periods and precipitation pattern studies. Seasonal variations of the water consumption was accounted for on a monthly basis, but the tool developed allows for daily variations to be considered in the simulations. The non-potable water consumption was determined as a fraction of the total water consumption. The tool allows the simulations to start with a percentage of water in the tank from 0 to 100% and be performed continuously from one year to the other or reset every year with a defined initial water volume.

A variable precipitation fraction before consumption (pfbc) is possible to define to simulate the daily temporal distribution of precipitation in relation to consumption. The value 0 is the most used storage algorithm, Yield After Spillage, which assumes no rain before consumption. The value 1 corresponds to the inverse algorithm, Yield Before Spillage, and assumes that 100% of the daily rain occurs before any consumption [14].

Figure 1 illustrates the methodology adopted to compute water savings in each time step.

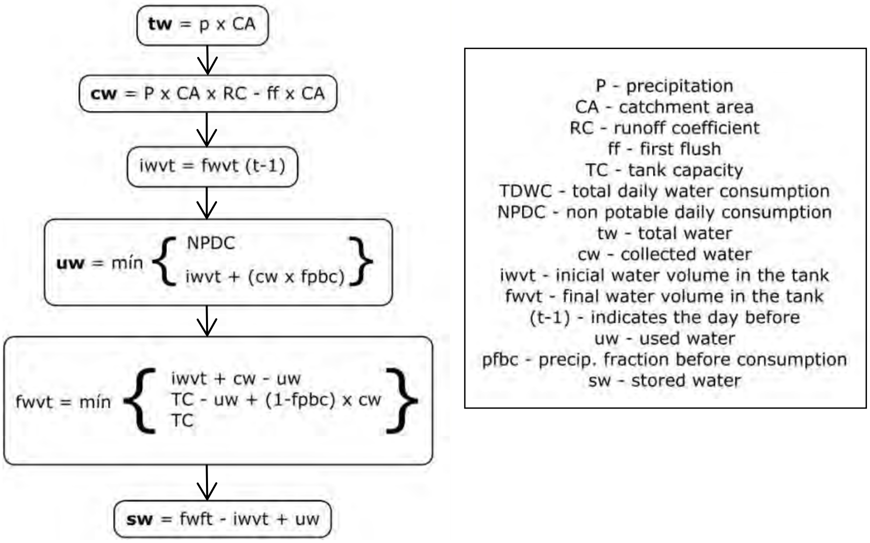

Fig. 1. Technical evaluation tool methodology.

2.1 Financial evaluation

Larger tanks are typically associated with higher savings but, simultaneously, with higher costs. Consequently, the proposed methodology includes viability analyses balancing costs and benefits to optimize payback periods. Annual benefits are obtained applying current water fees to the water savings estimated with the technical evaluation tool described in the previous section. Investment costs include network remodelling, tank construction/installation and the supply and installation of all necessary accessories. Operation (e.g. pumping energy) and maintenance costs per year are also included. Payback period is achieved when the summed discounted cash flows (benefits minus operation and maintenance costs) equal the investment costs.

3. VALIDATION OF THE TECHNICAL TOOL

Sonae Sierra is an international shopping center specialist that owns 46 shopping centers in 14 countries spread through 4 continents. The company has been demonstrating great environmental concerns, namely by introducing a large variety of measures to maximize the performance of the centers in terms of water and energy consumption, waste production and other aspects. RWHS have been introduced in some of their shopping centers around the world, namely in the Colombo Shopping Center, Lisbon, Portugal. Other centers are currently being analyzed for this purpose, such as Estação Viana Shopping in Viana do Castelo, Portugal, and Boavista Shopping, São Paulo, Brazil, that are the two case studies of this paper.

3.1 Colombo Shopping Center, Lisbon, Portugal

In 2011, Sonae Sierra installed a RWHS in Colombo Shopping Center (CSC). It uses a 40 000 m^2 catchment area and it has a 150 m^3 tank. The rainwater is used in cooling towers, with an annual consumption of about 70 000 m^3 of water. Monitoring demonstrated an average 6 500 m^3 of rainwater used per year between 2012 and 2014, which is equivalent to about 9,4% of the cooling towers consumption in non-potable water savings.

The technical evaluation tool was used to simulate the real system according to the consumption values recorded from 2012 to 2014. The precipitation records from the same period were retrieved from a monitoring station located in Cais do Sodré, Lisbon, about 12 km south of CSC [15]. The analysis adopted the Yield After Spillage algorithm, a runoff coefficient of 0,8 and a first flush of 1mm, following the most common international recommendations. No annual continuity and no water in the tank at the beginning of the simulation were assumed. Other implementation details and results description may be consulted in [16].
Even without any parameter tuning, the results indicate that the existing RWHS used about 6 600m^3 of rainwater per year, which is in accordance with the 9,4% non-potable water savings measured on site.

3.2. Parametric analysis

The results of the parametric analyses are presented in terms of efficiency and non-potable water savings comparing the original simulation with alternative options for the input data. Five alternative scenarios were tested, as summarized in Table 1. Each parameter is altered individually. Efficiency is defined in percentage from the relation between the stored rainwater and the collected rainwater. Non-potable water savings are computed dividing the used rainwater by the non-potable consumption.

Table 1. Parametric analyses data.

Parameter	Original simulation	Alternative
Precipitation	Daily values	Average daily values
Consumption distribution	Monthly average	Annual average
Precipitation stations	Cais do Sodré	Caneças ; Point 174
First flush	1mm	2mm
PFBC	0	0,5 ; 1

3.2.1 Precipitation Values

Figure 2 shows the efficiency of the system for different capacities of tank using both daily precipitation data and average daily data. Average daily precipitation values correspond to the average value of the precipitation in each day of the precipitation record series. Therefore, the average daily precipitation data shows more number of days with nonzero values and lower precipitation peaks. This results in a more uniform precipitation distribution throughout the year and, consequently, there is an unrealistic increase of the systems efficiency. The difference when compared to using the real daily precipitation data is about 20%.

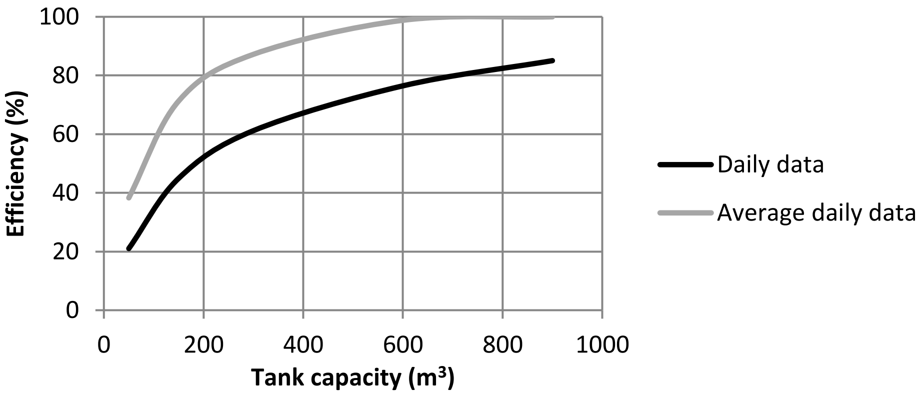

Fig. 2. RWHS efficiency depending on the precipitation data time scale.

3.2.2 Consumption distribution

Consideration of daily consumption values determined for each month was compared to daily consumption value determined as an annual average. However, Colombo Shopping Center has a much higher consumption than rainwater availability, so this parameter does not show significant differences in this case [16].

3.2.3 Precipitation Stations

Comparing the precipitation recorded at the Cais do Sodré station during the years of the RWHS operation with the historical 23 years precipitation series from the Caneças station (1983-2007) [17], used in the RWHS design, and with the 52 years precipitation series (1951-2003) on point P174 from the study of [18] it is possible to observe the importance of the precipitation data accuracy when analyzing the efficiency of RWHS. The three sources of data yield significant differences in the final annual results, as illustrated in Figure 3.

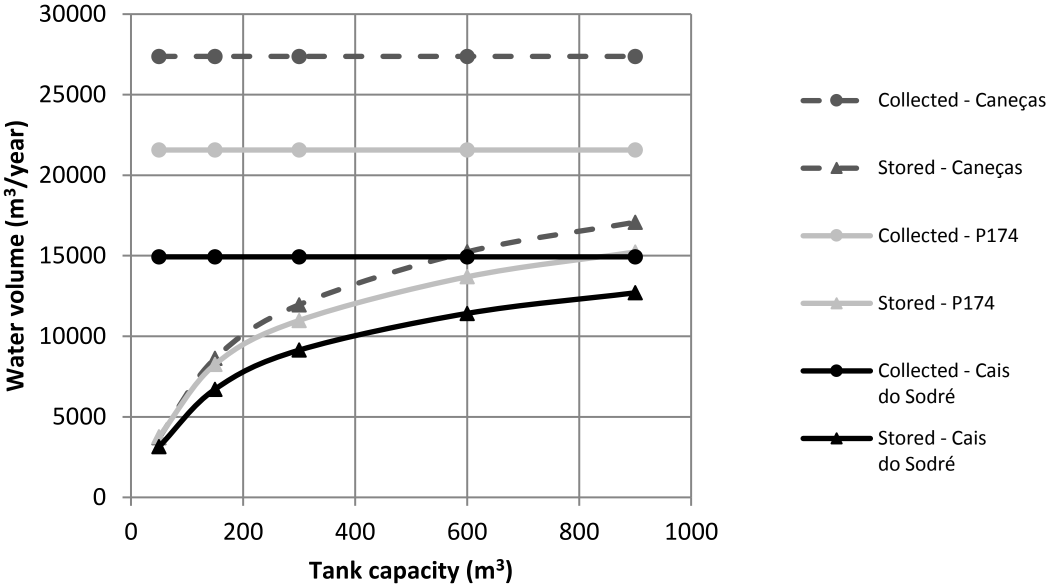

Fig. 3. Water volume variation for different precipitation stations.

3.2.4 First Flush

First flush variation does not affect the efficiency of the RWHS since the collected rainwater, already excludes first flush. Figure 4 presents the variation of non-potable savings for three different values of first flush (ff), indicating the higher first flush flows decrease the non-potable savings, especially for larger tanks.

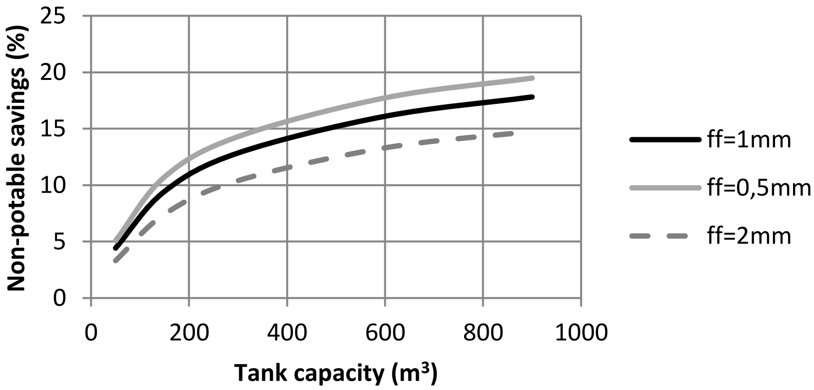

Fig. 4. Non-potable water savings for different values of first flush.

3.2.5 Precipitation fraction before consumption

Assuming that the entire precipitation occurs either before or after the consumption does not exactly correspond to reality. Intermediate values represent a more distributed sequence of events, which is expected to increase the systems efficiency. However, for larger tanks the differences tend to vanish since there is more capacity regardless of when consumption and precipitation occur. This behaviour is captured in Figure 5.

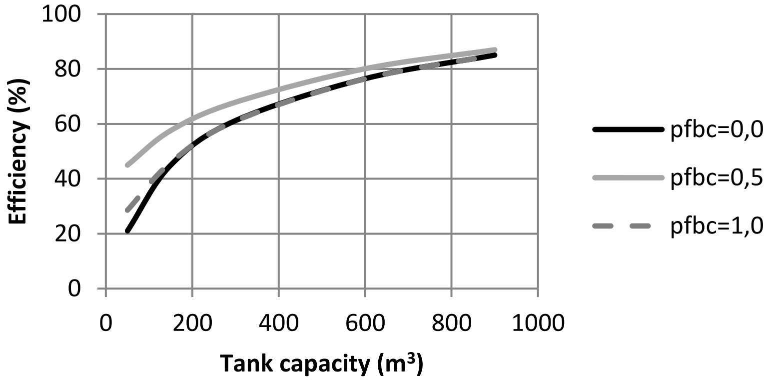

Fig. 5. Efficiency depending on precipitation fraction before consumption (pfbc).

4. CASE STUDIES - RESULTS AND DISCUSSION

After validation, the technical evaluation tool was applied to design the RWHS for two of Sonae Sierra's shopping centers.

4.1 Estação Viana Shopping, Viana do Castelo, Portugal

Figure 6 indicates the water use in Estação Viana Shopping (EVS) during 2013, divided per end-use.

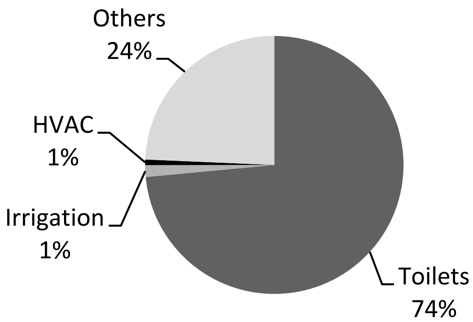

Fig. 6. EVS: water consumption in 2013.

Estação Viana Shopping architecture has two relevant catchment areas of A1 = 4 280 m^2 and A2 = 9 920 m^2. The analyses were performed for both areas. The total non-potable water consumption was determined assuming that irrigation and Heating, Ventilation, and Air Conditioning (HVAC) are 100% non-potable uses and the remaining consumption has a smaller percentage of non-potable use, resulting in three different scenarios: C1, C2 and C3, corresponding to 50%, 70% and 90% of non-potable use for toilets and other uses. According to the Sonae Sierra experience, when there are waterless urinals scenario C2 is expected to be more accurate, resulting in about 7000 m^3 of non-potable water use per year.

52 years of precipitation data series were obtained from [18]. The precipitation was determined from two points located at about 11 km north and south from EVS. The results in Figure 7 were calculated from the average of each precipitation point value. Figure 7 illustrates the non-potable water savings for different tank capacities and for each one of the six resulting combinations. It is possible to observe some stabilization around the 200 m^3 capacity, so the financial viability was studied for tank capacities of 200, 300 and 400 m^3.

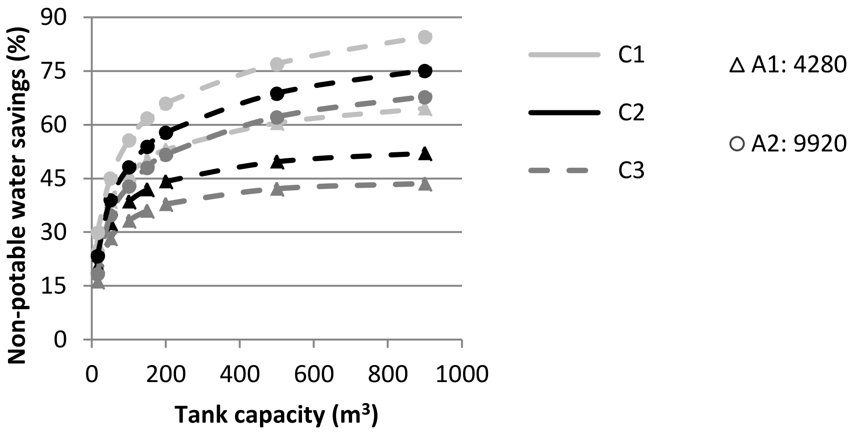

Fig. 7. EVS: Non-potable water savings.

The budget from Colombo RWHS provided by Sonae Sierra was adapted to EVS in order to estimate the investment costs of a hypothetical RWHS in this center. Additionally, the annual operation and maintenance costs of the Colombo RWHS totalized approximately 1,5% of investment costs, which was also adopted for the EVS RWHS. The cost estimates of the RWHS are detailed in [16]. Balancing costs with water savings and current water fees in Viana do Castelo, it was possible to compute payback periods that vary between 18 and 42 years. The most favourable situation was identified for a 9 920 m^2 catchment area and a 200 m^3 tank, which would allow annual non-potable savings of about 60%.

It is important to mention that water prices in Portugal are extremely low, when compared to other European countries. A sensibility analysis was performed to assess the influence of water fees in the final payback period, showing it decreased almost linearly until -18% (less 4 years) and then it stabilized (Figure 8).

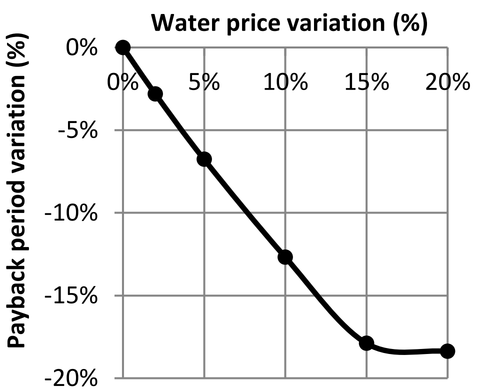

Fig. 8. EVS: Sensibility analysis.

4.2 Boavista Shopping, São Paulo, Brazil

After studying the consumption information provided by Sonae Sierra, it was possible to determine the Boavista Shopping consumption distribution by end-use (Figure 9).

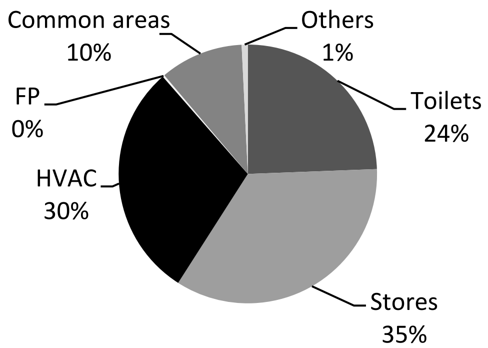

Fig. 9. BS: water consumption in 2013, per use.

Its uses are divided between toilets, stores, HVAC system, firefighting (FP) and common areas. About 22 500m^3 of water are annually used in non-potable consumptions and can be replaced by rainwater.

Boavista Shopping (BS) has two possible catchment areas, B1 = 4 190 m^2 and B2 = 12 240 m^2. B1 is non-accessible and B2 includes roof parking lot. The use of the parking lot as a catchment area required the installation of at least a hydrocarbon retention tank. Precipitation data from the Astronomical and Geophysical Institute of the University of São Paulo [19] and from the São Paulo/SP – Mirante de Santana meteorological station [20] were used. The first one is located at about 11 km from the shopping center and the second one is located at about 19 km in opposite directions, so the results presented in Figure 10 correspond to a 2/3 and 1/3 weighting.

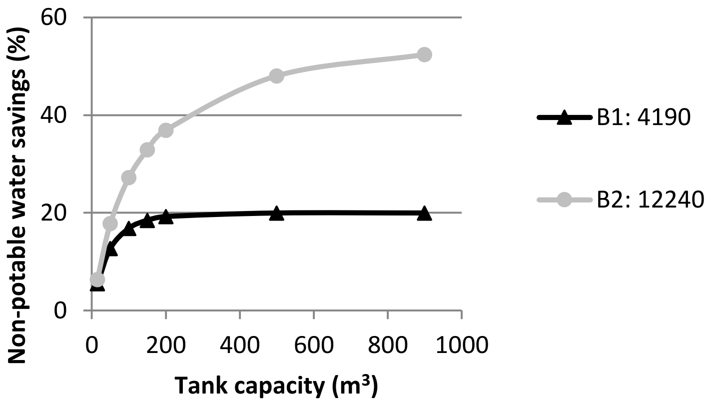

Fig. 10. BS: Non-potable water savings.

For B1, the results tend to stabilize for tanks with about 100 m^3 capacity, therefore financial viability was studied for volumes 100, 150 and 200 m^3. No stabilization is visible for catchment area B2, so in this case all volumes 200, 300 and 400 m^3 were considered in the financial analysis.

The cost of construction was adapted to the Brazilian market. Operation and maintenance costs of 2% of the investment costs were also taken into account. The cost estimates of the RWHS are detailed in [16]. The results show 20-50% of non-potable water savings, and payback periods under two years.

4. CONCLUSION

This work aims to contribute to water efficiency promotion in commercial buildings. It presents a tool to evaluate the technical-financial performance of rainwater harvesting systems. This tool has been applied to commercial buildings that show large possibilities for rainwater reuse, due to high non-potable consumption and large surface areas for rainwater collection. Validation of the tool is presented for Colombo Shopping Center, showing a perfect match. The parametric analysis carried out for Colombo showed that average daily precipitation values increase the systems efficiency when compared to real daily precipitation data. A similar behaviour is observed if the water consumption is estimated based on the annual average or the monthly average, since there is more water consumption in months without rain (June, July, August and September). The first-flush was found to impact significantly on the non-potable water savings, with a value of 2 mm resulting in non-potable water savings of only 7% and a value of 0.5 mm resulting in non-potable water savings of more than 11% for the CSC RWHS. Still, the parameter that was found to influence the results most was the precipitation record series. Using other precipitation series (with 23 and 52 years of records) resulted in estimated water savings of more than 12%.

Parametric analysis shows that even when design parameters are carefully selected, it does not imply that simulation results can predict the future system's performance. The evaluation tool estimates results based on historical precipitation data, and therefore it is expected that the estimated results are as close to reality as the historical data precipitation is to the real precipitation. Climate changes scenarios, namely the change on the temporal pattern of precipitation with more extreme events and longer dry periods, will tend to decrease the RWHS performance, as verified in the parametric analysis.

After validation, the technical tool was applied to two Sonae Sierra's shopping centers, Estação Viana Shopping in Viana do Castelo, Portugal, and Boavista Shopping, São Paulo, Brazil. In the former, the most favourable RWHS had a 9920 m^2 catchment area and a 200 m^3 tank, which would allow annual non-potable savings of about 60%. Still, due to the high investment cost and low water fees in Portugal, the return period was estimated at almost 19 years. Regarding the latter, the relatively low investment costs and high water fees resulted in return periods less than 2 years in all cases. In financial terms, the best option was the construction of RWHS with a catchment area of 12240 m^2 and a tank of 200 m^3, resulting in a return period of 10 months and non-potable water savings of 38%. In terms of water efficiency, a RWHS with a catchment area of 12240 m^2 and a tank of 200 m^3 would allow non-potable water savings of more than 50% with a return period of 1 year.

The financial viability of RWHS is closely linked to the relationship between investment cost and water fees. Differences between Portuguese and Brazilian case studies are huge due to higher investment costs in Portugal contrasting with higher water rates in Brazil. However, a financial decision for RWHS investment is limited since it does not account for all benefits, namely the broader economic impact of RWHS, including the water and drainage systems, company's image and the environment.

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The Portuguese tool for the classification of the water efficiency of buildings

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ABSTRACT

Considering climate change predictions, Portugal is a Mediterranean country that presents a high risk of hydric stress in the short/medium term. For this reason, it is urgent to develop increased water efficiency measures in all sectors.
The National Program for the Efficient Use of Water (PNUEA) has proposed the development of mechanisms for the evaluation and classification of buildings in terms of their efficiency in water use, to inform and promote awareness on this issue. The intention is to develop a model similar to that which has already been implemented in Europe in the field of energy efficiency, with mandatory application. In this context, ANQIP (the Portuguese technical-scientific *National Association for Quality in Building Installations*) decided to study two methodologies for this purpose and propose their adoption by the Portuguese Government.
One of these methodologies, which is presented in this paper, is based on a relatively simple and easily generalizable calculator, with analogies in relation to the BRE (Building Research Establishment) calculator developed in the United Kingdom, but also with significant differences in relation to the latter, based on the different realities and habits of the populations.
The other methodology, more demanding in terms of computational resources, is based on Fuzzy Logic, and is not presented in this paper.
It is hoped that the implementation of this tool should encourage the construction of more water efficient buildings and increase awareness of the importance of water efficiency in the urban sector.

Keywords: Water efficiency, Classification of buildings, Calculator

1. INTRODUCTION

Fresh water being a limited resource, it is necessary to protect and preserve its efficient use as an environmental imperative in any country in the world. In the case of Mediterranean countries such as Portugal, climate change could significantly affect the availability of this resource in the short/medium term; it is therefore urgent to develop measures in all sectors to increase efficiency in water use [1]. In fact, countries like Greece, Italy, Spain, and Portugal will be at risk of having a water stress equal to or greater than 40%, at least in part of their territories, within a few decades.
Overall inefficiency in the use of water in Portugal, including waste and leaks, was estimated at over 3 x 10^9 m^3/year, corresponding to about 39% of the total amount of water demand in the country [2]. With specific regard to the urban water supply sector (public and building systems),

total inefficiencies were estimated at approximately 250 x 10^6 m^3/year, corresponding to an economic value close to 600 x 10^6 €/year [2].
It should be noted that the concept of leak differs from waste. The term "water waste" can be easily understood based on the terms used in economics that define "waste" as "resources consumed but not incorporated into the final product". Thus, the concept of waste basically corresponds to an unnecessary consumption of resources in the process of "production". For example, a negligent use of water or a poor overall performance of the buildings' water systems or of their devices. In other words, water waste is, in essence, a set of actions and processes through which you spend without benefit or necessity.
The amount of water consumed in a building can then be described by the following expression:

Consumption = Minimum or efficient use + Waste + Leak.

Among the proposals of the National Program for the Efficient Use of Water (PNUEA) [3], a government initiative, ANQIP decided to launch in Portugal several measures to increase water efficiency in buildings, the first of which was the establishment of a labeling system of water efficiency of products, which was based not only on volumes or flow rates, but also on concerns of comfort, public health, and performance of the building networks (Figure 1). ANQIP, the National Association for Quality in Building Installations, was created in 2007 as a non-profit Portuguese technical-scientific association, which has among its members several universities, industries, fund managers and technicians, and having in its main objectives the promotion of an efficient use of water in buildings.

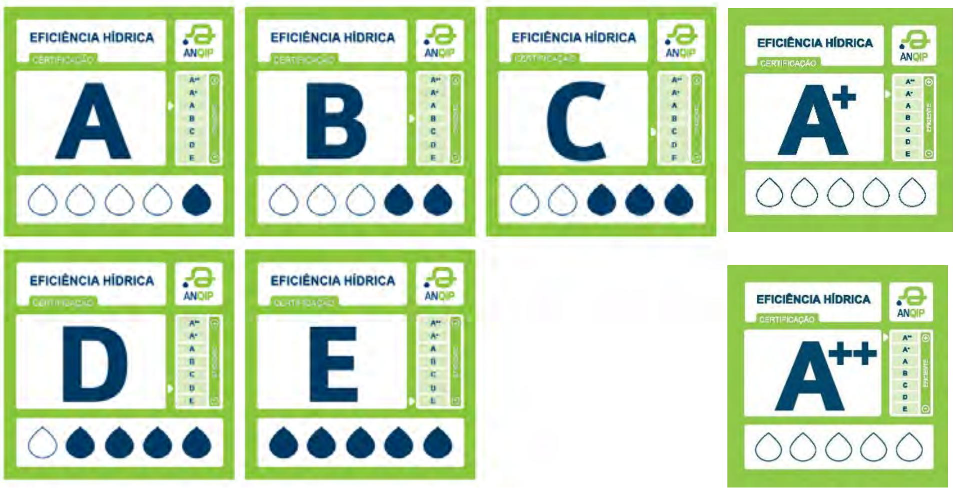

Figure 1 - Portuguese water efficiency labels [3]

As PNUEA also predicted the development of mechanisms for the evaluation and classification of buildings in terms of their global efficiency in water use, ANQIP decided to study two methodologies for this purpose. One of the methodologies – very demanding in terms of computational resources – is based on Fuzzy logic, and will not be presented in this paper. The other methodology, which is presented here, is based on the application of a relatively simple and easily generalizable calculator.
The model proposed for evaluation and certification of buildings in terms of their water efficiency presents many similarities with the model developed in the UK by BRE – Building Research Establishment – but it has also significant differences in relation to the latter, justified by the different realities and habits in these two countries. This BRE model establishes a calculation method to evaluate the total drinking water consumption in new housing, and is used to assess conformity in relation to the performance targets at the level of the water contained in Regulation 17.K of the Buildings and Sustainable Homes Code for (CHS) [4].

2. METHODOLOGY

The Portuguese model is based on a calculator, expressed in a base table, using up to its completion several auxiliary tables; it can be applied either to new buildings or those already in use, and is easily generalized for non-residential buildings.
Consumption estimated in Portugal in 2009 in an urban environment was 137 liters per person per day [5], excluding losses in public networks. In fact, this value depends on the characteristics of the building and habits of the occupants [6] [7], and it should be seen in weighted average terms. Although there are no current data available, it is known that there is a trend towards stabilization of consumption per capita in Portugal, either for economic reasons or for reasons of awareness of citizens about the importance of saving resources, which leads us to admit that this value will not have risen significantly in recent years.
However, this figure includes losses (household leaks) and outdoor uses with drinking water, which are estimated at about 14%, and which were accounted for in the model separately. Thus, taking a value of 125 L/(person.day) as an average reference consumption, the following consumption categories are established in the proposed model (Table 1), assuming that this average value is the medium letter (C), and considering increments in a proportion similar to the one adopted in the Portuguese scheme of certification and labeling of products:

Table 1 – Classification of buildings according to domestic consumption standards (liters/(person.day))

Category	Consumption of drinking water from public network
A^{++}	$0 < c \leq 60$
A^{+}	$60 < c \leq 80$
A	$80 \leq c \leq 90$
B	$90 < c \leq 115$
C	$115 < c \leq 145$
D	$145 < c \leq 180$
E	$c > 180$

We assume the possible use of alternative sources, recycling or reuse, in particular with regard to categories A^{+} and A^{++}. We can also consider in the future a category A^{+++} for "regenerative" systems with excess production of drinking water from alternative local sources such as rainwater.

The proposed model requires knowledge of the percentage affects for each use. For this purpose, observe the distribution of Figure 2 [8], which is considered valid for the residential sector in Portugal, on average.

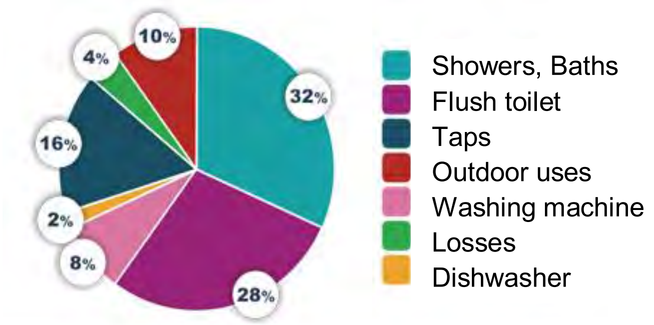

Figure 2 – Percentage affects for each use [8]

For application of the model, the losses are distributed in percentage terms, adopting the same criteria in relation to outdoor uses, which are accounted for separately. Regarding the different types of taps, whose percentages are not discriminated in Figure 2, approximate ratios of 2/3 for kitchen taps and 1/3 for taps for washbasins in current housing were considered, according to studies carried out by ANQIP [9].
Therefore, knowing that losses and outdoor uses account for about 14% of the total consumption in accordance with Figure 2, the corrected percentage for the other uses should be:

- Showers:

$$32 \times \frac{100}{86} \approx 37\ \%$$

- Flushing toilets:

$$28 \times \frac{100}{86} \approx 33\ \%$$

- Kitchen taps:

$$\frac{2}{3} \times 16 \text{ x } \frac{100}{86} \approx 12\ \%$$

- Washbasin taps:

$$\frac{1}{3} \times 16 \text{ x } \frac{100}{86} \approx 6\ \%$$

- Washing machine and dishwasher:

$$10 \times \frac{100}{86} \approx 12\ \%$$

In respect to the baths, it is known that the use of the shower tub as an alternative is not relevant in Portugal. So the tubs equipped with a shower system will be considered as showers for the purposes of the model. It should be noted that the percentages may be adjusted at any time to more stringent new values, which may eventually be determined for Portugal in subsequent studies.
For some outdoor uses, such as green areas, it is considered appropriate to adopt values between 450 to 800 L/m^2 for lawns, depending on the type of grass, soil type, and zone of the country, and between 60-400 L/m^2 for gardens, also depending on the type of crop, soil type, and zone of the country. For open outdoor pools, evaporation has significant weight and can be considered in Portugal to have an approximate value of 0.5 m^3/m^2 over a period of three months (assuming the compensation of evaporation by precipitation out of the dry season) [10], or an average value between 150 and 200 L/(m^2.month).
There may also be other uses, whose values are difficult to set, and these must be searched for in the specialized literature. In the case of washing courtyards, for example, an amount up to 5 L/m^2 may be used [11]. Since simple products labeled in water efficiency category D are the most common in Portugal, according to audits of ANQIP [12] (except in the case of showers, where the letter C is more common), the minimum consumption for category D (or C in the case of showers) is taken as a calculation of consumption for the purpose of determining the usage factor [9]. Based on the value of 125 L/(person.day) and established assumptions, the following values for use factors are obtained:

- Flushing cistern (category D = volume of 7 liters):

$$0{,}33 \text{ x } \frac{125}{7} = 5{,}9 \text{ uses/(person.day)}$$

- Showers (category C = flow of 9 L/min):

$$0{,}37 \text{ x } \frac{125}{9} = 5{,}1 \text{ min/(person.day)}$$

- Washbasin taps (category D = 9,0 L/min):

$$0{,}06 \text{ x } \frac{125}{9} = 0{,}8 \text{ min/(person.day)}$$

- Kitchen taps (category D = 12,0 L/min):

$$0{,}12 \text{ x } \frac{125}{12} = 1{,}3 \text{ min/(person.day)}$$

Maximum opening of the taps is not always practiced, for comfort reasons (water splashes out of the basin or sink), especially when the flow rate is high. In this sense it is more correct to adopt a "comfort flow", which is determined by multiplying the maximum flow by a factor of comfort, established according to the following table [9].

Table 2 – Comfort factors for sink and kitchen taps

Water efficiency label	Comfort factor
A	1,0
B	0,9
C	0,8
D	0,7
E	0,6

Introducing this correction in the usage factors previously determined for taps, the following values are obtained:

- Sink taps:

$$\frac{0{,}8}{0{,}7} = 1{,}1 \text{ min/(person.day)}$$

- Kitchen taps:

$$\frac{1{,}3}{0{,}7} = 1{,}9 \text{ min/(person.day)}$$

It is understood also that the inexistence of domestic hot water circulation lines can increase significantly the time of use, so whenever there are these circuits, the factors of use for the taps and showers should be increased by an estimated value of one minute for showers and 0.5 minute for taps (assuming that in the shower hot water is always used, and in the taps only in some applications). It is expected that future studies in this field will contribute to improving this criterion, which is based on the knowledge that a distance of about 15 meters between the device and the hot water production point may give a minimum waiting time of 30 seconds. This criterion also helps to integrate the circulation and return circuits, as recognized measures of water efficiency, within the proposed model. Thus, the use factors to consider in the model will be shown in Table 3:

Table 3 – Use factors

Devices	Use factors	
	With return circuits min/(person.day)	Without return circuits min/(person.day)
Showers	5,1	6,1
Sink taps	1,1	1,6
Kitchen taps	1,9	2,4

The so-called "fixed uses" of taps, which are considered, for example, in the BRE model to include some consumptions that are independent of the number of residents (the filler of the sink for dishwashing, basin filling, etc.) are not considered in this model, as a correction factor can be established to cover these situations, as referred to later. To determine reference values for the number of inhabitants in each building, we have adopted the tables contained in Portuguese legislation [13], which relate building typology with the number of residents.
The unit values of reference for the flow rates or volumes to adopt the model for the various categories of products were based on ANQIP's Technical Specifications 0804, 0806, and 0808 [14] [15] [16] for the labeling of products. For dual flush cisterns, for example, we have considered a volume of calculation in the proportion of two reduced discharges and one complete discharge. In the case of interrupted discharges, the relevant figure is a weighted value between a half and a full discharge (Table 4).

Table 4 – Volumes of flushing cisterns (L)

Flush Cistern	Category	Volume (minimum)	Volume of reference for the model
Dual flush	A++	4,0/2,0	2,7
Dual flush	A+	4,5/3,0	3,5
Dual flush	A	6,0/3,0	4,0
Dual flush	B	7,0/3,0	4,3
Dual flush	C	8,0/3,0	4,8
Interrupted discharge	A+	4,0	3,0
Interrupted discharge	A	5,0	3,8
Interrupted discharge	B	6,0	4,5
Interrupted discharge	C	7,0	5,3
Interrupted discharge	D	8,5	6,4
Complete discharge	A	4,0	4,0
Complete discharge	B	5,0	5,0
Complete discharge	C	6,0	6,0
Complete discharge	D	7,0	7,0
Complete discharge	E	8,5	8,5

In the case of certification of old buildings with devices that are not labeled, consumption or volumes can be locally measured. In the case of application of products not labeled in new buildings, consultation of the manufacturer's catalog must be effected and, if necessary, the relevant European Standards. The following table (Table 5) shows the base table calculator.
The correction factors that are indicated in the base table calculator take into account the existence of consumption not encompassed in the model (bidets, fixed use, etc.) which are not considered viable for intervention to reduce consumption, as well as the necessity of setting the results of the model application to the proposed classification for the buildings, as explained below.
The correction factors have a multiplicative component and additive components for the washing machine and dishwasher. As regards the multiplicative component, the value was set at 1.1, trying to match the current dwellings equipped only with devices with the label A with a rating of the building also in Category A. Obviously, this correction factor will be different for non-residential buildings, and will need a preliminary study in each case.
With regard to washing machines and dishwashers, Figure 2 shows a reference consumption of 125 L/(person.day), with the following average values:

- Washing machine:

8% x 125 = 10 L/(person.day)

- Dishwasher:

2% x 125 = 2,5 L/(person.day)

Also in relation to these household appliances, it is known that the average consumption in Portugal is 45 l/wash for washing machines and 10 l/cleaning dishwashers [17]. Thus, the value to be used in the calculation can be corrected with machine efficiency, as shown in the base table of the calculator. When the building is not equipped with washing machines or dishwashers, it is assumed that washing is manual. There is a large variability in values for hand washing, but since this is not a common situation in Portugal, at least in houses built in recent decades, the option is to consider in these cases consumption for manual washing equal to the reference consumption of machines.
As regards the use of rainwater and reuse of grey water, the model has auxiliary tables for their weighting.

Table 5 – Calculator for residential buildings (base table)

Type of installation		Units	Volume/ Flow (average) (a)	Factor of use (b)	liters/(person/day) (c)= [(a)x(b)]
Flush Cistern		liters			
Sink taps		liters /min			
Showers		liters /min			
Kitchen taps		liters /min			
Total consumption calculated = sum of column (c) = (1)		L/(person.day)			
Correction factors	**Multiplicative (2)**				1,1
	Washing machine	L/wash	*L* =		
		L/(person.day)	(3)	10 x *L*/45=	
	Dishwasher	L/wash	*L'* =		
		L/(person.day)	(4)	2,5 x *L'*/10 =	
Contribution of grey water recycling = (5)		liters/(person.day)			
Contribution of rainwater harvesting = (6)		liters/(person.day)			
Total water consumed = [(1)x(2)+(3)+(4)-(5)-(6)] = (7)		liters/(person.day)			
Outdoor uses (8)		liters/(person.day)			
Total reference consumption (*c*)= (7) + (8) = (9)		liters/(person.day)			
Building rating of water efficiency					

4. RESULTS AND DISCUSSION

The following case study illustrates the application of the model and the results obtained. This case study is based on an existent house (Figure 3) with about 100 m^2, with the devices listed in the following table.

Figure 3 – Case study house

Table 6 – Characterization of building devices (case study)

Device	**Number**	**Category of water efficiency (Label ANQIP)**	**Consumption (L/min) or (L/wash)**
Flushing cistern	2	A	-
Shower	2	-	7,5 (average)
Sink tap	2	-	4,0 (average)
Kitchen tap	1	-	7,0 (average)
Washing machine	1	(Energy efficiency A^+)	39,0
Dishwasher	1	(Energy efficiency A^+)	12,0

For devices not certified by ANQIP, flow rates were measured on site (using flow meters available on the market for this purpose). For measuring the flow in taps a test was carried out by opening the tap in a comfort regime (the water does not splashes out of the basin or sink). This criterion might have some behavioral influence, but it is considered that the range of variability is consistent with the precision of the model. The application of devices labeled by ANQIP is easily controlled by the existence of an *online* digital catalog of all products certified and labeled by ANQIP (including photographs).
The result obtained with the calculator application appears in Table 7.

Table 7 – Evaluation of consumption (calculator base table)

Type of installation		Units	Volume/ Flow (average) (a)	Factor of use (b)	liters/(person/day) (c)= [(a)x(b)]
Flushing cistern		Liters	4,0	5,9	23,6
Sink taps		liters /min	4,0	1,6	6,4
Showers		liters /min	7,5	6,1	45,8
Kitchen taps		liters /min	7,0	2,4	16,8
Total consumption calculated = sum of column (c) = (1)		liters/(person.day)			92,6
Correction factors	**Multiplicative (2)**				1,1
	Washing machine	L/wash	L =	39	
		L/(person.dia)	(2)	10 x L/45 =	8,7
	Dishwasher	L/wash	L’ =	12	
		L/(person.dia)	(3)	2,5 x L’/10 =	3,0
Contribution of grey water recycling = (4)		liters/(person.day)			0
Contribution of rainwater harvesting = (5)		liters/(person.day)			0
Total water consumed = [(1)x(2)+(3)+(4)-(5)-(6)] = (7)		liters/(person.day)			113,6
Outdoor uses (8)		liters/(person.day)			0
Total reference consumption (c) = (7) + (8) = (9)		liters/(person.day)			113,6
Building rating of water efficiency			B		

In the case of a recent building, the result obtained (B) reflects a reasonable level of water efficiency, but also reveals potential increase of this efficiency, especially in terms of the installation of more efficient devices (showers and kitchen taps have flow rates equivalent to category B of the ANQIP labeling system), and even the possibility of installation of a sanitary hot water return circuit.
Rainwater harvesting and the reuse of gray water are difficult to implement in an existing building of the type analyzed, with no significant technical economic feasibility; their contribution could rather be at the level of increase in the overall water efficiency of the building.
However, the concrete results of applying this model in improving the water efficiency of residential buildings in Portugal can only be assessed after a period of utilization.

CONCLUSIONS

In Portugal, the need for increased efficiency in water use in the urban water cycle corresponds to an environmental imperative and a strategic necessity, given the risk of water stress in the country, and has justified the development of a specific framework to evaluate the water efficiency of buildings, adapted to Portuguese reality.
The model assesses the global water efficiency in buildings, in relation to the water cycle, as well as analyzing and providing guidance on measures that can be implemented to improve their performance. With the proposed model, a set of procedures and criteria is established in order to standardize the assessment of water efficiency in buildings, assigning an indicative rating of this performance and also creating a methodology to integrate water resources within a more comprehensive framework for the environmental sustainability rating of buildings.
The model developed is based on residential buildings but can be generalized to other types of buildings. The evolution of water stress in Portugal can justify this, as has already been done

with the energy certification system for buildings. Furthermore, the certification of water efficiency in Portuguese buildings can come to take a mandatory character.
This model has been recognized and is expected to be implemented in a short time by the governmental entity that currently manages the certification system of energy efficiency in Portuguese buildings.

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Water Sensitive Cities in antiquity: Historical Sustainable Drainage Techniques for urban and rural water management

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ABSTRACT
Sustainable surface water management is not just a modern innovation, in antiquity it was used fairly extensively; the design and planning of these early drainage systems became the first examples of water management engineering. It was influenced by religious beliefs and the geopolitical, socio-economic and climatic challenges faced at the time. Water-sensitive approaches were used in many cities providing water for consumption, cleaning and washing in both urban and rural areas, the latter to enhance agricultural production in order to improve food security. This provided catchments with long-term drainage schemes, managing water from small areas up to transnational empires that functioned efficiently for extended periods of time. Sustainable water management maintained the balance of power and directly influenced the development and prosperity of entire civilisations at times of peace and war. The early Babylonians and Mesopotamians had surface water drainage systems, relying mainly on hard infrastructure. The Minoans used terracotta pipes to convey stormwater out of their settlements. However, similar techniques to Sustainable Drainage Systems or SuDS; like rain water harvesting, constructed wetlands, infiltration, non-structural approaches, storage in cisterns and ponds and slow conveyance were all well-known and efficiently operated in the Early Bronze Age. In fact, drainage techniques at Machu Picchu can be compared with Low Impact Development since infiltrating pavements and meandering swales were also used. Non-structural approaches included the appointment of a "superintendent of fountains" in Athens to ensure the equitable distribution of water as well as citizens being responsible for maintaining the city's stormwater cisterns. Climatic conditions were decisive in either limiting or exceeding water resource availability and can be compared with current climate change predictions, providing clues of how modern society could face this challenge. The principle of Water Sensitivity can be applied to water management in a number of ancient civilisations.

Keywords: Ancient Cultures, Sustainable Drainage, Low Impact Development, Water Sensitive Design

1. INTRODUCTION
The early Babylonians and Mesopotamians (4000–2500 BC) had surface water drainage systems, essentially regarding urban runoff as a nuisance, but also realizing that it carried waste with the potential to be a resource [1]. These systems were mostly hard infrastructure, for example, the Minoans (3200–1100 BC) used terracotta pipes to transport stormwater. However, these ancient civilisations also used techniques similar to sustainable drainage or SuDS and thus it is not new; water harvesting, storage and conveyance were all well–known and efficiently carried out as long ago as the Early Bronze Age (ca. 3500–2150 B.C.) in Crete. In the Mediterranean and near east, infrastructure for the collection and storage of rainwater was developed in the third millennium BC [2]. Water resource management dates back to the beginnings of early agriculture, to control water for crop irrigation in arid and semi–arid regions where rainfall would not normally have supported it. [3] state that rainfall extremes resulted in failed crops and famine – water management was a case of life or death, leading to the rise or fall of civilisations. Rainwater harvesting (RwH) was used extensively in antiquity, but other "*sustainable urban water practices*" [4], such as constructed wetlands, infiltration and non–structural approaches were also used. Ancient Greece developed water resource management techniques due to lack of water and high evaporation rates, particularly during summer. They therefore had to efficiently capture what rain fell, provide its safe storage with minimal losses, be able to convey it for long distances and bring in

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government structures and institutions to ensure its effective management [5]. [6] compared the Inca drainage of Machu Picchu (built ca. 1400 AD) to that of present day Low Impact Development. SuDs could simply be a case of history repeating itself, with techniques used in the past being relevant today.

2. SUSTAINABLE SURFACE WATER MANAGEMENT IN ANTIQUITY

Street drainage was first utilised in the Mesopotamian Empire, Iraq (4000–2500 BC), however, the Minoan and Harappan civilisations on Crete were the first to develop drainage and sewer systems which were designed well, organised efficiently and effectively operated [1]. Basic hydraulics were understood, with importance accorded to providing sanitation in cities. The Hellenes and Romans refined these techniques further, but further progress was minimal during the so-called “Dark Ages” post–300 AD.

2.1 Rainwater harvesting

The early Babylonians and Mesopotamians in Asia (4000–2500 BC) [1], and the Minoans in Europe (3000–1100 BC) [7], used RwH extensively in urban areas eg the City of Delos (the Cycladic, Greece) used it as the main water supply, collecting and storing it in cisterns [4]. Increased RwH coincided with abrupt climatic change which led to increased aridity, droughts and floods. Awareness of rainfall seasonality was important, particularly in Jawa and Petra, Palestine and the Mayan civilization in Mesoamerica, and elsewhere. Urban water management in Ancient Greece combined large–scale public RwH infrastructure such as reservoirs, but also small–scale semi–public or private cisterns and wells [4]. Rainwater was mainly used for bathing or washing [2], washing dishes and laundering clothes, irrigating rural agricultural land, flushing lavatories, for animal and human consumption and aquifer recharge [8]. It was also stored for use in times of war and for other socio–political purposes; Aristotle (385–322 BC) stated that the “*supply may never fail the citizens when they are debarred from their territory by war*” (quote taken from Politics, III, in [4]).

2.2 Water quality improvements

The main contaminant of water supplies in ancient times was suspended sediment, also human and animal wastes, organic matter and excess nutrients. Sand filters were used extensively and in Phaistos, Crete, coarse sand filters removed silt and other pollutants from the water before storage in cisterns. The rainwater collection surfaces were kept scrupulously clean [5]; apart from during times of war, the water was not used for drinking, but for clothes washing and other cleaning tasks [9]. In Ancient Egypt (2000–500 BC) they disposed of wastewater by letting it infiltrate directly into desert sand [1]. To prevent silt entering the water supply system, it was removed in settling tanks, eg the Palace at Tylissos, Crete (2000–1100 BC) had a stone sedimentation tank before the main storage cistern and terracotta infiltration devices filled with charcoal. Silting tanks and sediment settling was used at Tikal before the Temple Reservoir, with sand boxes at the inlets of several reservoirs. In ancient Maya, floating aquatic plants had multiple roles: to reduce water evaporating; prevent disease vectors, such as mosquitoes, from breeding by covering the water surface; remove nutrients such as nitrogen and phosphorus using water hyacinth, water lilies and ferns, like SuDS wetlands; to ensure the efficient functioning of what [3] call a “*constructed wetland*”; to provide an indicator of water quality since plants such as the water lily only thrive in still, clean water, deeper than 1–3m, are not tolerant of acidic conditions, or high concentrations of calcium. Any sediment would not have contained decaying organic matter as it releases methane and phenols, fatal to plants.

2.3 Water quantity reduction: sub–surface drainage

According to [10] infiltration of stormwater at Machu Picchu, Peru, was used widely on the terraces (see Fig 1), but was also found in the plazas where was stored and disposed of. Beneath some of the plazas were layers of loose rock and stone chips up to 1m deep providing subsurface drainage [10] and slow release to avoid causing a high groundwater table which could have caused instability of the plaza soils. [6] proposed that these structures were an early form of bioretention as there was vegetation on the surface course which would have trapped pollutants as well as providing biological and chemical treatment, improving water quality and slowing water velocity, hence attenuating the storm peak.

2.4 Water Storage

Large reservoirs or *barays* stored water in times of drought at Angkor Wat, their control structures at the inlets and outlets could also have functioned as flood control measures during storms. There are four barays at Angkor Wat, part of an intricate water infrastructure of canals and moats requiring regular maintenance to keep them functioning; one to the West of the site still holds water today.


Fig 1. Terracing at Machu Picchu, Peru

2.5 Reduction in water demand: Greywater recycling

Greywater reuse can reduce water volume in storm sewers attenuating the storm peak and reduce potable water demand. In ancient Greece and Minoan Amorgos greywater was used to flush toilets, simply by bucketing it from kitchens or baths. Water left over from ceremonial purposes in shrines fort example the Askleipieion, Kos, was also used occasionally. These uses of greywater are common now in the Aegean, due to the pressures of tourism seasonally increasing the demand for water, and the expense of building desalination plants. It is also suggested (Crouch, 1996, in [11]) that during the Minoan, water from cooking or bathing may have been used to water domestic animals, water indoor plants or wash floors. Stormwater and greywater were both used for irrigation purposes; surface water collected via the stormwater sewer system at villa Hagia Triadha for example were collected in a cistern from where it may have been used for washing, thus reducing water use and waste.

2.6 Reducing water velocity

Near the City of Cajamarca, Peru, Cumbe Mayo features the remains of a Pre–Incan aqueduct built about 1500 BC; it is 9 km long and constructed in volcanic rock. The channel meanders at points along its route to reduce flow velocity and prevent erosion. Reinstatement of meanders is a technique used today to slow water down and attenuate the storm peak. In some cases, the road can be used as channel to direct excess stormwater via raised kerbs as can be seen in Pompeii which has kerbs about 50–60 cm high. Whilst these open channels could have been used to control stormwater, they also took water from public fountains as well as sewage thus the flow would have contained human waste [1]. Stepping stones (or *pondera*), were used along the street, so that people did not have to walk through the foul water, or step down into the road.

2.8 Non–structural approaches to sustainable water management

During the 5th century BC, Plutarch recorded non–structural (institutional) arrangements which ensured the efficient operation and maintenance of the water system in Athens; this included appointing a "superintendent of fountains", which was an elected role, emphasising its importance. The superintendent of fountains enforced water resources regulation, ensuring the equitable distribution of water in the city. There must have been an obligation on the citizens of ancient Athens to maintain its storm–water cisterns, and thus provide flood resilience and water resource delivery [4]. In fact, in the centre of Mayan Tikal, Guatemala, the 5–months dry season became a matter of public works, and such investment in water supply infrastructure actually became a key consideration in the control of the population. Whilst water is now considered a right in most of the world, in ancient times the ruling elite could provide, or withhold it, this was one of the ways in which the population was controlled. An example comes from the Negev, Israel, where natural rainfall (80 mm) would not have been enough to support agriculture [12]. During the Nabatean (2nd century B.C. – 2nd Century A.D.) some people were encouraged to settle there by the Byzantine Empire. They constructed intricate rainfall harvesting systems which collected water from an area five times that to be irrigated. They were therefore able to collect the equivalent of 400 mm annual rainfall and enable agriculture to be carried out. The environment was challenging, but with support in the form of state subsidies from the Umayyad Empire settlement was possible [12].

3. DISCUSSION AND CONCLUSIONS

Mosso (1907) in [11] queries whether: "*our modern sewerage systems will still be functioning after even one thousand years*". Many stormwater sewer systems in modern cities are not fit for purpose after having been in-use for 150 years due to population growth, expanding urban areas and the potential wide-ranging impacts of climate change. [3] states that history "*provides lessons from the past from which we can learn*" but populations were much less dense in antiquity and thus drainage using hard infrastructure was more efficient and able to last millennia. In fact, perhaps a lot of what history tells us is instead what we have managed to forget over the millennia and we need reminding, rather than being taught these approaches anew since, whilst what this paper discusses is not, in the strictest sense, SuDs, nonetheless these ancient tools, techniques and practices included infiltration, detention, storage and conveyance; all processes [4] state can be classified as "*sustainable urban water management practices, which can be compared to modern–day practices*" (with reference to Minoan Crete) and "*the entire regulatory and management system of water in Athens must have worked very well and approached what today we call sustainable water management*" [4]. Whilst the ancients did not have the modern technologies and design methodologies for stormwater drainage, they were able to develop such systems effectively in order to accommodate their society's needs. Water was viewed as a valuable resource that they carefully harvested, stored, treated and recycled rather than it being hidden "out of sight, out of mind" as is much of current thinking. This is exemplified by the value of RwH in antiquity which [8] state *"…is an alternative freshwater source which to a large extent remains underexploited*". Ancient cities were far more Water Sensitive than cities are currently, and shows that even less technologically advanced cultures were able to use sustainable techniques for water harvesting and storage in urban and rural areas.

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Opportunity mapping of Natural Flood Resilience Measures: A case study from the headwaters of the Warwickshire-Avon.

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ABSTRACT
The use of Natural Flood Resilience Measures (NFRM) to address severe flooding was in the headlines in the UK during December 2015-January 2016 due to the widespread flooding which affected the North of England. This paper will discuss the use of these measures, such as ponds, swales, hedgerows and coppices of trees installed high up in the catchment to attenuate the storm peak and provide wider ecosystem services. The project involved working with multiple stakeholders informing an opportunity mapping process to determine the most suitable sites for interventions. Based in the Warwickshire-Avon catchment, it is the first example of an entirely community-led NFRM scheme in terms of its scoping and future implementation. A GIS database was constructed of catchment geomorphological characteristics that assessed environmental infrastructure, holistically identifying suitable measures that can simultaneously attenuate surface flow whilst providing wider ecosystem services that would encourage further uptake and address additional catchment based issues such as failing water quality status, habitat provision, and social-economic issues farmers faced with heightened levels of soil erosion. In total there were 208 opportunities identified for NFRM, these refer to individual areas/measures across the entire catchment area to WwNP.

Keywords: Natural Flood Resilience; Opportunity Mapping; Engagement

1. INTRODUCTION
Natural Flood Resilience Measures (NFRM) are techniques used to manage flood risk by altering, or enhancing, natural processes in a catchment. It is similar to Rural Sustainable Drainage (RSuDS; [1]), which also work with natural processes in the rural environment, to alleviate flood risk, improve water quality and increase biodiversity. There are two main NFRM approaches: 1) *Restoration*, which returns the existing system to a more natural one e.g. re- meandering, restoration of disconnected floodplains, uplands grid blocking, restoration of native catchment woodlands, reinstatement of riparian woodlands and coastal realignment. 2) *Alteration*, (including enhancement) improving or enhancing an existing function for the purpose of flood risk management, including partial restoration or natural processes and soft engineering e.g. enhancing the capacity for floodplains to store water (washlands), increasing channel roughness and RSuDS [1, 2, 3].

Recent reports such as [4] recognise that *defence* to relatively unknown climate change scenarios is not feasible as a long-term strategy to managing flood risk and state: *'Instead of further raising of flood walls and banks in Carlisle, Cockermouth and elsewhere in Cumbria, the existing defences could be supplemented by a range of measures to reduce flows and/or levels…*'. These 'supplemented measures', or NFRM, would be located in the upper reaches of catchments and require a great deal of support from and, consequently, incentives for landowners and farmers in order to alter land management practice. These incentives have become increasingly referred to as ecosystem service provision [3], whereby NFRM can also provide wider benefits to livelihoods and the environment beyond flood alleviation.

The argument to review catchment-wide flood risk management and move from the 'defensive' to a 'rewilding' approach has received a large amount of attention both politically and in the media. [5], for example, recognised that for continued changes in land management practices in order to go beyond the tradition approach, there must be a change in ethos. This ethos is also in accordance with the aims of wider national and international policies including the National Adaptation Programme (Section 58 of the Climate Change Act 2008), Making Space for Water [6] and European legislation on the assessment and

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management of flood risk (‘Floods Directive’), which encourage natural catchment-based runoff control and flood generation that go ‘beyond traditional engineering solutions’. The aim of the project was therefore to identify suitable alteration and enhancement options that could provide multiple benefits in the upper reaches of the Warwickshire-Avon.

2. METHODOLOGY

The headwaters of the Warwickshire-Avon was selected as the study site due to the proposition of a local community flood action group. It was broadly characterized using a conceptual mapping model that audits environmental infrastructure to assess flood risk mitigation potential, along with other services that NFRM could provide. This is known as a multi-criterion analysis (MCA), similarly conducted in previous mapping studies [9], and subsequently supported by expert judgment-based field assessment and accessing community knowledge including that of local farmers giving their view on land-management and land-use change in the area. The last was essential in engaging and increasing support for ‘buy-in’ of any recommendations by farmers and landowners, discussed more in 2.1. Table 1 details the data used for assessing the environmental infrastructure in order to identify suitable locations for NFRM across the catchment. The measures in particular were determined based on previous studies from donor catchments. This is comprised of two main elements, suitability mapping and constraints and sensitivities, in order to propose location specific suggestions [1].

Table 1. Considerations for the NFRM opportunity mapping screening process

Suitability Mapping	Constraints and Sensitivities
Hydrology of Soil Types (HOST – 29 classifications). The pedology of sub-catchments to specific locations is vital for understanding the interaction of water with soil. Measures can be accurately considered in terms of how they react with the areas HOST classification.	**Grade 1 Agricultural Land** (excellent quality agricultural land), often involves greater level of ‘off-setting’ cost in order to encourage implementation. On this principle, lower grade agricultural land is more favourable for NFRM implementation.
Updated Flood Maps for Surface Water (UFMfSW). These maps identify existing areas of surface water flow and points of sitting water, these are combined with **Risk of Flooding from Rivers** extents that indicate the relationship between the in-channel and overland flood flows.	**Urban/settlement buffer area** (500m) and **road networks** (300m). This allows for early consideration of possible ‘back water effect’. Combined with **National Flood Risk Assessment** data to determine likelihood of property flooding.
Digital Terrain and Elevation Models (DTM) and (DEM) illustrate topographic land use and elevation at high resolution, in order to identify contributing areas of surface runoff. This can indicate the major sub-catchments for flood generation in the area. Further supported by **Light Detection And Ranging** (LiDAR) data that locates flow pathways and potential storage areas.	**Environment Agency Washlands**, flood alleviation schemes have been developed which build on the natural behaviour of floodplains in alleviating the magnitude of floods that are passed downriver. They do this in a manner that goes beyond the simple concept of a single online or offline flood storage. Therefore, NFRM must avoid interrupting this process and its existing role in flood alleviation
Potential New Woodland (PNW) is a database developed by the Woodlands for Water Forestry Research group [9] that illustrates areas for woodland planting: riparian, floodplain and wider catchment. This is supported by the **Coordination of information on the environment** (CORINE) indicates the land-use of the catchment.	**Ministry of Defence (MoD) Land**, this is to consider the wider implications from interaction between water and possible chemical storage. These areas could lead to health hazards and it is best to avoid storage in MoD land as a result. This is combined with issues of changing practice of MoD as a result of increased flood susceptibility.
Climate change vulnerability zones is based on the National Biodiversity Climate Change Vulnerability Model (NBCCVM) to	**RAMSAR/ Sites of Special Scientific Interest (SSSIs)/ Biodiversity Action Plans (BAPs)/ Areas of Natural Beauty**

provide a spatially explicit assessment of the relative vulnerability of priority habitats based on established climate change adaptation principles. This ensures NFRM can mutually benefit key species with habitat provision.	**(AONBs)** are areas sensitively considered for their existing geographical or biological importance, and therefore, should avoid alteration.
Keeping Rivers Cool Natural England target areas indicate the importance of woodland planting for shading benefits. This is also supported by the **Countryside Stewardship** targeting areas that outline areas the grant scheme is spatially specified and for what reasons.	**Traditional Orchard Priority Habitat Inventory for England (Extract from Priority Habitats Inventory).** This inventory replaces Natural England's previous separate BAP habitat inventories and ensures these areas character are not altered.
Water Framework Directive (WFD) datasets indicate the water bodies' ecological status and the key pollutants for a failing status. This allows measures to be considered holistically.	**Scheduled Ancient Monuments** are common features across the study area. These must be considered with exceptional care, requiring a buffer.

1.1. ENGAGEMENT

The above mapping process was also informed by engagement with farmers and landowners through field walks, supported by participatory mapping on their land of areas susceptible to avulsion and overland flow. This allowed stakeholders to feel valued in the process and integrate both the academic and local knowledge.

3. RESULTS AND DISCUSSION

3.1. PRELIMINARY CATCHMENT ANALYSIS

Preliminary analysis of catchment extent and sub-catchment contributions indicated the headwaters contribution was 186.75 km^2, with a total of 36 watercourses across three dominant sub-catchments, listed in order of size, Knee Brook, River Stour and Nethercote Brook. Agriculturally, the land is dominantly (70%) mixed practice between arable and lowland sheep grassland. Further downstream there are settlements located with flood zones 2 and 3, the majority of properties at risk located in Shipston-on-Stour (80). In relation to water quality pressures, each sub-catchment is of 'poor' ecological status, as a result of diffuse pollution from mixed agricultural activities. The pressures themselves are from Phosphorous and Macrophytes and Phytobenthos, this is likely a result of the sediment contribution from overland flows as verified from LiDAR, HOST and CORINE data. This identified many upland areas that are of hard clay (dominant HOST classification of 21), with intense sheep grazing and limited woodland coverage (12.5%). Long term mean annual rainfall is 689 mm, with peak over thresholds from early avulsion and high discharge forecast to rise based on climate change allowances [10].

3.2. PROPOSED NFM MEASURES

Analysis of donor catchment characteristics, from FEH descriptors, including: area (km^2), standard percentage runoff (SPRHOST), as the percentage of rainfall that causes a short term increase in flow and the base flow index (BFIHOST), the ratio of long term base flow to total stream flow. The inclusion of HOST also recognises the importance of determining measures that can attenuate and/or infiltrate the peak, depending on local ground conditions. Furthermore, the importance of NFRM utilising local environments [3], these measures use present material sources and areas that could be altered in order to WwNP. An example of which is the Forested Water Retention Areas (FWRAs) [7], with existing woodland cover identified in areas of overland flow, these woodland areas could be altered to provide benefits for flood peak attenuation as well as habitat provision for the local wading birds (e.g. Corn Bunting). Additionally, altered coppice routines for FWRAs could supply a further source of timbre and encourage undergrowth that can further slow surface flow and provide perches for target mammals in the catchment (e.g. water voles). In total, 308 opportunities for NFRM was identified across the three sub-catchments (see Table 2); these predominantly look at slowing overland flow opposed to infiltration due to clay pedology and impermeable geology. These measures also incorporated local landowner and farmer suggestions on NFRM that could provide mutual benefits in terms of flood alleviation and improving the farm holding itself.

Table 2. Overview of NFRM measures and coverage

NFM measures	Knee Brook	Nethercote Brook	River Stour
FWRAs	0.0508km^2	0.0048km^2	0.0084km^2
Wider catchment afforestation	0.0067km^2	0.0024km^2	0.0049km^2
Hedgerows	400m	200m	280m
Soil aeration	0.0844km^2	0.0021km^2	0.0312km^2
Large/Coarse Woody Debris Dams	96	49	38
Riparian buffer	570m	230m	120m
Floodplain and riparian afforestation	0.0327km^2	0.0028km^2	0.0213km^2
Clay bunding	15	5	6
Offline pond	16	8	7
Offline retention pond	4	1	2

4.0. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

NFRM opportunity mapping enabled an extensive review of agricultural land that can be enhanced and/or altered in order to WwNP, to more effectively manage water both in the floodplain and in-channel, seeking to provide ecosystem services benefits across the 186.75km^2 catchment. However, there was uncertainty with changing land-management practice across the year, thus changing runoff patterns evident from LiDAR and UFMfSW, as well as the provision of environmental infrastructure over temporal change. Whilst this study provides an indicative overview of suitable measures across the catchment, it does not determine the NFRM schemes overall effectiveness as principally attenuating the peak as well as providing further ecosystem services. That would require detailed modelling of varied return interval events in order to determine the costs to benefit in regards to flood alleviation to downstream communities, as well as addressing the pollutant loadings issues present across the catchment. Furthermore, preliminary engagement has identified issues with current stewardship grant systems to allow for catchment scale NFRM to be implemented. Further social science analysis would be required in order to accurately note and then relay such issues to wider FCERM stakeholders.

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Integrated Water Sensitive Design: Opportunities and Barriers to implementation

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ABSTRACT

Flooding incidences are increasingly prevalent due to climate change, weather variability, building and land use practices. One of the regions to experience recent wide-spread flooding is located in the South West region in England. This region remains prone to flooding since the significant flooding of the Somerset levels during the 2014 storms. But with the growing demand for more housing in the UK and in North Somerset in particular, it is now important to review the current building and development practices for flood resilience.
The current regulations for water management in the built environment remains unclear for both new and existing development. However, this study focusses on the former and explores the potential for, and use of water-sensitive urban design (WSUD) solutions in two new housing schemes in North Somerset, South West England.
This study presents a brief overview of WSUD definitions and strategies, highlighting the corresponding opportunities and barriers to implementation. Then, primary research from documentary review and interviews of property development experts and the local council will be presented. The main drivers for WSUD were found to be led by the local authorities and regulatory bodies such as the Environment Agency. Key barriers include the up-front time and investment required to implement water sensitive design schemes. Also, mentioned were the maintenance cost and the health and safety implications of exposed water bodies in housing developments. The extended abstract concludes with recommendations to encourage better uptake of WSUD in future housing schemes.

Keywords: Flooding, Housing schemes, Resilience, Water Sensitive design

1. INTRODUCTION

Climate change is an ever-increasing reality and this has been largely attributed to human action since 1750 (Eggen & Urquhart, 2013). There has been recent research conducted by Sutton and Dong which demonstrates a link between the rise in sea surface temperature with the increased summer rainfall over Northern Europe, much like that experienced by the UK in 2012 (Sutton & Dong, 2012). Prior to the storm floods of 2015/16 in the north-west, one of the wettest winters was recorded in the southern part of the UK in 2013/14 (McKenzie, 2015). During the storms in December to January 2014, weather impacts were initially related to strong winds. However, as the rainfall levels continued to grow, the focus shifted from the wind to flooding. This included large watercourses such as the Severn and Thames but also resulted in coastal flooding in the south and west of the UK (MetOffice, 2014). A flooding event of similar significance occurred in 2000/01 and it was only after this storm event that groundwater flooding was recognized as a significant issue. These events have made flood resilience a focus of government planning, regulatory attention and academic research (McKenzie, 2015). Flood-risk management bodies in the UK have shifted the emphasis from engineered flood defences and intensive watercourse management to 'sustainable flood-risk management' (Ball, et al., 2013). This change of focus targets resilience as opposed to outright prevention.

Resilience is defined as 'the ability of individuals and/or communities to withstand and rapidly recover from a disaster such as a flood' (Ball, et al., 2013). The aim of this project is to evaluate the current state of the art of water sensitive design as a meaningful strategy for flood resilience particularly in the

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UK. It also purposes to highlight the opportunities and barriers to this integrated design approach. The qualitative case study approach is utilized because it is ideal for exploring incremental questions and developing an in-depth understanding and insight into an issue (Creswell et al., 2007). The analytic strategy is to identify issues within each case and then look for common themes that transcend the cases (Yin, 2003). The objectives of the study were:

- To review definitions, characteristics, types and methods for achieving water sensitive design.
- To present the context, state-of-the-art and key drivers for water sensitive design in the UK
- Using qualitative case studies, to investigate the opportunities and barriers to water sensitive design in the UK
- To consolidate finding and make recommendations for wider implementation in current and new housing schemes.

The results will be presented in the full paper as lessons learnt, from which recommendations are drawn for further work. The scope of this study is limited to new housing developments in the South West region of the UK. Irrespective of this, the planning frameworks and flood hazards are comparable with similar regions in the UK, and there is scope for transferable lessons to other flood risk regions across the world.

2. WATER SENSITIVE URBAN DESIGN (WSUD)

WSUD is the process, rather than a final condition (Institute of Civil Engineers, 2013), of integrating water cycle management with the built environment through planning and design (CIRIA, 2013). WSUD as a concept is gaining an increased amount of support as a means of urban water management through the better positioning of design processes and urban planning (Institute of Civil Engineers, 2013). This process seeks to meet people's needs but also recognises the importance of maintaining a healthy natural environment. In the UK, these WSUD features can also be known as SUDS (Sustainable Urban Drainage Systems), however WSUD is not simply stormwater management or a form of 'super SUDS' as SUDS deal with drainage alone (Institute of Civil Engineers, 2013).

The integrated design approach is required for a coherent and effective WSUD scheme. This requires complete collaboration between the government, local authorities, infrastructure providers, local communities and others (Arup, 2013). Some techniques of WSUD are: to use, reuse and exploit the management of wastewater, protecting and enhancing natural landscapes and integrating new structures and features by the use of water. Some other forms of WSUD could be reducing the demand for potable water by harvesting rainwater from roofs and wastewater reuse, minimising wastewater generation from properties and the treatment of wastewater so it can be either be reused or discharged into a local watercourse without polluting it. It also brings 'sensitivity to water' into urban design as it ensures that water is considered from the outset of the design process (Institute of Civil Engineers, 2013). An effective WSUD scheme brings together a variety of disciplines of design, engineering as well as environmental sciences to protect watercourses and aquatic environments.

Water Sensitive Urban Design (WSUD) can be categorised into three scales which are suited for both researching and for 'good practise'. These three scales of WSUD are: macro, meso and micro (Ellis, 1999). Some general key elements for mainstreaming WSUD are shown below in Figure 1.

Level	General key elements
Macro	• Climate • Urban growth • Socio-political capital and sustainability
Meso	• Attitude of stakeholders • Knowledge and trust • Complexity of stakeholders • Co-operation, involvement and communication • Regulation, guidelines, agreements and contracts • Cost and cost allocation
Micro	• Added value • Enthusiasm of individuals • Location characteristics • Construction, operation and maintenance

Fig. 1. Key elements of the different scales of WSUD (Rijke et al., 2008)

Cooperation between these levels is a fundamental requirement for successful, integrated and adaptive water management (Pahl-Wostl et al., 2008).

- ‘Macro’ scale refers to an entire city (or majority of one) and will involve large water management facilities.
- ‘Meso’ scale is of a smaller proximity to that of the ‘macro’ and will focus more on an urban block and neighbourhood.
- ‘Micro’ scale focuses on the individual building. (Ellis, 1999)

2. METHODOLOGY

The qualitative case study methodology was used, with interviews as the primary data collection method. The case study methodology allowed for the subject and key players to be fully studied within its context. Interviews can be adapted to be a flexible method of data collection and so the type of interview chosen influences the practical aspects of the interview (Punch, 2005).There are three main types of interviews: an informal conversational interview, the general interview approach and standardised open-ended interviews (Patton, 1990). A general interview approach was taken and once the data was collected, the process of ‘data reduction’ (Punch, 2005) began to reduce the quantity of data without significant loss of information, ensuring the results were not taken out of context.

Case Studies: The case study compares two housing developments in North Somerset. This area of the South-West England region was chosen due to being at high risk to flooding and also due to the Council’s plans to construct 5500 new homes by 2020. The selected ongoing developments are two of the biggest projects in this area with completed and on-going phases on site. Both of the house-building companies have differing target markets making the comparison of the use of WSUD possible.

The method: Two interviews were conducted with the project managers of the two development sites. Each interview duration was approximately 60 to 90 minutes and the data recorded using a Dictaphone. The interview questions and full findings will be detailed in the full paper. Both interviewees have been involved in the house-building sector for the majority of their careers. Following an interview with each of the project managers, a site ethnography was permitted and conducted and photographic records were taken. A telephone interview was also conducted with a Flood Engineer in North Somerset Council. This was to: expand on the planning approval process outlined by the project managers, to give an insider’s perspective on the drivers and implementation of WSUD in new developments. This phone interview also supplemented other documentary data provided by the council.

3. SUMMARY OF FINDINGS

The case studies provided good insight into the state of the art of WSUD in developments in the UK. Both developers had different target markets, one aiming for young families who were first-time buyers (low-end of the market) and the other targeting the middle-income market i.e. young professionals buying their second or third home and who have a larger budget. This reflected on the attention and resources used for communal WSUD features on the site. However, both developments used a significant amount of WSUD including multiple rhynes (Somerset term for drainage ditches or canals) and swales that were used to enhance the aesthetics of the site.

It was found that the policy tools and regulations were the main drivers for considering WSUD in housing developments in the UK. The main advocates were also found to be the Environment Agency and local authorities. These governing bodies have set requirements for the careful discharging of surface water collected from impermeable surfaces such as roads, pavements, driveways and roofs. Usually local authorities may not have as much focus on resilient design. However, this case examples showed that there are considerable benefits; including social-economic benefits, if the local council takes a proactive approach towards flood resilience. The planning approval process can be time and resource intensive. This remains a considerable factor also in this case were it was found that the negotiations for the implementation of WSUD extended the planning process even further for both case study sites. This was predominantly due to the sensitivity of the area and its location within a floodplain and also that the developers had to meet additional requirements such as generating at least 1.5 jobs per new house to be built, but also required that these employment opportunities had to be in place before house building could start. This additional requirement was to bring work to the area and reduce commuting outside of the immediate area, but still had implications in terms of time, resources and cost.

A common point raised by the developers was that these WSUD features would require future maintenance. The cost of maintenance compared to hidden drainage and infrastructure could be barrier. Also, access to the rhynes is required for regular maintenance which means that no fencing can be fitted to prevent cars or people falling into the watercourses. Therefore, these features could raise some health and safety concerns. Integrating natural water features into the housing developments have clear benefits but there is also the need to engage with residents to increase the awareness of this benefits. This will help to justify additional maintenance costs e.g. through services charges but also help to improve safety behaviours around WSUD features.

4. CONCLUSION AND RECOMMENDATIONS

The UK has made positive and encouraging changes to regulations and requirements for WSUD in housing developments, particularly if they are located within a floodplain or area of high flooding risk. From the case studies, it is clear to see that the uptake on WSUD is on the rise and the design of housing developments has significantly improved due to the need for better flood resilience. However, there is scope for more to be done especially at the individual housing scale. The general layout of an individual house remains largely the same so there is scope to extend regulations to spatial design and tectonics as well.

The main drivers for WSUD at present are the local authorities and regulatory bodies such as the Environment Agency. Therefore, there is still need for building professionals and developers to take the initiative in building and built environment resilience. This can be achieved through even better regulations and incentives. It was also found that the compliance framework and strategies for Flood and Water Management within the act could vary per region and local authority. Therefore, more detailed guidance is still required to make it easier for other local authorities to implement WSUD in new and large scale housing developments.

Lastly, a forward-thinking recommendation would also be that mechanisms including funding, grants and incentives should be put in place to ensure the maintenance of WSUD features such as rhynes and swales to ensure their continued functionality and efficiency in the longer term.

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Integrated Urban Water Management under Centralised Planning System – Sponge City in China

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ABSTRACT

Due to the rapid urban sprawl that paved the way for taller skyscrapers and wider concrete roads, cities in China are becoming increasingly vulnerable to frequent flooding events that are rather moderate in scale. Recent events such as the flooding in Beijing and Shanghai have attracted the attention of the central government, and President Xi Jiping is directing the focus of urban development back to flood prevention and drainage system after decades of neglect. As the Sponge City initiative is given high importance from the central government, it presents a unique opportunity for investigation of the impacts of centralised planning system on sustainable urban water management. This paper aims to outline the historical progression of Integrated Urban Water Management (IUWM), and provide an overview of the Sponge City initiative in China. As a preliminary attempt for analysis of the initiative, some underlying principles for IUWM are extracted and used to examine the current practices and opportunities for future investigation.

Keywords: Sponge City, Planning, Sustainable Cities, Low Impact Development, China

1. INTRODUCTION

Fresh water is a limited resource shared by the growing global population. Urban water infrastructure usually has high investment costs and long life span, which means that it is relatively static and has slower turnover rate compared to other types of infrastructure. The size and complexity of urban systems also delays the manifestation of structural problems and failures, and prohibits any simple and straightforward fixes.

As the pace of urbanisation quickens, existing infrastructure systems are stressed due to increase in demand for water supply. Furthermore, the system is becoming more vulnerable due to more frequent extreme weather events caused by climate change. As cities are becoming increasingly crowded, urban development and redevelopment are now inseparable from water resources and water infrastructure [1]. As the urban form becomes increasingly complex, the urban water system has to cope with higher level of demand in quality and quantity of services. The traditional supply, treatment, and drainage model is no longer sufficient to face the challenges of deteriorating water and urban environment.

Developing countries such as China find themselves in a difficult situation where a balance between economic expansion and social environmental conditions needs to be reached. While China is a pro-active champion of global sustainability and has pledged to find solutions to its environmental problems, such as greenhouse gas emissions and severe air pollution, making actual progress at the local level can be less straightforward [2]. Solving China’s urban water problems are compatible with the nation’s ambition in economic growth and aligned with their goals to implement stricter management of water resources and improving urban environment and life quality. Given China’s unique political structure and planning system, it provides a case study to investigate the influence of a rigid and hierarchical governance structure on the achievement of integrated urban water management, which usually relies on high levels of cooperation, coordination, and participation.

The intent of this paper is to outline the key factors to be considered in analysing the influence of centralised planning on the implementation of integrated urban water management, using the Sponge City initiative in China as a case study. In the paper, an outline of the historical progression of Integrated Urban Water Management (IUWM), as well as a brief overview of the Sponge City initiative are presented. As a preliminary attempt for analysis of the initiative, some underlying principles for IUWM are extracted and used to examine the current practices and opportunities for future investigation.

2. INTEGRATED URBAN WATER MANAGEMENT (IUWM)

As cities are becoming increasingly crowded, urban development and redevelopment are now inseparable from water resources and water infrastructure [1]. What began as a vision about how water resources are best managed to serve the people without damaging the environment, gradually developed into more holistic approaches with innovative strategies [3]. There are several milestones on the way to what we know today as the integrated approach to urban water management (IUWM).

In 1992, as a response to the increasing need for social and economic development without harming the environment, the Dublin Statement (from International Conference on Water and the Environment) and Agenda 21 (from UN Department for Sustainable Development) addressed integrated water management from both river basin and urban perspectives. The Dublin Statement principles addressed several criteria of best management, which include linking social and economic development with environmental protections within river basins, participatory approaches towards water development and management, acknowledging the role of women in water provision and protection, and the recognition of economic value of water [3]. The Agenda 21 then built upon the Dublin Statement and highlighted the needs for holistic management of water resources to achieve “environmentally sound management of water resources for urban use” [3]. However, the Agenda 21’s main objective is to eradicate poverty and the aim for improving urban water management still remains at satisfying the freshwater needs to development [4].

The “Bellagio Statement” formulated by the Environmental Sanitation Working Group of the WSSCC (Water Supply and Sanitation Collaborative Council) in 2000, and the UNEP 3 Step Strategic Approach [5], went a step further and presented greater emphasis on prevention and recycling in urban water system. The “Bellagio Statement” principles were meant to achieve universal access to safe environmental sanitation with respect for the economic value of wastes [6]. According to the principles, good governance should include stakeholders at all levels in decision making to produce solutions that are responsive and accountable to the needs and demands in the local setting, as well as include holistic waste management and recycling to promote efficiency and reduce the spread of pollution [6].

To balance environmental protection and urbanisation, the UNEP 3 Step Strategic Approach shifted its focus from technology-centred end-of-pipe fixes to a three step process for wastewater management – pollution prevention, treatment for reuse, and disposal with stimulation of self-purification capacity [5]. Rather than improving the treatment processes while the consumption level remains status quo, the 3 step strategic approach starts with reducing water use, thereby minimising the wastewater generation and discharge. This concept is important because following the three step strategies in chronological order requires a collaborative effort from industries, households, planners, and institutions, and produces specific solutions to specific situations [5].

As summarised by Mitchell [7], IUWM describes a sustainable urban water system where all parts of the water cycle are planned, managed, and monitored as an integrated system to produce context specific solutions in a process that engages stakeholders in all levels. In fact, IUWM is only one the terms describing this concept, otherwise known as water sensitive cities, water sensitive urban design and low impact development. These different movements in urban water management have experimented with different frameworks and, while the processes involved and the theoretical basis may differ, the underlying objectives and the necessary measures to be taken are similar. Some underlying principles or criteria of success that are present in all contexts include the need to address water infrastructure as socio-technical rather than technical systems, the need for coordinated decision making and water management, as well as diversified urban water infrastructure and service types [7], [8], [9].

2.1 Sponge City initiative in China

Sponge is a material known for its capabilities in absorption and adaption in shape and volume. When the words “sponge” and “city” are combined, it is to describe a city that has high resilience, adaptability, and sustainability [10]. In the case of the Sponge City Initiative in China, a city is being described as a “sponge” for its abilities to soak up and release water when necessary, which means it is equipped with healthy water system network that co-exists and co-evolves with the urban residents and other urban infrastructures. The Sponge City principles aim to find the balances in urban water quantity and quality, centralised and decentralised infrastructure, landscape and water function, water ecology and water safety, as well as green and grey infrastructure [11].

Rapid urbanisation accompanied by frequent flooding events and deteriorating water environment as a consequence of past development is pushing the Chinese government to re-evaluate its strategies toward water resources and infrastructure planning [10]. Much like the development process of WSUD in Melbourne, Australia described by Brown et al [9], the take up of the sponge city ideology by the government is the result of continuous effort by a group of “champions” in academia, industry and government, combined with “historical accidents” such as the 7.21 Flooding (2012) in Beijing that killed and injured many [10]. The term “city at sea” was used to describe the city under heavy storms, and it became apparent to the government officials that measures must be taken to prevent such incidences in the future.

The philosophy behind the Sponge City is to encourage the co-habitation of urban residents and their water environment. Although elements of Low Impact Development and Water Sensitive City are used as the basis of the sponge city concept, it is trying to overcome the tunnel vision that planners tend to have when applying broadly single engineering methods or techniques across different problems [12]. The earliest group of advocates for the sponge city concept were architects and urban planners who recognised the need for incorporating the natural elements into the planning of urban landscape, and the proposals to the central government were submitted by the Jiu San Society (political party) and the National People’s Congress deputy of Hunan province [13]. The close cooperation of the local government and active participation of the academia are elements that set the Sponge City initiative different from past green (environmental) initiatives in China, and this will be discussed more closely in the next section.

Before the introduction of sponge city concept into the urbanisation policies from the central government, many urban landscape projects aiming to better control and treat stormwater were implemented since 2008 [13]. Once the Party Central Committee has recognized the need to adopt measures for urban stormwater control, the Sponge City initiative gained momentum and was passed down from the State Council to the Ministries of Finance Housing and Urban-Rural Development, as well as Water Resources, who collectively became responsible for overseeing all the Sponge City projects. The official Sponge City initiative was adopted in the national policy in 2014, and the Technical Guideline for Sponge City Implementation (self-translated) was published and distributed in the same year. Once the initiative was on the national development agenda, the pace of policy implementation increased and by April 2015, the first batch of sixteen pilot cities for the Sponge City programme had been selected through a competition of proposals. There is much diversity within the pilot cities, in terms of their social, economic, and cultural backgrounds, as well as their location, size, and level of development [14]. The selected pilot cities will receive project funding from the Ministry of Housing and Urban-Rural Development (MOHURD) as well as from the provincial fund for Sponge City initiative. The rest of the funding will come from low interest loans from banks, and through Public-Private

Partnerships. According to the State Council's Guideline on Development of Sponge City, the overarching objective of the programme is to use low impact methods to manage and reuse 70% of stormwater at source in urban areas, and 20% of urban areas should meet the target by 2020 and 80% by 2030 [15]. In 2016, the results of the second round of selected of national pilot cities are already announced, and there are 14 new pilot cities including mega cities such as Beijing, Shanghai and Shenzhen, as well as a number of prefecture-level cities in Southwestern China [16].

The progress and performance of the pilot cities are closely monitored and evaluated. The most recent "Evaluation Methods" of Sponge City pilot cities is published by the Ministry of Finance and the Ministry of Housing and Urban-Rural Development (MOHURD), which is the programme manager. There are seven evaluation criteria, including funding usage and management, Public-Private Partnerships performance, establishment of capital protection scheme (operation and management of completed projects), output quantity (project areas), output quality (annual runoff control), project effectiveness (percentage of environmental targets met), and technicality of projects [17]. The progress of each pilot project is regularly evaluated, and the cities with unsatisfying results are given warning and assistance so they can improve their performance before the next evaluation. The pilot city projects are meant to be experimental or explorative, so that relevant policies, regulation and guidelines can be modified or developed to ensure improvement in the future.

3. METHODOLOGY

This research project aims to investigate the influence of centralised planning system on the transition towards integrated urban water management. The goal is to first evaluate the success of the Sponge City initiative as a standalone "mega-project", and critique its current practices with an attempt to identify options and opportunities to aid the transition from an initiative towards formal planning agenda and regulation. Then shift the focus to the centralised planning system and place the Sponge City initiative against a wide range of urban water projects with similar approaches in an effort to find its advantages and disadvantages. The preliminary contextual review and analysis will lead to the formulation of the problem, research questions, as well as specific research objectives and methodologies, which will in turn set the groundwork for a more extensive study of the Sponge City initiative.

3.1 Methods

The preliminary research should focus on the following steps to build a knowledge base of the political structure and planning environment in China. The first step is the understanding of the history and context of urban planning and environmental policy making in China. This will be accomplished through extensive review and analysis of policy and media literature, as well as informational interviews with experts and staff members from the different groups of actors directly involved in the Sponge City projects. In order to assume a neutral standpoint and eliminate any a priori bias, this will be followed by the mapping of relevant actors and networks, using methods including semi-structured interviews with key actors and stakeholders. Focus group studies are highly recommended, however given the known challenges in setting up platforms for multiple organisations in China, the groups may need to be kept small and participants should ideally be under the same organisation. Similarly, focus group studies consisting of cross-disciplinary participants are highly recommended but will present challenges as well. The results will produce an inventory of actors, their interests, objectives and perceptions, as well as their formal relations.

The specific aim of this paper is to describe three underlying criteria for integrated urban water management, and use these criteria to provide a review of the Sponge City initiative based on current policy, organisational and media literature available.

3.2 Evaluation criteria

3.2.1 Water infrastructure as a socio-technical system that consider all parts of the water cycle

A socio-technical system, compared to a technical system, is made of the technological development as well as the social environment consisting of scientists, policy makers, cultural and user preferences, and markets and industries [9], [18]. Conventional water management approaches are highly compartmentalised, prioritising short term alleviation over long term sustainability [9]. Any change to the urban water system should consider its trajectory and consequence in both time and space. The transition towards a more sustainable form of urban water management should not be limited at the structural level, meaning changes should not be only applied to infrastructure through technological advancement, but should be placed in the context of society.

3.2.2 Coordinated decision making and management

Since water systems are complex such that the social, environmental, and economic as well as the technological aspects of management are intertwined. Stakeholders and actors from various disciplines and background are involved, and sometimes bring with them conflicting interests and goals. Coordinated decision making is important for any integrated management since it provide opportunities for sharing expertise and opinions that can facilitate more informed decisions. In terms of project implementation, operation, monitoring and evaluation, coordinated effort can gauge the progress against the plan and modify either accordingly.

3.2.3 Diversified urban water infrastructure and service types

In contrast to the highly compartmentalised conventional water management approach, integrated urban water management should treat the urban water cycle on its entirety in order to align the interests and benefits with those of urban development [9], [19]. By diversifying infrastructure and service types, water treatment or management techniques can be “fit-for-purpose” in the local context, and be multi-functional to achieve maximum efficiency [8]. However, this is not a transition from compartmentalised to de-compartmentalised, or centralised to decentralised approach. Rather, a more sustainable urban water management approach should be one that is flexible and adaptive to fit the different dynamics between society and technology.

4. “SPONGE CITY” AS IUWM UNDER CENTRALISED PLANNING SYTEM

4.1 Water infrastructure as a socio-technical system

This initiative presents a unique opportunity to enforce a radical change in the water management approach without having in place a complete shift in the socio-political system. In other words, instead of instigating an institutional (regime) change after the highly compartmentalised urban water regime is able to function as an integrated system, the initiative places the priority on sustainable over conventional water management approach first while the institutional changes will fall in place gradually to allow the transitions to occur [9].

Given the history of environmental governance in China, it is reasonable to doubt the success of the Sponge City initiative. In the past, government funded projects on public infrastructure tended to lack transparency and efficiency as a result of poor central-local communication and sometimes even conflicting interests, and the financial funding sometimes would not be used to meet environmental targets [20]. Scott W.R [21] defined three mutually reinforcing “pillars” that are essential to successful institutional changes – cognitive, normative, and regulative. Within the context of sustainable urban water management, past institutional reforms were rarely a success because interventions were usually focused on one or two of the pillars [9]. The past failure in environmental governance of China could be attributed to the lack of balance of changes within each pillar. As described by Lo [2] is his study of the low-carbon governance of China, regulations imposed by the central government often fail on the ground because the local government and enterprises’ values are misaligned with those of the national government. Because of the absence of knowledge support as well as the necessary shift in the values towards energy conservation at the local level, the central government was having a difficult time gaining control of progress and impose reward or punishment effectively. The Sponge City programme faces similar challenges but has also advantages over the past efforts. In contrast to the low-carbon governance, where energy conservation could be in conflict with the local interest in economic growth, the implementation of sustainable urban water management in line with the local government's target in reducing risks associated with floods and droughts. In recent years, the local authorities have been trying to reform urban development but there is lack of necessary skills and support, so the Sponge City initiative is readily taken up by the local government since it is seen as a solution to their problem [14].

By pushing for the Sponge City initiative, the central government provides a space for innovative technologies and infrastructure to compete with conventional approaches, and minimise the influences of financial implications and technological and infrastructural lock-ins [22]. Incremental changes are typical to technological transitions, because radical new technologies usually have a hard time to fit in the already established socio-institutional framework [23]. In the case of urban water management in China, some of the technologies being used are not radically new, so it is not definite that the institutional context in China can better foster innovation. However, what differentiate the Sponge City initiative from others is the opportunities for closer cooperation of local government and enterprises, thus giving new technologies a better chance to compete against conventional approaches.

4.2 Coordinated decision making and management

Sponge City is one of the initiatives implemented by the Chinese central government to promote a more sustainable and heathier environment, and its target area is urban stormwater treatment and control. It excludes elements in a water system such as the collection, treatment, and recycling of grey and black water. Although wastewater recycling is listed as mandatory for cities under certain population or has very low quality water environment [24], the definition of wastewater is likely to be limited to stormwater (greywater). Similarly, the emphasis on wastewater recycling in general is on the retention and reuse of rainwater. This initiative also doesn't expand to watershed management. Although watershed pollution problems have been recognised, the Sponge City initiative currently does not provide financial or technical support for projects at watershed level [25]. On one hand, there are less factors to be considered when projects are local and small scale, but on the other hand it doesn't contribute significantly to the management of water resources as a holistic cycle where multiple cities (sharing a watershed) will be involved.

The central government is aware of the limitations of the current programme design. Although "Sponge City" is a standalone initiative, it's on the agenda that also pushes for treatment of "black" water bodies, construction of underground pipelines, and treatment of rural environment [26]. Furthermore, among the requirements of proposals for the 2016 pilot cities selection, the candidate city must demonstrate that it plans to include a greater percentage of old city areas compared to last year, as a way to integrate the design with other programmes on the agenda [27]. There are a couple cities sharing borders among the pilot cities selected in 2016, which is an opportunity or even a necessity for decision making to be coordinated between the two cities. As more cities will be selected as pilot cities at various government levels, the need for having cross borders and cross programmes coordination, as well as the necessary requirements and guidelines will become more apparent.

In addition to the horizontal coordination, which is across different infrastructure and service types, as well as geographic and political boundaries. There is also need for vertical coordination, which is across difference levels of government. In order to achieve true integration of urban water management using the Sponge City concept, there needs to be an alignment of interests, objectives and knowledge capacity at all levels. Given the unique political structure and historical background of China, it is not the lack of willingness to introduce the sponge city concepts into local government planning agenda that warrants concerns, but rather is the potential lack of knowledge and support needed by the local authorities to adhere to the water management principles as outlined in the national policy. Furthermore, the indirect control the central government has over city-level government is also adding difficulty to monitoring and evaluation. The MOHURD recognises the importance of having the city authorities understand the intention and objectives behind the design guidelines, and it will only make a difference if there is enough expertise at the local level [14].

The SWITCH research program (2006-2011) was a 6th EU Framework project looking at innovative urban water management approach. It identified the Learning Alliance as a key platform for bringing cross-discipline expertise together to foster a learning environment that can benefit all stakeholders. This network needs to include a broad range of stakeholders to ensure social equity, as well as outsiders to enforce transparency [31]. What is more important is the level of commitment and cooperation of the stakeholders, and it sometimes is highly relied on effective facilitation and strong leadership that pulls the members with different expertise together. While some cities such as Accra (Ghana) benefited from the SWITCH approach and was able to bring together stakeholders and identify key water issues and transition strategies, it was more difficult in Beijing to establish trust between stakeholders by holding frequent multi-stakeholder meetings for ideas exchange, due to cultural reasons. The same cultural difference in China also prompted the change from multi-stakeholder meetings to more informal bilateral meetings with the universities served as “honest brokers” [31]. Although the multi-stakeholder platform was not successful in the project in China, a similar platform is needed for the Sponge City programme to encourage information exchange across disciplines, and prevent single experts or ideas from dominating the conversation [18]. Currently, it is a common practice in the private sector where teams from various disciplines (firms) cooperate to bid for a project. However, it is still more difficult to realise close cooperation between ministries or disciplines because they are involved in the projects at various extents and have different levels of power.

Effective communication and coordination between different levels of government in monitoring and evaluation process is most crucial at the pilot stage, as it provides feedback for the incorporation of the initiative to formal planning and environmental regulation. According to the “Evaluation Methods” published by the MOHURD, cities self-report their progress, and the monitoring and evaluation of city-level progress is carried out by provincial level Housing and Urban Rural Development Ministries, and MOHURD will select few cities for inspection based on the results submitted by the provinces [28]. This scheme of M&E can be efficient if there is proper supervision, but there is also risks of having incomplete or biased reporting of progress in order to obtain rewards or avoid penalisation. Other potential problems may include misrepresentation of the sponge city concept to increase public support but results in false expectation, as well as sustainable management and operation of the ever increasing number of projects in each city [29].

This year, the eligibility requirement for the second batch of pilot cities is including the monthly submission of progress up to the competition deadline as well as the ability of continue the submission after being selected [26]. It is in fact worth noting how much emphasis is placed on the information technology that can enable better information and knowledge sharing among city departments as well as across multiple city authorities. These measures include online portals for local authorities to submit data and report progress, online platforms targeted at the general public or interested persons and private sector business owners. Apart from this, social media is also playing a big role in information and knowledge dissemination, as well as public participation. At the moment, these are separate platforms and access to certain pages are restricted. As the programme matures, MOHURD should consider having all the platforms consolidated into one to provide easy access for information sharing and monitoring purposes.

4.3 Diversified urban infrastructure and service types

This criterion is testing the capacity and capability of centralised planning system. Because IUWM is largely decentralised and dependent on the local context, but the centralised planning system is subjecting all the cities under a universal design and technical “guideline”. Consequently, many people in academia and industry alike question the likelihood of success of the sponge city initiative based on this criterion, and some even believe that the initiative will again fall under the “tiger head snake tails” category and won’t be able to achieve the goals that are set out.

In recent years, the Public-Private Partnerships (PPP) model is becoming an important source of project funding, and is promoted by the central government as the go-to business model. In fact, the proportion of financial investment in PPP is one of the criteria for success in progress evaluation [17]. While the PPP model may help promote private sector's investment in public service infrastructure, and lower the burden of debt on the local government, aside from the known uncertainties and risks associated with PPP [30], it also creates a problem that can lead to blind uptake of new technologies without considering the needs.

A similar issue is the tendency of certain officials to use sponge city as a "one size fits all" fix of urban water problems. While the MOHURD understands the transition into "Sponge Cities" is a long term process (20-30 years), the success depends on how well the local government interprets the policy and understands the time commitment required [14], [26]. If the local government is being too anxious to demonstrate success by investing in projects that are an "overkill" or even a disturbance to the local environment, then the purpose of implementing sponge city is defeated and funding is spent wastefully [20]. Therefore, it warrants a closer investigation to determine the benefits as well as the downsides of PPP model in China, and its role in the transition towards "sponge cities".

5. CONCLUSION

The Sponge City initiative can be described as a "mega pilot study" that involves simultaneously a large number of cities with different types of water stress and demand. It presents a unique and exciting opportunity for studying the life cycle of a sustainable urban water management approach, from initial policy incorporation to the diffusion and implementation at various government levels, and then to formal legislation. This paper gave a description of Integrated Urban Water Management and how the Sponge City initiative in China fits the criteria based on current findings and progress. As the Sponge City initiative expands and matures, more findings will be available for a more extensive study that aims to understand the influence of centralised planning on the efficiency and effectiveness of integrated urban water management, especially its effectiveness on cross-departmental and cross-disciplinary cooperation, and how this particular initiative compares to urban water projects with similar approaches internationally.

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Greywater and Green Infrastructure

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ABSTRACT

Green Infrastructure (GI) relies upon the efficiency of natural and constructed water systems to provide water of sufficient quality and quantity to sustain its growth and ecology. Greywater arising from human bathing and personal washing is prolific and ubiquitous and theoretically may be useful for sustaining GI in locations close to points of generation and in rural locations. However, the concept of discharging untreated greywater directly to the environment for the purpose of irrigating GI is often unpalatable in environmental quality terms. It is sometimes illegal under pollution prevention legislation and regulations, depending on the greywater source, nature and flow characteristics.

In contrast, separating greywater before it combines with sewage and laundry effluents can be used to sustain urban environments and their GI more reliably. Subsequently, discharging treated greywater directly to the environment for the purpose of sustaining GI is environmentally beneficial. An analytical approach to the quality and reuse opportunities for greywater leads to the determination of water reuse and irrigation potential, feasibility and water stewardship.

Previous evidence of greywater quality applied to irrigation, and the respective soil and growth effects measured, is compared with a recent research study and the irrigation and growth effects observed. In consequence, the potential benefits for treated greywater to be used to directly sustain GI can be estimated.

Keywords: greywater; irrigation of green infrastructure; greywater quality.

1. INTRODUCTION

The option for utilising greywater for irrigation and for sustaining Green Infrastructure (GI) is an important potential means for sustaining GI during times of drought. While this principle achieves wide, cursory acceptance, and would be unlikely to be rejected during an intensely dry period, significant barriers exist to regular watering using greywater.

1.1 Quality of Irrigation.

The potential for watering gardens with greywater has been questioned on the basis of the general quality of greywater and it's potential suitability for, or impacts on, the sustaining of growth. The variation of the quality of any greywater means that its pollutant concentrations cannot necessarily be predicted on any particular discharge day. Nevertheless, greywater originating from a set number of appliances in a home or office, will tend to fall within an approximate range according to the appliances that are in place, the ages of the occupants and a number of other key variables.

A number of basic tests can be conducted to check the variability of certain key quality characteristics of any greywater. Although it is preferable to know the concentrations of a full range of quality parameters of the greywater being discharged, very often this is impractical. Most domestic greywaters are not "regulated" [1], in the sense that they are not required by UK Regulations to be tested daily or weekly according to a frequent and specific regime, and there is no requirement to keep daily quality records. Where discharges are regulated there is likely to be a more strenuous regime in place.

Some authors such as [2] have reported test results using untreated rather than treated greywater. Other authors [6], [7], [8], have tested various categories of greywater, and in this respect the common nomenclature 'greywater' can lead to misunderstandings. [3] used 'greywater' that included a significant proportion of laundry detergent solution, typical of washing machine wash cycles. Washing powders and solutions may often contain aggressive ingredients. However, much of the greywater currently recycled in the UK excludes laundry detergent. Latterly in the UK, most recent published studies have focused on greywater collected only from hand basins, baths and showers, thus excluding greywater obtained from washing machines. This is a critical differentiator since studies using bathroom and hand basin greywater only, will derive their research results and conclusions from greywaters that usually contain lower concentrations of surfactants and salts than are used in washing machines. Furthermore, avoiding the use of wastewater from kitchen sinks ('sullage') avoids problems associated with, for example, the accumulation of Fats, Oils and Greases, known in the water industry as 'F.O.Gs.'

At a local scale, it is theoretically possible for households to control their own greywater quality by controlling the volumes of water used for showers, baths and hand basins, and by controlling the amounts of soap and other personal hygiene products that are used. In practice, this is usually too onerous for an average household to undertake on a regular basis.

1.2 Soil Impacts.

Previous studies such as [2], have conducted plant growth evaluations and tests when irrigating with untreated greywater. The same authors [2] focused on the application of laundry water for growing crops, being significantly more heavily contaminated than greywater from baths and showers. [3] reported that irrigation with insufficiently treated greywater is a practice that is mistakenly considered safe. They suggested that known surfactant concentrations in greywater range from 0.7 to 70 $mg.L^{-1}$ and that accumulation in soils can cause water repellence, affecting soil productivity.

Other authors such as [3], [4] have discussed the specific impacts upon soils of various greywaters used to irrigate them. The evidence seems to indicate lightly loaded greywaters as demonstrating a greater reliability in avoiding any unwanted and damaging effects on crops and soils. In contrast, the most heavily loaded greywaters have been observed to have very adverse effects causing death in both lettuce and okra [2].

Similarly, if the organic loading of greywater can be reduced by treatment, then that is likely to lead to less severe or less significant effects upon crops. Further research is needed to determine the extent of treatment needed for greywater from different sources, to achieve suitable parameters that reduce adverse impacts and encourage crop growth.

[2] reported that surfactants in irrigation waters containing detergents have been recognised as a major contributor to the reduction of hydraulic conductivity of soils. In the cases of irrigation water with higher detergent concentrations, more advanced soil degradation can occur, leading to water repellent soils. [4] showed that these have adverse impacts on agricultural productivity and environmental sustainability. The question of the application of dilute greywaters for sustaining GI appears less widely known.

1.3 Interior System Design/ Facilities Management.

In order for treated greywater to be used for sustaining GI and to confer the most significant water cycle enhancements, separation (or segregation) should be achieved at the earliest possible stage following use. Lightly contaminated domestic greywaters with only a light organic loading can be protected from becoming more extensively polluted by heavy organic contamination for example, from sewage. As a consequence, less complex systems are then required for greywater treatment to be available for irrigating GI.

1.4 External System Design and Implementation.

Designs for GI systems often aim to mirror and utilise natural processes. These include infiltration and evaporation basins, runoff control, storage for peak runoff, and detention and retention basins [5].

2. HISTORIC EVIDENCE OF GREYWATER CHARACTERISTICS APPLIED FOR SHORT TERM IRRIGATION; CONSEQUENT IMPACTS

[6] reported in Table 1 the key chemical characteristics of the potable and the greywater quality used in their irrigation and growth trials, during a growth period of 60 days.

Table 1. Greywater and tap water quality used in irrigation and growth trials [6]:

Sample	pH	Electrical conductivity (EC), uS/cm	Total Nitrogen, (TN) mg/L	Total Phosphate, (TP) mg/L
Grey water	10.5	1358.0	0.2	4.4
100% potable	7.0	277.0	0.16	0.0

[7] applied greywater with a pH in excess of 8.0 during some of their growth tests. The authors observed that greywater has the potential to increase the soil alkalinity if applied to gardens for a long period. However, [6] reported pH results in excess of 10.0 and described the phytotoxicity arising from greywater reuse being principally due to anionic surfactants altering the rhizosphere microbial communities. Such phytotoxicity effects arising from greywater reuse demonstrate significant variability according to the species type impacted.

In Table 2, the authors [2] provided Electrical Conductivity (EC) results in comparison to low, normal and high concentrations of surfactant, expressed in terms of $mg.L^{-1}$ of LAS. Of those three surfactant compositions, the greywater applied in [6] aligns more approximately with the EC of the Normal Concentration Surfactant used in [2]. The pH of the Normal Concentration Surfactant at pH 9.9 [2] also lies within a reasonably comparable range to the Greywater pH of 10.5 applied by [6].

Table 2. Constituents in greywater tests [2]:

Watering solutions	Distilled Water	Low Concentration Surfactant, $0.1\ g.L^{-1}$	Normal Concentration Surfactant $1.0\ g.L^{-1}$	High Concentration Surfactant $5.0\ g.L^{-1}$
pH	6.9	9.1	9.9	10.2
EC ($mS.cm^{-1}$)* unit assumed to be correct	28	159	1082	4870
Detergent as LAS ($mg.L^{-1}$)	Not Detected	13.5	135.6	678
N_{total} ($mg.L^{-1}$)	Not Detected	0.01	0.12	6.6
C_{total} ($mg.L^{-1}$)	Not Detected	15.3	153	765.1
P_{total} ($mg.L^{-1}$)	Not Detected	13.2	132.3	661.6

The increasing concentrations of detergent (LAS) gave rise to increasing pH and EC values, as well as increasing values of Total N, Total C and Total P.

3. STUDY RESULTS OF GREYWATER CHARACTERISTICS FROM MEDIUM TERM IRRIGATION USING TREATED GREYWATER

In comparison to the results of other authors shown in Tables 1 and 2, the University of Reading monitored growth trials using greywater irrigation during a six-month period from 2015 to 2016. The statistical mean values calculated from six-months of data are shown in Table 3. Irrigation was conducted using untreated greywater, treated greywater and the mains tap water control. The green wall boxes constructed as floor-standing structures were planted with sedum, to enable the evaluation of analytical variables producing potential growth effects that could then be specifically attributed to irrigation.

Table 3: Treated greywater and tap water quality monitored from 02/09/2015 to 02/03/2016, [8]

Sample	pH	Electrical conductivity (EC), µS/cm	Total Nitrogen, (TN) mg/L	Total Phosphate, (TP) mg/L
Treated greywater	7.6	669.9	4.5	0.02
100% potable (tap) water	7.8	520.2	0.5	0.01

Table 3 shows that the chemical characteristics of the greywater used in this project were based around the British Standard ‘recipe’ for synthetic test greywater [8]. This constituted a ‘lightly loaded’ greywater quality according to the EC and TP results, although the TN is significantly higher than the TN applied [6].

The potable (tap) water comprises the largest component of the synthetic greywater and so, unsurprisingly for a lightly-loaded greywater, the pH of the tap water and the pH of the greywater are very similar, as are the Phosphate results. The Electrical Conductivity (EC) is higher than that of the potable water which is due mainly to the organic and inorganic loading associated with the presence of the surfactants (detergents and shampoo), as well as the constituents of the treated sewage final effluent, or FE. The Total Nitrogen is also higher in the greywater than in the potable water due to the nitrogen content of the treated sewage effluent included the synthetic greywater recipe, as well as the bathroom products component.

Treated sewage effluent was not added for any reason of being representative of greywater, but rather; 1) because the synthetic mix requires a source of pollutants containing some similar components to shower greywaters, which follows the UK standard for Bacteriological Examination test procedures that would be difficult or impossible to replicate; 2) because the test procedure must challenge the greywater treatment system to demonstrate that higher bacterial loads are safely eradicated from the treated greywater by a satisfactory process.

4. GROWTH RESULTS REPORTED

In [2], the plant growth parameters in okra and lettuce were measured every week, including the dry weights of stems and leaves of all plants. Soil pH and soil EC tended to increase as the detergent concentrations increased in the irrigation solutions. There were no significant differences in okra’s fruit growth (fresh and dry weight) using Distilled Water (DW), Low Concentration (LC) and Normal Concentration (NC) treatments. However, plants in High Concentration (HC) treatments died 20 Days after Planting (DAP). No significant difference was noticed in lettuce shoots (dry weight) between LC, NC and DW treatments but lettuce in HC treatments died 12 DAP. The Electrical Conductivity measurements significantly increased in all the treatment regimes. Laundry detergent can inhibit plant growth and the application of greywater containing high concentrations of detergent can exacerbate soil salinity.

In [8], the green wall sedum plants watered by bathroom greywater during the 6 month experimental period in 2015 and 2016, showed a gradual decrease in size and plant health during the winter months. This applied to the plants in every test category of irrigation water, whether greywater, treated greywater or mains (potable) water. However, with the return of average ambient temperatures above approximately 10deg C, the growth in all the irrigation categories and soil types provided more leaf growth than in autumn 2015.

Sedum boxes that were kept in the greenhouse during the first 1.5 months of the trials [8] showed a significant increase in plant development and a higher growth volume during that period, than their external counterparts. Subsequently, those plants were moved to an external location in order to compare their respective performance during UK winter weather conditions with the plants that were already outside. The health of the latter group of plants decreased more quickly than that of the plants that had been outside from the beginning of the trials.

Fig. 1 shows that all plants had similar leaf Sodium concentrations at the start of the trials, followed by a reduction during the first two months of the trials. Subsequently, the Sodium was limited in plant material during the 6-month experimental period, in all the planted green wall boxes. This tends to suggest that any influence of Sodium ions on plant growth might be considered a secondary effect during the autumn and winter test period. The influence of cold and wet weather conditions over the winter period was the most likely cause of deteriorating plant health, since the watering regime also continued to use the same irrigation rates throughout.

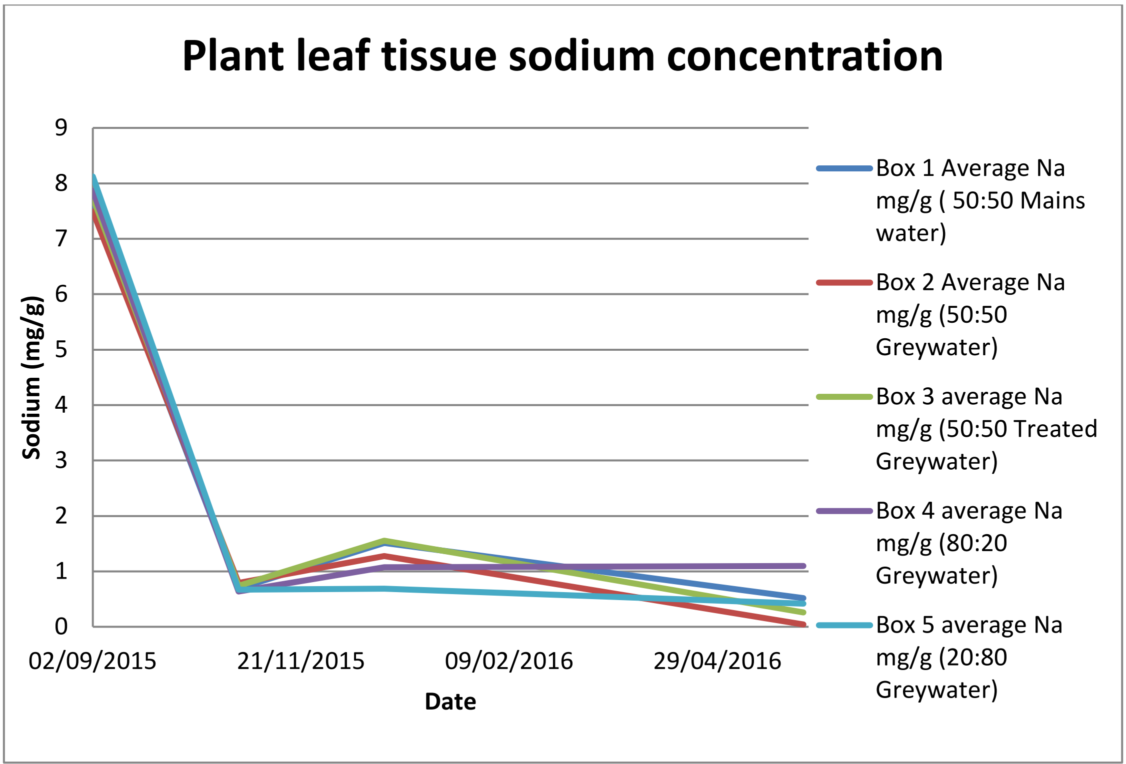

Figure 1: Longitudinal changes in plant leaf Sodium concentrations for differing watering regimes; '50:50' refers to a plant substrate of 50 parts growing medium to 50 parts compost; '80:20' refers to a plant substrate of 80 parts growing medium to 20 parts compost; and '20:80' to a plant substrate of 20 parts growing medium to 80 parts compost.

5. APPLYING CONTROLLED WATERS' PRINCIPLES TO GREYWATER DISCHARGES FOR SUSTAINING GREEN INFRASTRUCTURE

Academic evidence has established that greywater can affect crops and other green spaces when higher concentrations of detergent are applied (even producing plant death).The evidence from the Reading trials demonstrated that impacts from watering green boxes using dilute greywater, gave rise to only limited impacts during a winter period when the plants were stressed due to low ambient temperatures.

If significantly reduced impacts arising from low concentrations of detergent could be demonstrated, consideration would then be given to the concept of allowing treated greywaters to be liberally used for watering GI. [9] states that the EA does not require risk assessments for greywater discharges from domestic properties unless a trade discharge is included in the effluent, or there is a discharge to ground or surface water of more than 15 cubic metres per day, or the discharge to ground is more than 2 cubic metres per day and the location is within a groundwater Source Protection Zone, SPZ1 (an area of highest risk to groundwater quality).

[9] does not require screening tests if the water is discharged to the same river or groundwater that the water was originally taken from or if no hazardous pollutants are added to the water. This is potentially of assistance to small greywater discharges that contain no hazardous pollutants, since the greywater discharge could potentially support GI in the same area of the catchment.

The stages required for screening for a particular discharge include; identification of the pollutants released from the greywater treatment plant or source, gathering data on the environmental impacts of the pollutants prior to screening, undertaking the screening itself. This is likely to apply to discharges of greywater containing surfactants. Pollutants must be measured if they are hazardous and released to freshwaters, estuaries and coastal waters, or to sewers. The EA [9] specifies that pollutants could be present in the discharge if:

i) they have been detected by chemical analysis;

ii) they are allowed to be added to the discharge (eg water company trade effluent consent or discharges from installations);

iii) they have been added to the discharge by means of a treatment process (eg using iron or aluminium to remove phosphorus).

Membrane greywater treatment systems, such as that trialled at the University of Reading [8], do not normally introduce chemicals to the greywater as part of the treatment process. If this interpretation is correct, the quality of the treated greywater could potentially comply with EA requirements. However, substances, such as bathing and personal hygiene products, are introduced to greywater by human use. Routine testing may then be required to demonstrate that greywater is of a suitable quality for reuse.

The average flow rates, times and duration of discharge, eg 12 hours per day, will be required to be stated for assessing and monitoring compliance. The risks arising at the site are assessed, including the risks of the discharge creating environmental pollution and the sources of the risks. The assessment steps include [9]:

1. the identification of the receptors at risk from the site (people, animals, property etc);
2. the identification of the possible pathways from the sources of the risks to the receptors;
3. the assessment of the relevant risks to the specific activity; check they are acceptable;
4. the statement of the plans for controlling the risks if they are unacceptably high.

The risk assessment must be submitted as part of a permit application and a copy of the risk assessment must be included in the management system. The criteria for unsatisfactory overflows include; operating a breach of Permit conditions and/or causing a breach of water quality standards and other regulatory standards [9].

6. CONCLUSIONS AND REVIEW OF THE OUTCOMES OF GREYWATER TRIALS FOR IRRIGATING TO SUSTAIN GREEN INFRASTRUCTURE

The evidence from the authors cited and from [8] at the University of Reading, shows that lightly loaded greywaters can probably be used with confidence for watering certain types of green infrastructure. This is an important potential means for sustaining GI during times of water stress or drought.

For larger volume discharges, affordable system configurations for achieving licensable discharges to support GI need to be identified and approved. For smaller, domestic scale discharges, it appears that there is often little legislative barrier to direct irrigation using treated greywater.

Rationalisation of the technology configuration and thus the potential costs to be incurred, will provide an opportunity to carefully design and implement landscaping specifically to work in conjunction with a GI irrigation system, and to provide new greywater treatment capacity.

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ROOF WATER-FARM: A Multidisciplinary Approach to Integrate Wastewater Reuse with Urban Agriculture

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ABSTRACT

The Roof Water-Farm project (RWF) adopts an onsite resource cycle approach combining urban water management with urban farming in an attempt to close the loop. It investigates the local production of fresh food in urban settings via aquaponics and hydroponics linked to the qualitatively safe reuse of residential wastewater. Greywater from showers, kitchen sinks and washing machines is recycled for onsite reuse as a non-potable water source (toilet flushing, home gardening). The high quality recycled greywater is further reused to produce food (plants and fish). Recently, a pilot blackwater treatment plant turns the blackwater from 50 residents into a liquid fertilizer for use in hydroponic plant production.The building-integrated combination of water treatment with food production aims at making use of the spatial potential of buildings' roofs within an urban context, where space is usually limited or expensive. The project includes approaches for user participation, water-farm operation strategies and formats to promote acceptance for the technology in the urban environment. Initial research results on water and food (plants and fish) quality are presented here.

Keywords: Water recycling, greywater, blackwater, urban agriculture, aquaponics and hydroponics.

1. INTRODUCTION

Global demographic developments, poverty, water shortages and climate change are a few of many challenges facing our world today and resulting in radical infrastructural changes in urban areas. The inter-linkages between water and sustainable development go far beyond its social, economic and environmental dimensions. By 2050, global water demand is projected to increase by 55 %, mainly resulting from growing urbanization in developing countries [1].

Urban agriculture is associated with local production of food thus decreasing the "food miles" associated with long-distance transportation. In addition, it offers fresh seasonal products, adds greenery to cities and supports the local autonomy and social integration.

Wastewater is a resource for water, energy and nutrients and wastewater recycling is becoming increasingly important, especially in water-poor regions. Nevertheless, wastewater recycling today plays a less significant role in the residential sector than in the industrial sector.

Innovative greywater recycling concepts aim also at utilising the thermal energy in greywater as well as incorporating the high load greywater sources from washing machines and kitchens

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to produce high quality service water. The recycled water can be used for applications other than toilet flushing such as for laundry or, as in the Roof Water-Farm (RWF) project, for local fish and plant production.

A prominent example is the ECF Farm in Berlin. According to owner it is the largest urban aquaponics farm in Europe with a total of 1,800 m² floor area, where fish and vegetables are grown[1]. The first European pilot water-farm greenhouse, the Stensund Wastewater Aquaculture, which combines decentralized wastewater management with aquaculture and hydroponic production modules, was realized in 1989 at the Folk College Campus in Stensund, Sweden [2].

The RWF project aims at achieving high resource efficiency by closing the local material cycle. It further explores the potential of fresh food production in urban settings via hydroponics (water-based plant cultivation) and aquaponics (combined fish and plant culture), while being linked to water treatment technologies for greywater, blackwater and onsite rainwater management. Aquaponics saves water and space and is very well suited for urban areas. Treatment of blackwater aims at turning it into a liquid fertilizer (NPK) for use in hydroponic culture. This recovery could offset the scarcity of non-renewable phosphorus resources as well as bolster the local fertiliser supply [3].

How safe these products are grown with recycled water, is one of the key questions in this project. A further goal of the RWF project is to investigate the impact of interacting feedback cycles, with focus on water management and food production, on infrastructures, architecture and urban form, public space, urban land use and density as well as city life [4].

2. MATERIAL AND METHODS

2.1 Site description and plant setup

The study area, referred to as "Block 6", is a community-based dwelling in the centre of Berlin consisting of seven 3-4 storey residential buildings. Figure 1 shows the water activities in the RWF project.

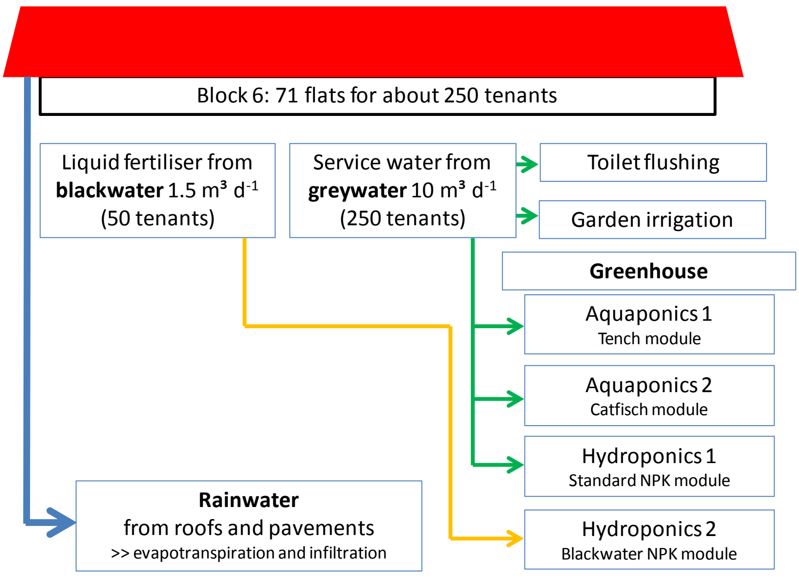

Fig. 1. Overview of the water activities in study area Block 6

[1] *http://www.ecf-farmsystems.com/*

Rainwater originating from 2,350 m² of roof surface area and 650 m² of sealed open space is currently disconnected from the municipal combined sewer and discharged onsite into a constructed wetland. The collected rainwater is eventually subjected to evapotranspiration (cooling effect approx. 680 kWh m^{-3} of rainwater) or a time-delayed infiltration in an adjacent trough following heavy rain events.

2.2 Greywater recycling

The infrastructure in Block 6, which exists since 1987, includes water saving measures and a dual-piping system for the separate collection of greywater and blackwater as well as an inoperative constructed wetland [5]. In 2006/07 a reconstruction/optimization phase followed, in which an advanced greywater recycling system was installed and a new rainwater management concept was developed.

Greywater from showers, bathtubs, hand washbasins, kitchen sinks and washing machines collected from 71 flats (250 tenants) undergoes an advanced, aerobic mechanical-biological treatment in a multi-stage moving bed biofilm reactor (MBBR). The system consists of 10 polyethylene (PE) tanks connected in series, each with a capacity of 1.4 m^3 designed to treat about 10 m^3 of greywater daily. The effluent is fed into a sand filter for final polishing followed by UV disinfection to yield a high quality, non-potable water (service water), which is reused to flush 90 toilets and irrigate home gardens. No chemicals are used at any stage of the treatment process. The decentralised greywater recycling process shows high operational stability since almost 10 years.

The RWF project, which was launched in 2014, uses the treated greywater with bathing water quality [6] for the production of plants and fish (aquaponics, hydroponics) in an adjoining greenhouse built for this purpose. A third component of the RWF project is the treatment of blackwater (from toilets) and its safe reuse as a liquid fertiliser for the hydroponic cultivation of fruits and vegetables in the greenhouse.

2.3 Blackwater recycling

Blackwater is pumped from a collection tank installed at the basement of one of the residential buildings providing partial equalization to the roughly 50 P.E. worth of flowrate generated by the 20 apartment units.

The treatment train consists of a 1 mm sieve, followed by two aerated 800 litres moving bed biofilm reactors (MBBR) and an aerobic membrane bioreactor (MBR: 6.25 m² flat-sheet ultra-filtration module, MARTIN Membrane Systems AG, Schwerin, Germany). Treated effluent is collected in a storage tank, from which it is pumped to the greenhouse as needed. The MBR is operated on a semi-batch basis, whereas the MBBR as a batch reactor.

2.4 Aquaponics and hydroponics

The 50 m^2 greenhouse (pilot water farm) which is connected to the decentralised wastewater treatment plant is divided into two test tracks. The aquaponics system consisting of 2 miniature aquaponics modules use the service water originating from the greywater treatment plant for fish farming and plant breeding. Each aquaponics module consists of the (plant) components fish tank, sedimentation, plant channels, water storage tank and biological filter (Figure 2). Overall size of an aquaponics module is 6 m², of which 3 m² are for plant cultivation. Both modules are identical in their system design as well as plant stocking. They differ only in their fish stocking, with one module containing catfish (*Clariasgariepinus*) and the other tench (*Tincatinca*).

The hydroponics system consists of 2 hydroponics modules (ebb and flow system) which use liquid fertiliser for plant breeding. The plant cultivation size for each module is 5 m². One module runs with the liquid NPK fertiliser originating from the blackwater treatment plant (BW-NPK module), while the other module runs with a conventional hydroponics liquid complex fertiliser (standard-NPK module). The plant stock is similar to that in the aquaponics system in order to compare all modules in the pilot water farm.

Fig. 2. The greenhouse harbouring the aquaponics and hydroponics systems

3. Analytical methods

3.1 Chemical and physical analyses

Online greywater monitoring was carried out using the following devices: Hach Luminescent Dissolved Oxygen Sensor (LDO) for oxygen, Hach Ultraturb for turbidity and Dr. Lange BDA 256 for the Spectral Absorption Coefficient (SAC). Dissolved Oxygen (DO) of fresh samples was measured using Dr. Lange ECM Multi type LXG090. Turbidity was measured for fresh and settled samples (2h) using a portable WTW Turb 430 IR Turbidity Metre.

Chemical Oxygen Demand (COD), phosphorus (P) and nitrogen (N) measurements of settled samples were carried out photometrically using Dr. Lange LASA 100 and quick test cuvettes. Dissolved Organic Carbon (DOC) for filtered samples was measured using LAR Quick TOC (LAR Process Analysers AG, Berlin, Germany). Biological Oxygen Demand (BOD) was determined in fresh settled samples using WTW OxiTop®Control OC 110.

Composite samples of influent and effluent were collected periodically to assess the extent to which N and P were conserved in the system. Measurement of volatile suspended solids (VSS) and total suspended solids (TSS) were performed in accordance with standard methods.

In the aquaponics and hydroponics systems, water was tested in every single module in 14-day intervals and products at the end of the growth period for quality.

3.2 Quality control analysis

An extensive analytical monitoring programme was carried out to test the product quality performance. Analyses for microbiological parameters (enterococci, total coliforms, *E. coli*) as well as selected micropollutants and heavy metals were done in several accredited laboratories for water and food samples. Plants and fish were also tested regularly for vitality and growth behaviour.

4. RESULTS AND DISCUSSION

4.1 Greywater recycling

Online monitoring of daily volumes of greywater inflow (GW), average temperatures and service water (SW) quality (turbidity, DO and SAC) are shown in Figure 3.

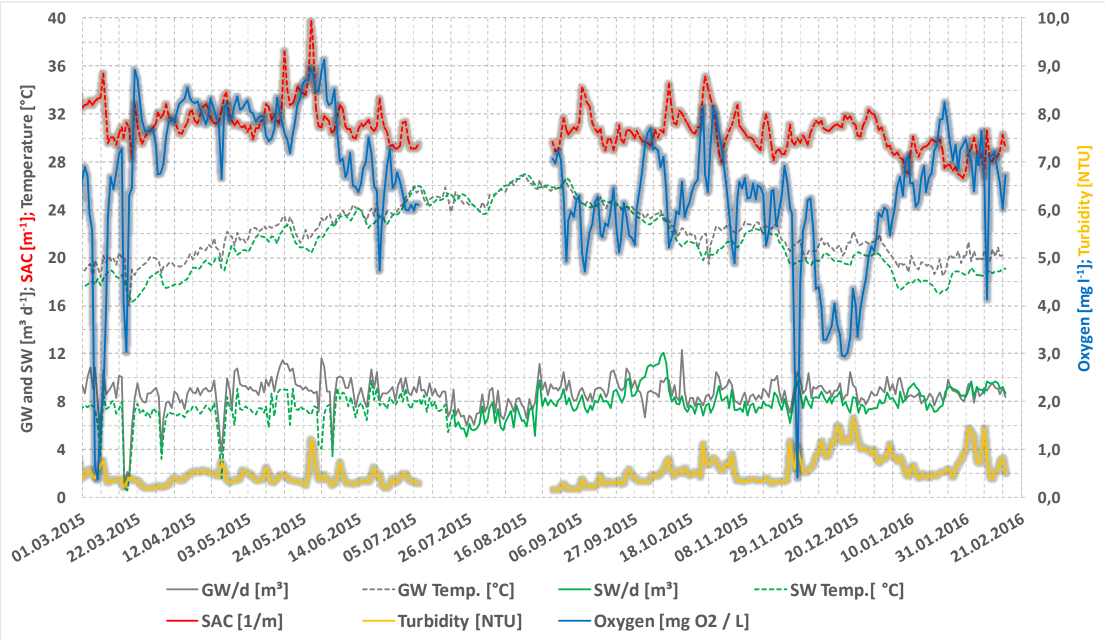

Fig. 3. Online monitoring of the greywater recycling plant (between July and August, monitoring was interrupted due to a power cut)

The greywater treatment system shows high operational stability. On average, about 8.6 m^3 of greywater were treated daily, of which 7.5 m^3 were reused for toilet flushing. Turbidity of service water was low (< 1NTU) and oxygen saturation achieved concentrations above 5 mg L^{-1} (at 22.2°C), while SAC showed soft peaks, when more than 10 m^3 d^{-1} had been treated.

The main goal of greywater treatment is the degradation of the organic matter, which is the major pollutant load of greywater. Independent sampling campaigns conducted by Sievers et al. [7] showed an average of 77 L P^{-1} d^{-1} of greywater entering the above recycling system. Table 1 shows average greywater influent and treated effluent concentrations of the measured chemical parameters compared to those from the effluent of municipal wastewater treatment plants (WWTPs) in Berlin [8, 9]. Compared to municipal wastewater, the organic load of raw greywater (homogenised samples) was higher (BOD_5 = 460 mg L^{-1}; COD = 858 mg L^{-1}), while lower concentrations of phosphorus (TP = 4.7 mg L^{-1}) and nitrogen (TN = 16.2 mg L^{-1}) were measured in greywater as had been expected. COD in municipal wastewater is only reduced to about 40 mg L^{-1}, whereas this was already achieved in reactor 5 of the greywater recycling plant (Figure 4).

Following initial sedimentation and sieving, the organic load in greywater was reduced to between 40 - 50%. Total suspended solids (TSS) as well as sludge produced during the biological treatment, which amounted to 69.5 g m^{-3} (approx. 2.3 g P^{-1} d^{-1}), are quite considerable and can be given in the future to a biogas plant.

Table 1. Average greywater influent (24-h composite, settled, homogenised samples; n=10) and effluent concentrations, compared to municipal WWTPs in Berlin [8, 9]

		Greywater System		Municipal WWTP	
Parameter	**Unit**	**Influent**	**Effluent**	**Influent**	**Effluent**
TSS	mg L^{-1}	113	**< 0.1**	387	5.8
Turbidity	NTU		**< 1**		
BOD_5	mg L^{-1}	460	**<5**	218	3.8
COD	mg L^{-1}	858	**25**	610	40
TOC	mg L^{-1}		**7 - 10**	54	12,2
TN	mg L^{-1}	16.2		72	
NH_4-N	mg L^{-1}	2.7	**< 0.03**	45	0.9
NO_3-N	mg L^{-1}		**3.5**		6.9
TP	mg L^{-1}	4.7		16	0.3
PO_4-P	mg L^{-1}	1.6	**1.5**		0.09

The performance of each reactor (R1 - R9) in the degradation of organic matter in greywater was investigated by measuring DOC reduction in each reactor (Figure 4). The degradation rates of organic matter in the final treatment stages (R6 – R9) were low. Nevertheless, these stages contribute crucially to the final high service water quality as well as to the low maintenance expenditure (approx. 3-4 days per year), even under conditions of temporary influent peak loads.

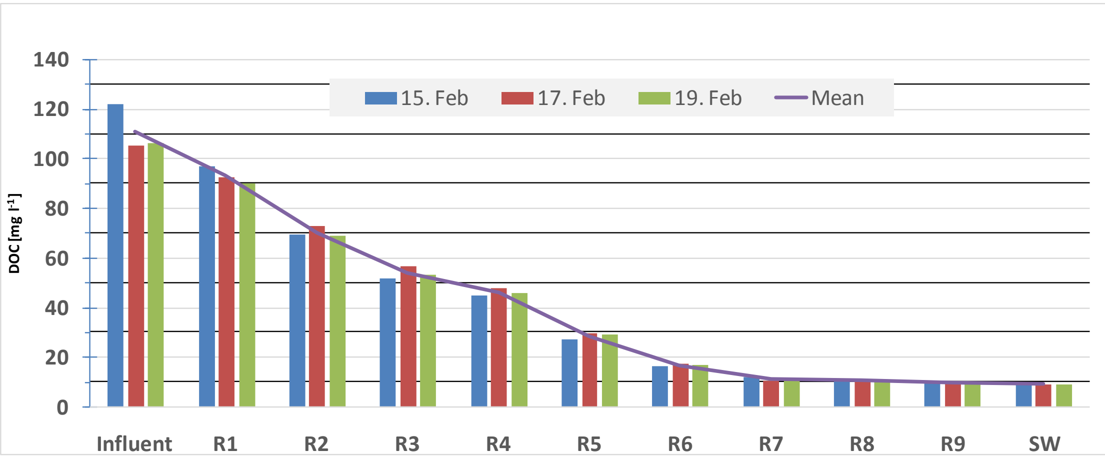

Fig. 4. Biological greywater treatment in terms of DOC-reduction (mg l^{-1}) in 24 h composite samples in the different reactors (R1-R9) of the greywater recycling plant

4.1.1 Micropollutant analyses

Presence of micropollutants in wastewater is largely dependent on the wastewater origin. In this study, several micropollutants (e.g. contrast agents, beta-blockers, etc.), which are commonly found in sewage were not detected in greywater (Table 2). Others, such as the corrosion inhibitor Benzotriazole and other household chemicals were found in lower or comparable concentrations as in municipal wastewater. Of interest in this study is the biodegradation of the artificial sweetener Acesulfame in R7 of the MBBR system, which is known to be non- or poorly biodegradable in municipal WWTPs [10]. Influent concentrations of

> 15 µg L^{-1} were reduced to < 1.5 µg L^{-1}. Similarly, the anti-inflammatory agent Diclofenac, which is usually poorly removed in conventional systems, was reduced from 3 to < 0.7 µg L^{-1}.

Table 2. Concentrations of micropollutants from 24 h composite samples in the different stages of the greywater MBBR system and in the influent and effluent (SW)

Stage of biological treatment	Acesulfam	Atenolol	Amidotrizoe-säure	Benzotriazol	Bezafibrat	Carbamazepin	Diclofenac	4-Formylamino-antipyrin	Gabapentin
	LoQ 0.25	LoQ 0.1	LoQ 0.1	LoQ 0.1	LoQ 0.05	LoQ 0.05	LoQ 0.1	LoQ 0.1	LoQ 0.05
	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
SW	1.29	n.n.	n.n.	17.36	n.n.	0.153	0.67	n.n.	0.283
R 9	2.38	n.n.	n.n.	14.38	n.n.	0.218	1.05	n.n.	0.321
R 8	2.07	n.n.	n.n.	17.10	n.n.	0.169	1.33	n.n.	0.326
R 7	2.87	n.n.	n.n.	19.97	n.n.	0.217	1.73	n.n.	0.440
R 6	11.89	n.n.	n.n.	24.85	n.n.	0.189	1.87	n.n.	0.522
R 5	10.70	n.n.	n.n.	21.55	n.n.	0.158	1.57	n.n.	0.624
R 4	11.94	n.n.	n.n.	20.68	n.n.	0.166	2.41	n.n.	0.582
R 3	15.99	n.n.	n.n.	25.75	n.n.	0.145	1.95	n.n.	0.569
R 2	18.68	n.n.	n.n.	24.41	n.n.	0.176	1.99	n.n.	0.589
R 1	16.57	n.n.	n.n.	22.77	n.n.	0.185	3.17	n.n.	0.639
Influent	14.200	n.n.	n.n.	20.019	n.n.	0.205	3.11	n.n.	0.593

Stage of biological treatment	Gabapentin-Lactam	Iomeprol	Iopromid	Methylbenzo-triazol	Mecoprop	Metoprolol	Primidon	Sulfmethoxazol	Valsartan	Venlafaxin
	LoQ 0.05	LoQ 0.1	LoQ 0.1	LoQ 0.05	LoQ 0.05	LoQ 0.01	LoQ 0.5	LoQ 0.05	LoQ 0.1	LoQ 0.05
	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
SW	0.210	<LoQ	<LoQ	0.876	n.n.	0.350	n.n.	n.n.	n.n.	n.n.
R 9	0.231	<LoQ	<LoQ	0.899	n.n.	0.285	n.n.	n.n.	n.n.	n.n.
R 8	0.189	<LoQ	<LoQ	0.938	n.n.	0.340	n.n.	n.n.	n.n.	n.n.
R 7	0.139	<LoQ	<LoQ	1.057	n.n.	0.310	n.n.	n.n.	n.n.	n.n.
R 6	0.076	<LoQ	<LoQ	1.391	n.n.	0.464	n.n.	n.n.	n.n.	n.n.
R 5	0.107	<LoQ	<LoQ	1.156	n.n.	0.412	n.n.	n.n.	n.n.	n.n.
R 4	0.094	<LoQ	<LoQ	0.718	n.n.	0.338	n.n.	n.n.	n.n.	n.n.
R 3	0.068	<LoQ	<LoQ	0.577	n.n.	0.455	n.n.	n.n.	n.n.	n.n.
R 2	0.084	<LoQ	<LoQ	0.399	n.n.	0.425	n.n.	n.n.	n.n.	n.n.
R 1	0.097	<LoQ	<LoQ	0.376	n.n.	0.355	n.n.	n.n.	n.n.	n.n.
Influent	0.095	<LoQ	<LoQ	0.370	n.n.	0.254	n.n.	n.n.	n.n.	n.n.

No elevated heavy metals concentrations were detected in service water. Merely, elevated concentrations of copper (2,461 mg kg^{-1}) were measured in the greywater sludge, which exceeded the limit of the Sewage Sludge Ordinance [11] of 800 mg kg^{-1} dry matter. These high values may have originated from the drinking water pipes, which are usually made out of copper.

4.1.2 Microbiological analyses

Table 3 shows the results of the microbiological parameters for greywater and blackwater influents and effluents as well as the resulting liquid fertilizer, compared to the effluent of municipal WWTPs in Berlin. As expected, influent concentrations of faecal bacteria were highest in blackwater. Although no toilets are connected to the greywater system, relatively high concentrations of total and faecal coliforms were found in greywater, which almost lie in the range of those found in municipal sewage.

Table 3. Microbiological results for all water flows in the RWF project (typical bacterial concentrations; values per 100 ml), compared to municipal wastewater effluent

	Total coliforms	*E. coli*	Enterococci
Greywater influent	$1x10^7$ - $1.8x10^7$	$7.5x10^5$ - $1.4x10^6$	$5.5x10^3$ - $4x10^4$
Service water	**36 - 473**	**2 - 3**	**0**
Blackwater influent	10^9	$7x10^8$	$1.95x10^7$
Liquid fertiliser from blackwater	**56**	**2**	**0**
Effluent of municipal WWTP (Berlin)		10^4 - 10^5	10^3 – 10^4

4.2 Blackwater recycling

At the time measurements were conducted on the blackwater recycling system, no steady state was yet established, since plant operation had to be repeatedly interrupted due to the presence of atypical solids in blackwater such as small plastic parts and textiles.

As can be seen in Table 4, the measured influent N and P concentrations in blackwater in Block 6 are significantly lower than those found for blackwater in literature [12]. At the present time it is not clear whether the low nutrient concentrations in blackwater influent are due to the presence of fewer tenants during the day, such that only a small fraction of the blackwater stream from the connected apartments end up in the blackwater recycling system. For more clarity, further optimisation and research work is needed.

Table 4. Calculated influent concentrations of COD and nutrients in blackwater based on data from the literature compared with data from Block 6

		undiluted [12]				urine + faeces + 30 L toilet flushing water			
		Urine		Faeces		Blackwater		Block 6 [13]	
			mg l^{-1}		mg l^{-1}		mg l^{-1}	mg l^{-1}	%
Quantity	L P^{-1} d^{-1}	1.37		0.14		31.5			
COD	g P^{-1} d^{-1}	10	7,299	60	428,571	70	2,222	**1,929**	**86.8**
N	g P^{-1} d^{-1}	10.4	7,591	1.5	10,714	11.9	378	**283**	**74.9**
P	g P^{-1} d^{-1}	1.00	730	0.5	3,571	1.5	48	**32**	**66.5**
K	g P^{-1} d^{-1}	2.5	1,824	0.7	5,000	3.2	102		
S	g P^{-1} d^{-1}	0.7	511	0.2	1,429	0.9	29		

However, preliminary results showed that the clear, gold-coloured blackwater effluent (liquid fertiliser) was free from suspended solids and odour and the measured COD concentrations were always below 100 mg/l.

4.3 Aquaponics and hydroponics systems

The pilot water farm with 2 test tracks (aquaponics and hydroponics) was investigated during two seasons (from April 2014 to October 2015). The greenhouse is not heated or additionally illuminated. The duration of a plant cultivation period is 5 weeks on average. Fish stocking occurred per season and the duration of the fish cultivation period is 6 months, which allows for 5 plant cultivation periods. The yield of the catfish test track was higher than in the tench test track.

In the 4 modules different lettuce yields were obtained. The aquaponics modules (tench and catfish) were not as profitable as the hydroponic modules (BW-NPK and standard-NPK). However, among the two hydroponics modules only small differences in the yield were observed. Compared to conventional market lettuce, yield in all modules was lower.

The variable yields in the different modules can be attributed to the different nutrient concentrations in the circulating water. The circulating water in the aquaponics modules (tench and catfish), which is service water originating from the greywater treatment plant and which also contains NPK from fish food and excrements showed lower NPK concentrations compared to the hydroponics modules (BW-NPK and standard-NPK).

Lettuce grown under the different modules was examined for nitrate and certain heavy metals as prescribed for lettuce grown under glass [14]. Nitrate concentrations were below the maximum guideline levels, whereas the heavy metals lead, cadmium and mercury were not detected in the cultured lettuce.

The harvested products (fish and lettuce) from the different modules were tested for possible contaminant residues. Despite the presence of very low concentrations of certain micropollutants in the irrigation water, these were neither detected in fish nor in lettuce.

4.3.1 Microbiological analyses

In both aquaponics modules the microbial load was slightly elevated compared to DIN 19650 for irrigation water [15]. Since the initial irrigation water (service water from greywater) is only lightly polluted and according to DIN, the modules are designed as open systems, the slight increase in the microbial load is probably due to contamination by persons involved in the projects or visitors. The hydroponics modules (BW-NPK and standard-NPK) also showed microbial values during the cultivation period which fall within the tolerances set out in the DIN standard. The microbiological quality of harvested lettuce from all modules meets the recommended requirements of the German Society for Hygiene and Microbiology (DGHM) for food [16], and is therefore suitable for human consumption.

5. CONCLUSION

Based on the initial research studies, recycled greywater is well suited for use in aquaponics and hydroponics systems. The above greywater recycling system, which also treats high load greywater from laundry and kitchen, shows high operational stability, low maintenance and provides a high-quality service water effluent for reuse.

Generally speaking, nutrient recycling and/or removal of micropollutants (pharmaceutical products, pesticides) from wastewaters can be easier and more effective prior to its dilution with other wastewater streams. Initial results from the blackwater recycling and food production activities are promising. However, to achieve a higher nutrient recovery from blackwater and to assess the transferability of urban farming concepts from single buildings into an embedded neighbourhood, more research and optimisation work is still needed.

The integration of greenhouses in the urban environment can contribute to a lower carbon footprint (CF) as a result of reduced transportation routes for food products. Also the reuse of the waste heat from wastewater can further contribute to a lower CF and higher system efficiency. Studies have shown that even during the cold winter months about 10 - 15 kWh of thermal energy per cubic metre of greywater can be recovered daily to warm the greenhouse [17].

Considering the high costs for a new centralised wastewater infrastructure in the city, in some cases more than 6,000 €/person [18], decentralised and multifunctional infrastructure systems can offer alternative solutions to centralised ones. The planning process for decentralised systems, which usually involves a more complex building technology, offers several benefits over conventional systems in terms of less infrastructure and operations costs in addition to environmental benefits. Onsite water recycling and urban farming combined can help ease pressure on the environment and close the material loop.

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Water Efficiency Conference 2016

Evaluating FlushRain Retrofittable Rainwater Harvesting: A Pilot Study

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ABSTRACT

Aims: To evaluate a novel rainwater harvesting (RWH) system in a real-world setting.
Study design: A RWH system (FlushRain) was retrofitted to a house and monitored.
Place and Duration of Study: Exeter, UK. 12 months to October 2015.
Methodology: Meters and data loggers were used to record water savings, electricity consumption, rainfall and rainwater temperatures. Calculations were used to establish potential cash savings, and reductions in stormwater discharges.
Results: Monthly water savings were highly dependent on rainfall yields as the small tank volume was quickly emptied by the users. Annual water savings equated to 15m^3 (£83 saving) despite a relatively small tank capacity (280l). Energy consumption was higher than expected at 3.08kWh/m^3 (£6.95 cost). This was linked to the high standby-power consumption of the control-board rather than the cost of pumping water into the tanks. Capital costs for future installations have been estimated at approximately £1000 giving a simple payback period of approximately 12 years. Despite concerns that roof-located water tanks may experience higher water temperatures than below ground systems, mean monthly tank water temperatures were reported in the range of 11.5-20.6^{o}C. Widely used chemical toilet treatments were used at the point of use to mitigate any potential risks associated with using rainwater in WCs. No frost issues were observed during the study with a minimum temperature recorded at 7.7^{o}C.
Conclusion: A novel RWH system was installed and its performance monitored. Financial savings in areas with frequent rainfall (and high water costs) are sufficient to offset the cost of installation with a payback period of 12 years. Significant rainwater discharge reductions were achieved (38% annually) as a result of the system's installation.

Keywords: Rainwater Harvesting, Retrofit, Stormwater Control, SuDs, Water Efficiency.

1. INTRODUCTION

Rainwater harvesting (RWH) in the UK is an infrequently used technology that is often cited as a low cost option that can provide stormwater control and water efficiency benefits. Melville-Shreeve *et al.* [1] undertook a detailed review of novel RWH technologies and demonstrated that they are able to help mitigate a range of potential threats such as drought, increasing energy costs and stormwater flood risk. Novel systems were identified which warrant evaluation and monitoring to establish their holistic value when considered from a range of lenses. Leading on from a laboratory study described in Melville-Shreeve *et al* [2], this study investigates the viability of small-scale, loft-based RWH systems to provide rainwater as an alternative water resource. Previous work [2] showed that the prototype FlushRain RWH (FRWH) configuration worked within a laboratory setting and tested the system's characteristics in terms of maximum pumping head and electrical consumption. This study extends the laboratory work by investigating the real-world deployment of the technology at a house in Exeter, UK. As part of a wider project, two further properties were installed with FRWH. However, data from these properties is not presented here and this study reports on data from the property with the highest occupancy (four residents) and least gaps in data availability (<1 month of data logging failure).

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2. MATERIALS

In accordance with the UK's British Standard for RWH [3], systems are designed to provide non-potable water for WC flushing, laundry use and garden watering. Here we investigate a FRWH system that was solely installed to feed the upstairs WC. The property also had a downstairs WC, which was not fed by rainwater as retrofit plumbing costs were considered prohibitive and the homeowner confirmed the upstairs WC was more frequently used.

2.1 THE FLUSHRAIN (FRWH) SYSTEM

Comprehensive details of the product tested are described in laboratory assessment work in Melville-Shreeve *et al.* [2]. The FRWH system evaluated here included a loft-located suction pump, which draws water from downpipe chambers into a header tank with a 280l functional volume. A control-board enabled the pump to activate and empty the downpipe collectors into the tank when rainfall was detected. Rainwater stored in the loft tank was fed under gravity to the upstairs WC. The system is described and illustrated in Figures 1 and 2.

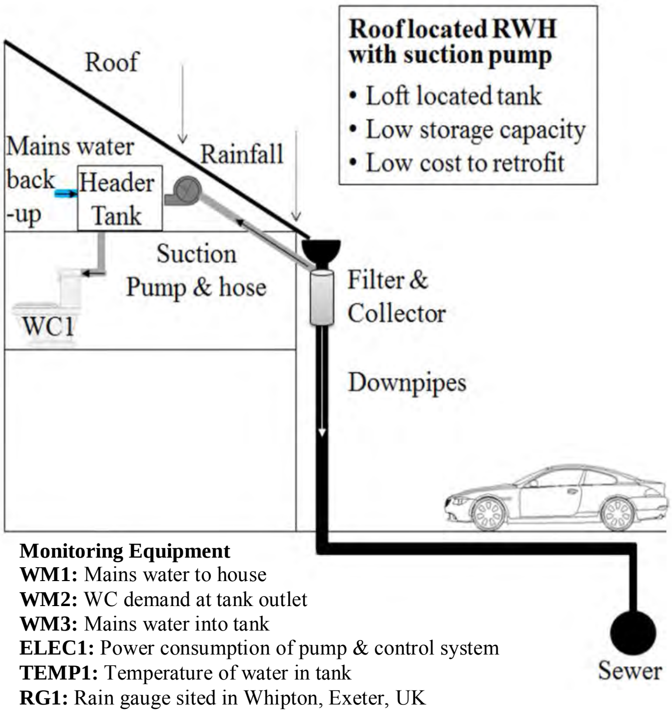

Fig 1. FlushRain configuration and monitoring equipment installed at the trial site

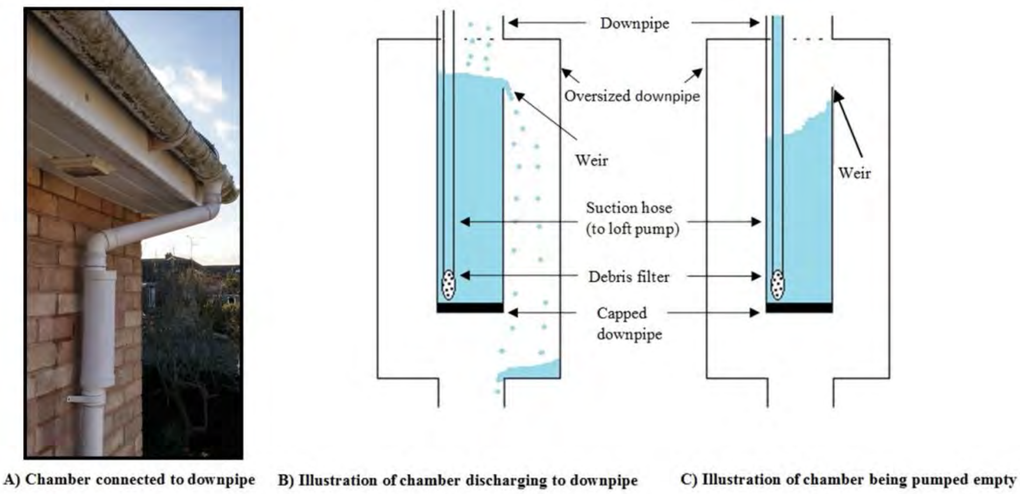

Fig 2. Illustration of the FlushRain collection chambers

3. METHOD

The study ran for 12 months (Oct 14-Oct 15) and sought to answer the following research questions:

RQ1: What reduction in annual water demand was achieved by deploying the FRWH system? This was assessed in terms of total rainwater used (m^3/annum) and percentage of total household water demand. Three volumetric water meters (with data loggers capturing usage in 1l increments at 15 minute intervals) were installed at each property as illustrated in Fig 1. These measured; Total household mains water demand (WM1); Total mains water top-up entering the rainwater tank (WM2); and total water used for (upstairs) WC flushing (WM3). A fourth "virtual water meter" (WM4) was calculated by subtracting WM2 from WM3 for each 15 minute time step. Manual water meter readings were also taken during monthly site visits over a 380 day period. Data processing allowed data to be viewed at daily, monthly and annual time-steps.

RQ2: What electricity consumption was needed to operate the FRWH system? This was evaluated by taking monthly readings of electrical power consumption (kWh) at the control-board for the system. This data was analysed alongside the water meter outputs to identify the electrical consumption in kWh/m^3.

RQ3: What were the highest and lowest temperatures experienced in the header tank? This question was set to enable risks associated with frost damage and legionella growth to be further evaluated. A temperature logger was installed below the minimum water level in the rainwater tank to capture this data at a 15 minute time step.

RQ4: What proportion of annual rainfall was captured and used by the FRWH system. This research question enabled empirical evaluation of the RWH system's ability to contribute towards stormwater discharge reductions entering downstream combined sewer networks.

4. RESULTS AND DISCUSSION

Results and discussion of each research question is investigated in the following sections.

4.1 RQ1: What reduction in annual water demand was achieved by deploying the FRWH system?

The data logging outputs included 35 days of corrupted data over the 365 day study. This was removed from the analysis during pre-processing. The remaining logger data indicated that total household (mains) water demand averaged 337l/d (111m^3/yr) with a maximum of 676l/d. The mean WC (upstairs) consumption was 88l/d of which 40l/d was provided by rainwater. This suggests the FRWH system achieved a total water demand reduction 14,600 l/yr or 11.6% of total household water demand. A review of manual water meter readings illustrated that the data loggers slightly under-recorded rainwater usage by 3% when compared with the manual readings over a 380 day period.

The manual water meter reading data indicates that 15,042l of rainwater was saved in a single year. At a cost of £5.52/m^3 [4], an £83 reduction in the annual water bill was calculated. Although capital costs for the pilot installation were notably higher, the target cost of future installations has been estimated at approximately £1000. At this price point, a simple payback period of 12 years would be achieved, assuming water prices remain static and maintenance costs are not included.

4.2 RQ2: What electricity consumption was needed to operate the FRWH system?

Previous work demonstrated that the system's pump can deliver 1m^3 using 0.12kWh of electricity in a lab setting [2]. Data from the trial site showed an average usage of 3.08kWh/m^3 was required to supply the rainwater over a 380 day period. Rainwater usage and power consumption were poorly correlated (i.e. months with low rainwater use still experienced high power consumption). Data from the trial site concurs with work done at a laboratory scale [2] which suggested that high electricity consumption for the control-board is the largest contributor to system's electricity consumption (£6.95/year).

4.3 RQ3: What are the highest and lowest temperatures experienced in the header tank?

Temperatures recorded within the header tank are shown in Fig 3 for the 12 month study. A maximum summer temperature of 25.3^{o}C was recorded with a minimum of 7.7^{o}C during winter. Fig. 3 also shows vertical spikes where the temperature reduces suddenly as a result of rainfall entering the tank. This data suggests that (in the absence of a rainfall event) the water within the tanks slowly increases in temperature, i.e. it is heated by the sun and potentially captures heat from the property below during cold periods. The loft tank was located within a “cold roof” (i.e. one which is not insulated) and was individually insulated using a standard cold water tank insulation blanket provided by Polytank. It is anticipated that this insulation reduced the risk of the water freezing in the winter whilst slowing the increase in temperatures during the hottest days. This in turn is likely to inhibit legionella growth within the tank which reaches its highest virulence at around 37^{o}C [5]. It is further noted that mains water top ups (i.e. chlorinated water) entered the tank on 262 days during the study, although the effect of these inputs on the quality of water in the tank are not further investigated here.

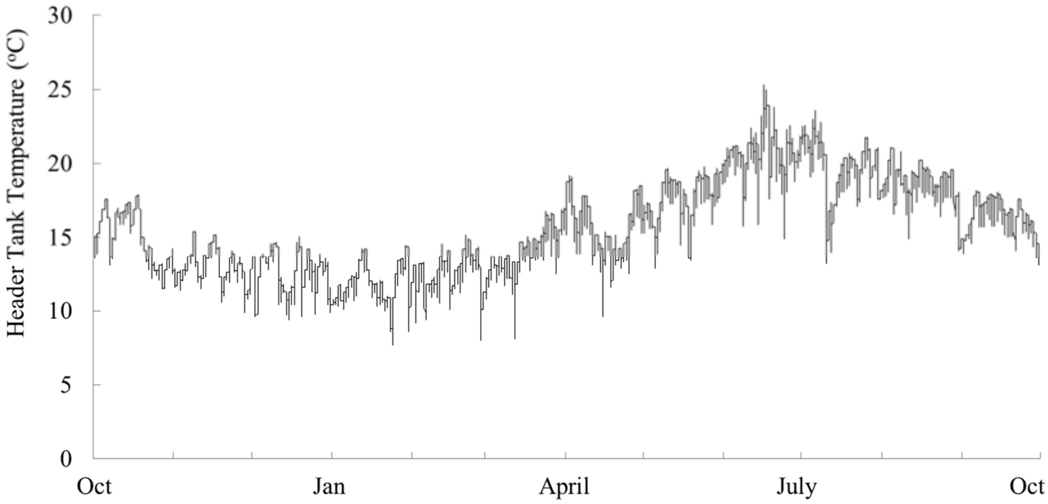

Fig 3. FlushRain rainwater tank temperatures (October 2014-October2015)

4.4 RQ4: What proportion of annual rainfall was captured and used by the FRWH system.

The potential for stormwater management benefits associated with RWH are increasingly being recognised by industry and academic studies [1][3][6][7]. The added benefits to stakeholders (e.g. stormwater management authorities) of using RWH to manage stormwater poses a significant opportunity for further empirical studies. The roof of the trial site had a plan area of 55m^2. Rain gauge data for a nearby site [8] was analysed. The rain gauge showed 169 rain-days comprising a total annual volume of rainwater available to the property 39,546l (assuming average loss coefficient of 10% and a 5l/d loss for first-flush losses).The most rainwater available to the FRWH system in a single day was 1,871l (24/7/2015). Data loggers show the rain tank was empty at the beginning of this storm and full after the event. The FRWH system’s capacity of 280l reduced the peak discharge from this storm by 15%. Over the year monitored, the property used 15,042l of rainwater. This reduced the total annual stormwater discharges by 38% in comparison to an equivalent property without FRWH installed.

5. CONCLUSION

The following conclusions were delivered from this study; 1) The FRWH system was successfully installed to feed the upstairs WC at a trial site in Exeter with four occupants and a roof of 55m^2; 2) Potable water demand for the WC was reduced by 15,042l over the one year monitoring period; 3) Cash savings of £83 were realised assuming a water cost of £5.52/m^3; 4) Future installations could achieve a 12 year payback period assuming the data collected for the study is representative of long term functionality; 5) Electrical consumption was identified as reaching 3.08kWh/m^3 due to high power consumption of the control systems; 6) Mean monthly tank water temperatures were observed in the range of 11.5-20.6^{o}C; 7) The largest annual storm was reduced in volume by 15% with total annual stormwater discharges reduced by 38%.

ACHNOWLEDGEMENTS

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COMPETING INTERESTS

The authors of this paper conducted this research on an independent basis on behalf of the University of Exeter at the request of the patent holder for the system. A research contract between FlushRain ltd and University of Exeter Consulting Ltd. was set up to allow the University of Exeter to be remunerated for staff time and laboratory costs associated with the study.

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Water Efficiency Conference 2016

Improving Efficiency of Integrated Urban Water Systems Using Smart Rainwater Harvesting Schemes

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ABSTRACT
This paper aims to explore the potentials of the new concept of using smart technologies in rainwater harvesting (RWH) schemes and their impact on the improvement of the integrated urban water systems (UWSs) efficiency. The smart equipment enables RWH tanks to proactively control water level and allocate water to different applications using a real-time control system. The multi-purpose RWH tanks can mitigate local floods by collecting the rainwater during rainfall events and use the collected water for domestic consumption. Multi-objective optimisation is used to identify optimal operation of different tank configurations to control the storage volume of the tank according to water demand and seasonal inflow variations. The efficiency of the proposed methodology is demonstrated through modelling a real case of integrated UWS using the WaterMet^2 simulation model. The results of the Pareto solutions obtained for various RWH tank configurations indicate that using smart RWH schemes, compared to conventional, non-smart schemes, improves the UWS efficiency in terms of reliability of both the water supply system and the excess stormwater in sewer systems.

Keywords: Urban water systems, rainwater harvesting scheme, smart technologies, real-time control.

1. INTRODUCTION
Assessment of sustainability-based performance of various strategies in the integrated urban water system (UWS) indicates that high ranked intervention strategies are those supporting all water supply, stormwater and wastewater subsystems such as rainwater harvesting (RWH) and greywater recycling schemes [1]. In addition, water recycling schemes in urban water management have received a lot of attention in the recent decades as a reliable alternative water resource [2]. In particular, the RWH schemes can have considerable impact on both water supply and sewer system due to the fact that it can reduce both runoff entering the sewer network and potable water demand.

The performance of RWH schemes has been evaluated on either water supply system only [2] or integrated UWS [3]. The RWH schemes considered in previous researches have usually been assumed as an alternative water supply source which can harvest rainwater from impervious areas (e.g. building roof and pavement) and supply water for non-potable water uses (e.g. irrigation and toilet flushing). This operational configuration in conventional RWH schemes is characterised as static, i.e. non-smart scheme as it allocates water supply based on pre-defined priorities. The main disadvantage of this scheme is that water volume in the tank cannot be controlled and thus it will overflow when it becomes full and rainfall is still harvested. With the opposite of this configuration, i.e. smart RWH scheme, harvested water can be allocated to different users based on the available water budget and can keep a specific amount of the tank free (or be pre-empted completely) to collect future rainfall and attenuate potential urban flooding. Despite a plethora of investigations into the performance of the RWH scheme, to the best of the authors' knowledge, none of the previous works has evaluated the performance of smart RWH tanks. Hence, the main aim of this paper is to explore the potentials of a smart RWH scheme in an integrated UWS for reducing urban flooding while supplying water for non-potable use. This paper also aims to identify the optimal operation of smart RWH schemes to achieve the best performance in the integrated UWS and then compare it with the status quo (i.e. when no RWH schemes are available) and also non-smart RWH schemes.

2. METHODOLOGY

This paper evaluates the optimal performance of the smart RWH scheme in an integrated UWS including both water supply and sewer systems. The performance of the smart RWH scheme is strongly influenced by the system operation which makes use of sensors to measure rainfall depth and water volume in the tank and actuators (i.e. valves/pumps) to proactively control water volume/level in the tank. A multi-objective optimisation model is developed here to identify the best operation for the smart RWH scheme which is incorporated within an integrated UWS.

Two objectives are defined here in the optimisation model to identify the optimal RWH system operation: (1) minimisation of total potable water supplied from the mains (i.e. conventional distribution system); and (2) minimisation of total urban flooding (i.e. total volume of stormwater which exceeds the capacity of a sewer system in a one-year simulation). The multi-objective evolutionary algorithm NSGA-II is used to solve this optimisation problem [3]. The smart RWH system sensors are assumed to measure tank inflow and volume. Then actuators release a specific water volume from the tank (R_t) at time step t as a function of water volume (V_t) and inflow into the tank (I_t), i.e. as follows:

$$R_t=a_i(V_t+I_t)^{b_i} \qquad i=1,\dots,12 \qquad (1)$$

where a and b are two parameters which have different values for each calendar month. These values are optimised in the above optimisation model. Therefore, the total number of decision variables in the optimisation model is equal to 24. The released water (R_t), which is discharged into the pervious areas, allows the tank to keep some space free and on standby for future rainfall and therefore mitigate potential flooding. Required water demands are assumed to be supplied from the RWH tank if water is available in the tank and if not, it will be supplied from mains water.

The objective functions of the optimisation model are calculated based on the performance assessment of these schemes in an integrated UWS, which is undertaken by using the WaterMet^2 model. WaterMet^2 is a conceptual and mass-balanced-based model which simulates the performance of an integrated UWS including water supply and sewer systems over a specified planning horizon [1, 4]. WaterMet^2 tracks down water flows both in water supply systems and in sewer systems. All this enables WaterMet^2 to simulate RWH which can potentially provide collected rainwater for water demand profiles.

3. CASE STUDY

The suggested methodology is demonstrated on a real-world UWS of a northern European city [1]. The real-world UWS is modelled here by using the WaterMet^2 tool, an integrated UWS including water supply, wastewater and stormwater collection. Two existing water resources, both connected to a Water Treatment Works (WTW) and water distribution pipelines comprise the current water supply subsystem. The wastewater subsystem is characterised by a largely combined sewer system along with two WWTWs. Single WaterMet^2 subcatchment with two associated Local areas, one with RWH schemes and the other without RWH schemes, is used to define water consumption. The integrated UWS is simulated here with a daily time step with a duration of one year time horizon. All RWH schemes are assumed to collect runoff from roofs, roads and pavements and to supply water for toilet flushing and garden watering (irrigation). Irrigation in the case study is carried out only between mid-April and end of August. The UWS consists of 320,000 household properties. It is assumed that the adoption rate of RWH schemes in all households is 50%. Based on the recommendations of conventional designs, the full tank capacity of the household RWH schemes is predefined at 3m^3 [4]. Here, four tank capacities (i.e. sizes) in proportion to the full tank capacity are analysed. Thus, the total sum of the tank capacities analysed in the UWS are: 1) 12.5% of full capacity, i.e. 0.06 million cubic metres

(MCM); 2) 25% of full capacity, i.e. 0.12 MCM; 3) 50% of full capacity i.e. 0.24 MCM and 4) full (100%) capacity i.e. 0.48 MCM. The UWS performance with smart RWH schemes is compared with non-smart RWH schemes.

3. RESULTS AND DISCUSSION

Fig. 1 illustrates the Pareto optimal fronts obtained for UWS with smart RWH schemes for the four analysed tank capacities. The solutions of the optimal fronts represent the trade-off between the two objective functions. The first objective is expressed as a percentage of the total water demand if it was only supplied by mains water and the second objective is expressed as a percentage of the total urban flood when no RWH scheme exists. In each Pareto front, the solution with the minimum flood reduction (or the most potential for water supply using RWH), i.e. the most left hand side point on each front, represents the performance of non-smart RWH schemes. Each front also shows the maximum potential of flood reduction achievable by adding smart equipment to each tank capacity. This indicator can show the impact of smart technologies of the RWH schemes on the improvement of flood attenuation in the sewerage while compromising potable water supply. More specifically, the maximum impact of flood attenuation for the smallest tank capacity (i.e. 0.06 MCM) is only 2.5% reduction (i.e. from 91 to 89) whereas total volume of flood attenuation for larger capacities (i.e. 0.24 and 0.48 MCM) can be considerable at approximately 8%. This can be linked to the increased flexibility of larger capacities which cover both a higher number of floods and larger flood events.

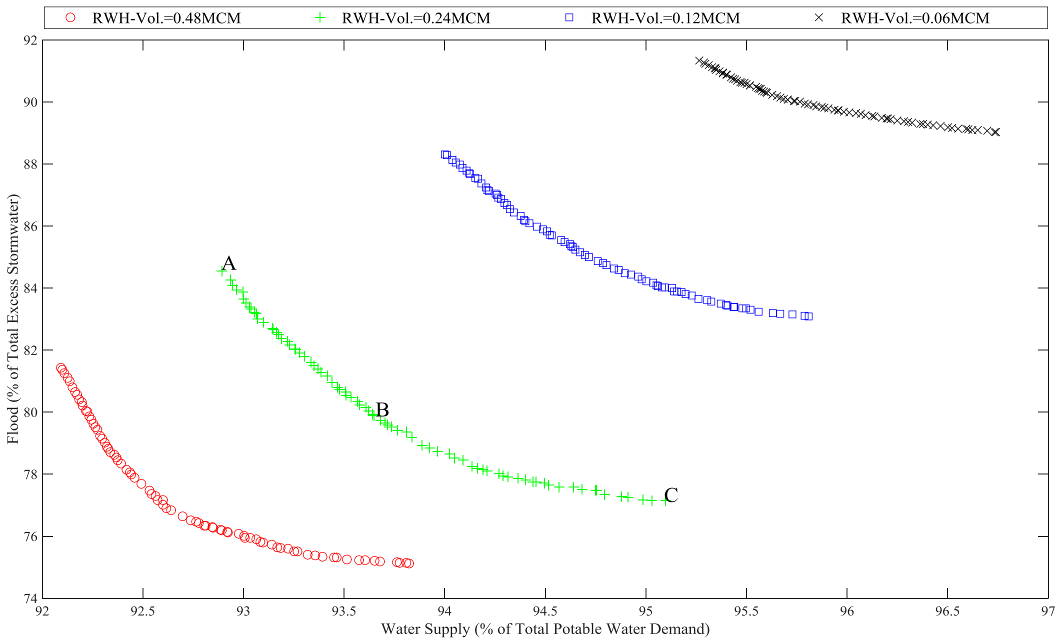

Fig. 1. Pareto optimal solutions for different sizes of RWH tank

Further investigation is conducted in Fig. 2 on the monthly aggregated performance of the three solutions in the Pareto front with the total RWH capacity of 0.24 MCM (solutions A, B and C on the green curve in Fig. 1). These solutions represent the performance of three various RWH types including a maximum water supply from RWH (i.e. solution A representing conventional, non-smart RWH scheme), smart RWH scheme with maximum flood reduction (solution C) and the compromise solution B. When comparing the overall performance of non-smart and smart RWH schemes in the Fig. 2, three time periods can be distinguished (i.e. months 3-4, 5-7 and 9-11) based on stormwater inflow and water use from RWH schemes (i.e. toilet flushing all over the year but garden water use between months 4.5 and 8). In the first period (months 3-4) with relatively high rainfall and low demand, the tank volume and inflow into non-smart RWH (i.e. solution A) are relatively high and thus the average overflow is high due to low demand. However, the smart RWH scheme (e.g. solution C) keeps the most of the tank volume empty (i.e. 88% of capacity is free) in order to attenuate more flood and therefore the average overflow in this solution is trivial. In the second period (months 5-7) which is characterised as being both high rainfall and high demand, the performance of all RWH types are quite similar. However, in the third time period (months 9-11) characterised by high rainfall and low demand, the smart RWH keeps storing small water volumes to increase the capacity for capturing larger inflows. As a result, the tank overflow in this scheme is considerably smaller compared to much larger overflows in the non-smart schemes.

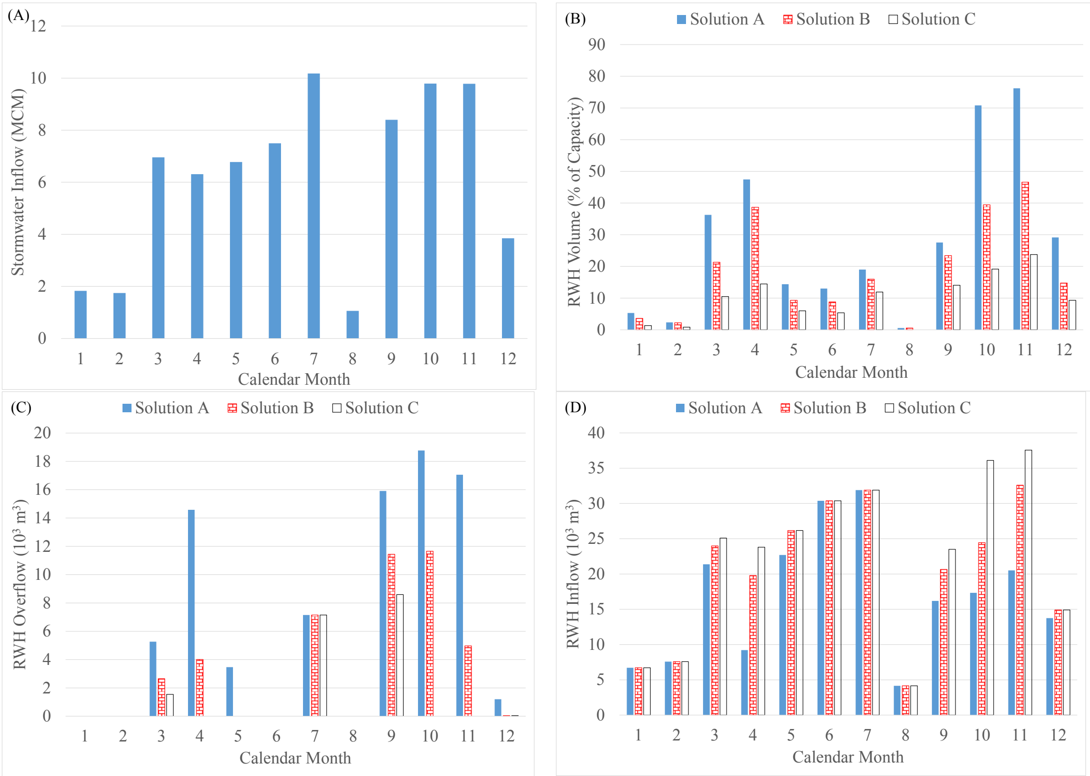

Fig. 2. Monthly aggregated results of three solutions of smart schemes for (a) stormwater inflow in the UWS; (b) average RWH volume; (c) average RWH overflow and (d) average RWH inflow.

4. CONCLUSION

This paper presented the new concept of the smart RWH scheme for improvement of integrated UWSs performance. A multi-objective optimisation model was used to identify optimal operation of different tank configurations in controlling the storage volume of the tank according to the variations of water demand and seasonal inflow. Application of the proposed approach in a real-world UWS showed the significant impact of smart RWH schemes on the flood peak attenuation and reliable water supply from the mains. The proposed approach was able to optimally control the operation of the tank over different time steps for variable rainfall and water consumption conditions. Further investigation needs to be conducted to validate the effectiveness of smart technologies in RWH schemes under different climates and uncertain inflows.

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The potential for Water Sensitivity, sustainable drainage and adaptive management in West Africa using Lagos, Nigeria, as a case study.

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ABSTRACT

Currently, there would appear to be a paradigm shift towards more sustainable, integrated, adaptive and participatory management leading to new policies for stormwater being adopted by many developed countries. However, in undeveloped countries, the problems are highly complex and challenging when considering the implementation of such approaches. On the one hand, the slate is reasonably clean since the infrastructure for dealing with surface water is fragmentary at best, non-existent at worst, whereas for developed countries this network is in place, but ageing, inefficient and lacking in capacity. Cities in developed countries can aspire to Water Sensitivity, but some in Nigeria are presently not even a Water Supply City, particularly those with dense, poor and unregulated informal settlements on their periphery. Using Lagos, Nigeria as a case study, this paper therefore examines the ability and willingness of a city in West Africa, with a substantial informal settlement, to engage in sustainable surface water management. The views of policy makers, Local Government officials, and stakeholders in Lagos, Nigeria, have been sought on the implementation of Sustainable Drainage systems (SUDs) as a starting point for the development of sensitivity towards water for residents of Lagos.

Keywords: Adaptive management; Sustainable Drainage Systems; water sensitivity; less developed countries; informal settlements

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MODELLING THE POTENTIAL OF NATURAL FLOOD RESILIENCE MEASURES IN THE WARWICKSHIRE AVON

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ABSTRACT

Modelling is being undertaken in order to assess the impacts of installing Natural Flood Resilience Measures (NFRM), identified using opportunity mapping and field-based assessments, on the flood peak in a sub-catchment of the Warwickshire-Avon. The land-use in the study area is predominantly arable (68%) with a high intensity of upland sheep grazing, much of which is under-drained, and thus the ADAS35 Rational Method was utilised with the *xpswmm*© 1D/2D integrated model, to account for underdrainage and varying degrees of surface runoff. The inclusion of 1D/2D integrated modelling recognises in-channel conveyance and storage (1D) and overland flow routing and flood inundation across elevation grids (2D) for an accurate representation of the sub-catchments, and the rainfall-runoff contributions made to the catchment as a whole. This paper will discuss the data used in building the model and the changing ethos in using wider-catchment modelling to determine effectiveness of NFM and integrated land-use management, as opposed to a hard-engineering approach that was the focus of previous studies and flood risk management. This particular catchment has an area of 186.95 km^2 with 36 tributaries arising from both spring sources and steep agricultural runoff. By targeting hydrological flow pathways at source, such as overland flow, field drain and ditch function, a significant component of runoff generation can be managed, in turn reducing soil nutrient losses, a key pressure for this catchment in failing to meet 'good ecological status' as part of the EU WFD agenda.

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