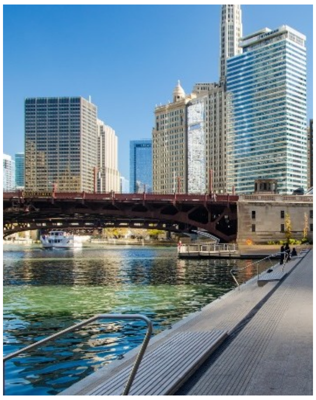

Mid-Project Progress Report

Achieving Urban Flood Resilience in an Uncertain Future

An EPSRC-funded Research Consortium
October 2016 – November 2019

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v8	5th June 2018	SA edits (WP1) SM edits (Proofing and formatting)

Contents

INTRODUCTION

1.1. Context

In March 2015 House of Commons Commission of Inquiry into flood resilience highlighted the challenge of dealing with increasingly frequent and severe floods, stating, "*what is required is a fundamental change in how we view flood management, from flood defence where we protect ourselves to one of resilience, living with and making space for water and the opportunity to get "more from less" by seeing all forms of water as providing multiple benefits* (House of Commons, 2015)." The Commission's statement immediately followed a prolonged period of severe and widespread coastal, river, surface water and groundwater flooding between December 2013 and 2014 (Thorne, 2014). It was, in turn followed by intense, prolonged rainfall and catastrophic flooding in December 2015 that provided an unwelcome but powerful endorsement of that statement. The Environment Agency estimate 5.2 million properties in England are at risk of flooding and the Adaptation Sub-Committee (ASC) of the Committee on Climate Change reported in October 2015 that significant additional investment and adaptation action will be needed to counter the increase in UK flood risk expected under global warming of 2°C (Sayers *et al.,* 2015). Key infrastructure will also be at significantly increased risk, with numbers of assets exposed to flooding by a 1:75-year event increasing by 30%. The ASC stress that the most significant contribution to risk reduction will stem from a whole system approach to adaptation, recognising interdependencies with other urban systems, including transport, energy and land-use.

The aim of the engineering-led, multidisciplinary *Achieving Urban Flood Resilience in an Uncertain Future* project is to conduct research necessary to make urban flood resilience[1] achievable nationally, by making transformative change possible through adoption of the whole systems approach to urban flood and water management advocated by the ASC. The central research question to be addressed is how planning, design, operation and organisation of both existing and new urban water systems (including flood risk management, waste/stormwater management and water security) should be re-envisaged and transformed to:

- ensure satisfactory service delivery under flood, normal and drought condition states; and
- enhance and extend the useful lives of ageing grey assets by supplementing and integrating them with multi-functional Blue/Green infrastructure and urban green spaces.

This aligns with priorities set by Defra/EA and the Living with Environmental Change (LWEC) partnership, which recognise adaptable infrastructure, working with natural processes and effective stakeholder engagement as key to achieving multiple benefits. It is also central to the growing

1 We define *urban flood resilience* in terms of a city's capacity to maintain future flood risk at tolerable levels by preventing deaths and injuries, minimising damage and disruption during floods, and recovering quickly afterwards, while ensuring social equity and protecting the city's cultural identity and economic vitality.

investment in water engineering in the current EPSRC portfolio, specifically in ways which see the key challenge of dealing with flooding and water scarcity as a single inter-connected problem.

Our approach builds on the successful EPSRC Consortium 'Delivering and Evaluating Multiple Flood-risk Benefits in Blue-Green Cities' (EP/K013661, www.bluegreencitires.ac.uk), which worked in partnership with stakeholders through a Learning and Alliance (LAA) to deliver methods for evaluating the multi-functional benefits of Blue/Green approaches to sustainable urban flood risk management that incorporate Sustainable Drainage Systems (SuDS).

In addressing urban flood and water resilience, three distinct research themes were identified, mapping onto five integrated work packages as follows:

Table 1.1.1: Research Themes

Theme	Work package/s
1. Engineering design to enhance service delivery Engineering Design of the spatially-integrated treatment trains of the Blue/Green and Grey (B/G+G) infrastructure needed to permit resilient management of urban water quantity and quality in an uncertain future. i.e. coupling models for urban hydrology, hydrodynamics, stormwater storage and water quality to enhance continuous *service delivery*.	**WP1:** Resilience under change
2. Engineering development for resource use across the flood-drought spectrum Engineering Development of Urban Flood Risk Management (UFRM) and water assets that function inter-operably with other urban systems including transport, energy, land-use and natural systems. i.e. integrating systemic infrastructure interdependencies to reduce disruption during floods and enrich *water resource utilisation*.	**WP2:** Managing stormwater as a resource **WP3:** Inter-operability with other systems
3. Putting urban flood risk management at the heart of planning, at multiple scales Conception of new approaches that put UFRM at the heart of urban planning, i.e. focusing on the interfaces between planners, developers, engineers and *beneficiary communities*.	**WP4:** Citizens' interactions with urban flood resilience assets **WP5:** Achieving urban flood resilience in practice

1.2. Research team

The names, affiliations and research interests of the Consortium Team are listed in Table 1.2.1. Short biographies of the team members can be found in the Inception Report, or via their personal websites.

Table 1.2.1: Research Team

Member	University	Research in Urban Flood Resilience Project
Colin Thorne	Nottingham	Urban flooding, geomorphology and sustainable flood risk management
Emily O'Donnell	Nottingham	Learning and Action Alliances, overcoming barriers to sustainable Blue-Green flood risk management, flooding
Shaun Maskrey	Nottingham	Learning and Action Alliances, stakeholder engagement, participatory modelling and other social science methods
Lindsey Air	Nottingham	Consortium Administrator
Nigel Wright	De Montfort	Urban flood modelling (surface water, river flooding and coincident flooding events)
David Dawson	Leeds	Infrastructure adaptations and evaluation
Kim Vercruysse	Leeds	Multi-functionality between systems
Richard Fenner	Cambridge	Urban drainage systems, multi-criteria analysis of flood risk management benefits; stormwater as a resource
Leon Kapetas	Cambridge	Urban drainage systems, multi-criteria analysis of flood risk management benefits; stormwater as a resource
Chris Kilsby	Newcastle	Urban inundation modelling (coupled surface and sub-surface systems)
Vassilis Glenis	Newcastle	Urban inundation modelling (coupled surface and sub-surface systems), CityCAT development
Greg O'Donnell	Newcastle	Hydrological modelling, model coupling (e.g. combining CityCAT and SHETRAN models)

Jessica Lamond	University of the West of England	Citizen and stakeholder attitudes and behaviours with respect to flood risk management
Glyn Everett	University of the West of England	Processes of social inclusion/exclusion as they relate to and affect citizen and stakeholder engagement in flood risk management
Scott Arthur	Heriot-Watt	Risks of blockage at structures in urban watercourses due to sediment and/or debris
Vladimir Krivtsov	Heriot-Watt	Hydrology, water quality, sediment, suspended particulates, biodiversity and ecological dynamics; public participation and multiple benefits
Karen Potter	Open University	Planning and flood risk management, use of social science theory in understanding and overcoming barriers to innovation
Tudor Vilcan	Open University	Resilience, land-use and flood risk management, use of social science theory in understanding and overcoming barriers to innovation
David Butler	Exeter	Water engineering, integrated modelling of urban water systems, urban drainage and water efficiency
Zoran Kapelan	Exeter	Water engineering, flexible design/Real Options, metabolism based methodology for long-term planning of urban water systems
Sangaralingam Ahilan	Exeter	Sustainability and integrated modelling of urban water systems, urban drainage and water efficiency

1.3. Research themes and outcomes

Within each of the three research themes, the following deliverables were identified as being significant project outcomes.

Theme 1: Engineering design to enhance service delivery

Next generation flood and water management models that bridge the interfaces between urban/rural and engineered/natural hydrological systems, making them capable of: simulating urban floods, droughts and water cycles within their wider catchment and metropolitan contexts to deliver acceptable service provision 24 hours a day, 365 days a year [WP1a].

The steps necessary to design, implement and operate coupled B/G+G stormwater treatment trains through development of adaptation designs and pathways that are appropriate to their location, community and scale [WP1a].

GIS toolbox for a National Assessment based on:

a) identifying appropriate location-specific B/G+G infrastructure combinations,
b) considering catchment and urban water resources and their variability,
c) location-specific flood risk assessment (especially from coincident flooding),
d) sewer condition and capacity, and
e) stormwater resource potential for UK cities,

under present and future climates [WP1b].

Theme 2: Engineering development for resource use across the flood-drought spectrum

Enhanced design methods that co-optimise management of urban runoff simultaneously to mitigate flood hazards *and* capture the benefits of treating stormwater as a valuable, though under-utilised, resource, leading to practical solutions for stormwater recovery, recycling and reuse [WP2].

Improved integration of UFRM and water, energy and transport infrastructure leading to expanded inter-operability of urban 'systems-of-systems' [WP3].

Theme 3: Putting UFRM at the heart of urban planning, at multiple scales

Characterisation of citizens' behaviours and decision-making concerning flooding and urban water use, and the means of informing those decisions through improved appreciation of flood risk and water literacy [WP4].

New protocols for placing flood and water management decision making at the heart of urban planning, as recommended by Pitt (2008) and legislated for in the Flood and Water Management Act (2010) [WP5].

Case studies demonstrating Blue-Green approaches to flood and water management that are innovative, inclusive, resilient and suitable for application in the contexts of:

a) retrofit/urban renewal, and
b) new build/new town applications [WP5].

Taken together and explored practically in the case study cities these carefully inter-woven models, tools and implementation approaches have the potential to co-produce the necessary understanding needed for coupling blue, green, grey and smart infrastructure in new and context specific ways, so that excess water quantities and poor water qualities can be dealt with using the integrated treatment trains required to achieve the modern paradigm of a water-sensitive city.

1.4. Approach

The research takes a radical approach based on methods and models that are locally-defined (making them applicable), but spatially-linked through the ‘stormwater cascade’ (*Figure*), making them transferrable and suitable for up-scaling, regionally and nationally.

The engineering core of this project couples an array of carefully selected, physics-based models to support investigation of how stormwater cascades through a city's drainage system, accounting for the dynamics of not just water, but also sediment, debris, natural solutes and contaminants carried by urban runoff. Based on the capability of this suite of models to simulate water flow, storage and quality within an urban system, we will investigate how the performance of grey systems (e.g. lined drainage conduits/channels/ditches, underground pipes and detention tanks) can be improved by adding Blue-Green Infrastructure (BGI) and SuDS, to create integrated treatment trains designed to manage both the *quantity* and *quality* of urban runoff. Models and design solutions will be developed and tested in the contexts of retro-fit (as part of urban renewal and uplift in Newcastle-upon-Tyne) and new build (as part of creation of a 'garden city' in Ebbsfleet, Kent). Our intent is to work out and demonstrate how resilience to floods and droughts can be achieved using integrated systems of B/G+G assets, no matter how the climate changes in future, assuring continuous, long term service delivery.

The research will adopt a *whole systems perspective* that recognises interdependencies with other urban systems, including transport, energy and land-use. This will identify new opportunities for managing stormwater as a resource that will then be explored. This will add to the multi-functional benefits of using BGI to manage flood risk by increasing water security. Possibilities range from non-potable uses in homes or commercial buildings (based on rainwater harvesting (RWH)) to irrigating green infrastructure (e.g. street trees), managing subsidence in clay soils, soil moisture enhancement and groundwater recharge. Wider benefits may extend to local energy generation using drainage infrastructure (i.e. micro-hydropower) and enhancement of urban watercourses and ecosystem services.

In short, the models and protocols developed will form the basis for assessment of the potential for the optimised combinations of B/G+G and smart infrastructure to deliver multiple-benefits in UK cities nationwide.

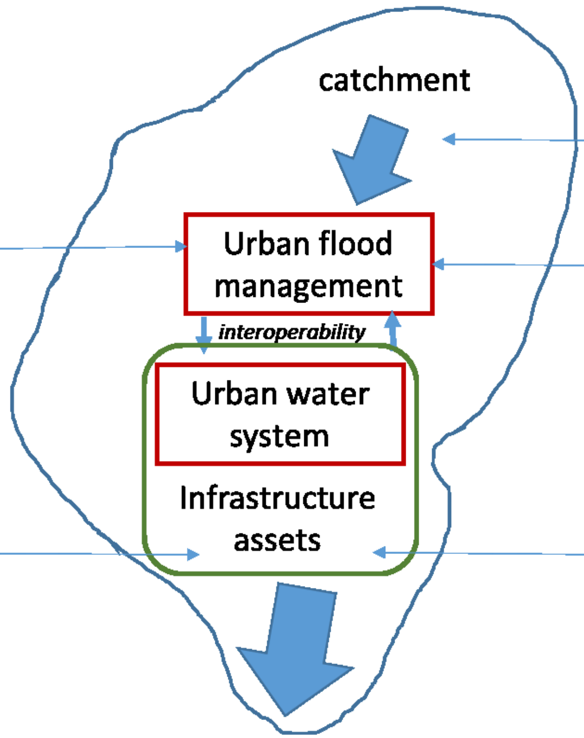
Stakeholder actions and system evaluations:

Participatory Action Research and **Social Practice Theory** to examine relationships between researchers, UFRM practitioners and communities, based on **Local Action Alliances** in locations such as Newcastle and Ebbsfleet. *This will explore tacit knowledge, behaviours and citizen's attitudes with respect to diverse flood mitigation measures and link the desirability of specific asset interventions with wider urban planning.*

Real Options analysis will find the most synergistic mix of B-G and G assets, with new objective functions for option isolation based around maximising multiple benefits and service delivery. *This will apply methods for evaluating the benefits of SUDS-GI developed in the Blue Green Cities project. Optimisation will include Totex (including maintenance liabilities) and monetised benefits (generated using CIRIA's BeST tool).*

System interdependencies will examine interactions with other components of urban fabric including open spaces, highways and buildings. *This will evaluate systemic resilience and the uncertainties arising from climate and socio economic futures to be accounted for in infrastructure planning and decision making.*

GIS visualisation of the flood mitigation performance of potential of Blue-Green & Grey assets and their multifunctional benefits. *This will consolidate the model outputs for use locally to guide development and be up-scaled regionally/nationally to inform policy, and form the basis for a National Assessment of flood resilience.*



Stormwater Hazard + Resource potentials

Urban flood risk
Non-potable use
Irrigation of Blue Green infrastructure
Groundwater and soil moisture recharge
Micro-hydropower
Maintaining urban green spaces and ecosystem services

Physical Models:

SHETRAN handles water, flow multi-fraction sediment transport and multiple, reactive solute transport within a river basin model. *This will couple catchment hydrology and sediment/contaminant inputs to urban systems (simulated using CityCAT and WaterMet2).*

CityCAT models urban flooding to assess pluvial and fluvial flood risk and flood alleviation measures with simulations driven by rainfall, flow and/or water depth time series. Maps of water depths and velocities at different times are combined to animate the flood propagation. *This central tool will simulate how stormwater cascades through urban systems, show where capture and re-use is possible and where its resource potential is constrained.*

WaterMet2 is an urban water system performance model providing flows/fluxes in 4 subsystems: water supply, sub-catchment, wastewater and water resource recovery. *This will be coupled with CityCAT to explore the interconnections between all forms of urban water.*

Eco-hydrological modelling links plant physiology within SuDS to water availability, using a water balance model linking the total water in the rooting zone with rates of rainfall, interception, runoff, evapotranspiration and leakage (in mm/d). *This will apply time series data from CityCAT and WaterMet2 to determine the resilience of vegetation in Blue-Green infrastructure and SuDS systems.*

Figure 1.4.1: The scope of this project covers the entire 'stormwater cascade' from when water enters to when it leaves the urban area (centre panel), employing a suite of linked research methods and models to simulate physical and bio-chemical processes, and cross-tabulating with water governance, planning/development and stakeholder attitudes, preferences and actions at every stage

However, the goal of optimising urban flood and water management can only be achieved through a deep understanding of citizen and community preferences with respect to managing flood risk. This will be addressed using Participatory Action Research (PAR) and Social Practice Theory (SPT) to examine the attitudes and responses of citizens and communities to innovation in flood and water management. Moreover, engineering solutions must be better informed by and explicitly accounted for in urban planning and development at all spatial scales. For this reason, our research will extend to investigation of the socio-political planning, development and organisational context and how this impacts the collaborative governance of UFRM. This aspect of the work is essential to underpin and enable implementation of the engineering analyses and solutions identified in the core research outlined above.

The mechanism for bringing together engineering, social and planning components of the project will be co-location research by the entire project team in Newcastle-upon-Tyne, Tyne and Wear, and Ebbsfleet, Kent. Team research in these case study cities will establish how barriers to innovation can be overcome despite uncertainties in future urban climates, land-use, development and political leadership. Critical engagement with planners, developers and land-owners throughout the project will feed back and inform the core engineering focus of the work, building on the current trend towards the development of urban infrastructure observatories to explore responses to the innovative changes needed to achieve urban flood resilience.

1.5. Project duration

The Project commenced at the University of Nottingham, De Montfort University, Open University, University of Leeds and University of Exeter on 1st October 2016. University of the West of England started on 1st September 2016. University of Cambridge started on 1st November 2016, and Heriot-Watt University started on 1st December 2016. Research at each institution is scheduled to be completed 36 months after the start date.

RESEARCH PROGRESS TO DATE

2.1. Research Structure and Schedule

The project is organised into five Work Packages (WPs) within the contexts of Key Themes and Pressures (Figure 1.1.1). WP boundaries will be permeable. WPs and activities within them are scheduled to supply outputs needed to support progress other WPs, and test applications in the case study cities, at appropriate times.

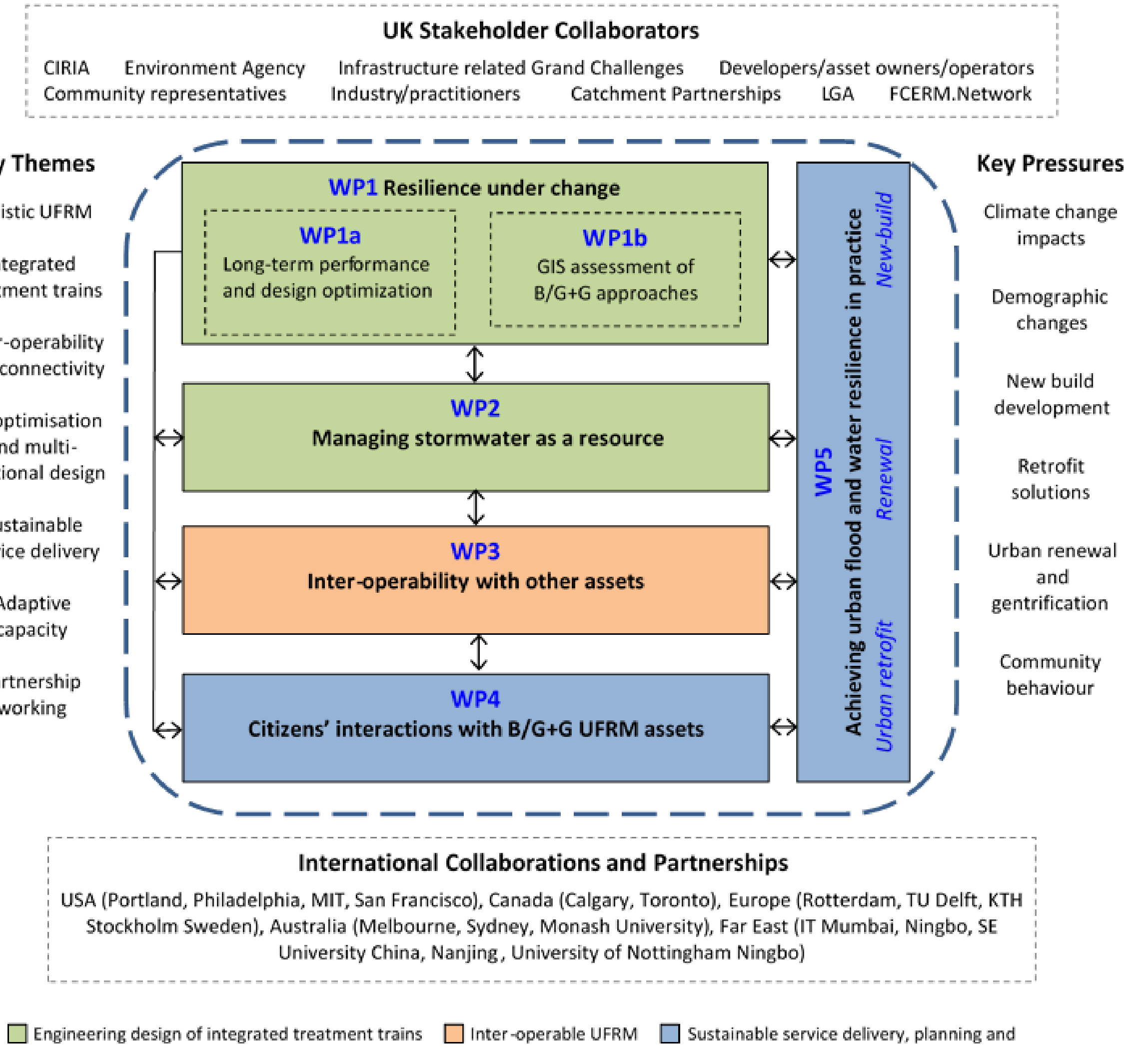


Figure 1.1.1: Project structure

2.2. Work package reports

2.2.1. WP1. Resilience under change

WP1 investigates how blue-green and grey systems can be co-optimised to offer maximum flood risk reduction, as well as multiple other benefits, under a range of future scenarios that account for climate and socio-economic changes. Using state-of-the-art modelling methods, such as the fully coupled surface/sub-surface urban drainage model CityCAT, in conjunction to models developed throughout the project, WP1 will help to establish how integrated systems can deliver a service that is resilient to future uncertainty.

Objectives

1. Quantify performance of traditional and green infrastructure systems using novel and/or proven methods to trace flows, debris, sediments and pollutants from source to sink, while paying close attention to interfaces with other systems.
2. Evaluate how proprietary SuDS devices (e.g. planters and filters) inter-operate with other assets.
3. Undertake field surveys to identify opportunities and challenges with regard to installing (and retrofitting) these devices in the case study cities.

Work Package Team

Richard Fenner and Leon Kapetas (Cambridge); Chris Kilsby, Vassilis Glenis and Greg O'Donnell (Newcastle); Scott Arthur, Brian D'Arcy and Vladimir Krivtsov (Heriot-Watt); David Butler, Zoran Kapelan and Sangaralingam Ahilan (Exeter).

Study Approach and Methods

1. Cambridge and Newcastle Universities

Urban drainage infrastructure developed to meet specific performance can require retrofit interventions when pressures are exerted dynamically. In this respect, extreme storm events due to climate change and urban densification are the two most significant pressures. As both are uncertain, drainage systems are over-designed when rainfall and/or urbanization levels have been overestimated or under-designed in the opposite case. Making good judgement on such projections is a hard task and has significant economic implications. This creates a need for flexible/adaptive designs that allow incremental investments in infrastructure, matching the performance requirements while maintaining cost-effectiveness. At the same time, other criteria can complement the conventional Cost Benefit Analysis, such as adaptiveness, ease of implementation and multiple benefits delivered.

This work presents an adaptation pathways methodological guide for relevant stakeholders such as water companies and lead local flood authorities interested in drainage infrastructure flexible/adaptive design for long-term planning. The methodology is designed to answer the question *"what is the most effective mix of blue-green and grey systems in any given location at any time?"*

This gives rise to the following questions:

(i) What is the desired performance threshold?

(ii) How do different interventions combine one with the other?

(iii) Which interventions should be prioritised?

(iv) What is the assessment approach?

(v) When should they be implemented?

(vi) How do we respond to climate change and urbanisation?

This methodology is tested in Sutton, a Borough of South London, where a set of SuDS interventions are currently implemented and more are planned for the future to reduce existing flood risk. This approach can also be applied to new-built environments, such as Northfleet in Ebbsfleet Garden City.

The modelling work is led by Newcastle University. Modelling is carried out using the in-house software CityCat which solves overland 2D flow and sewer network flow under free surface and pressurised conditions. Different rainfall inputs will be tested to represent the effect of climate change and an increase in impermeable area with time will represent the denser urban environment conditions expected in the future. The possible interventions (e.g. swales, raingardens or grey infrastructure) will be modelled in separate or combination to assess the different steps along the possible pathways (see Figures 2.2.1.1 and 2.2.1.2). Flood depths will be calculated for different return periods to produce flood damage – frequency curves. The blue areas shown in the simulation results shown in Figure 2.2.1.3 are areas with a water depth greater than 10cm. These results are being compared to known instances of flooding.

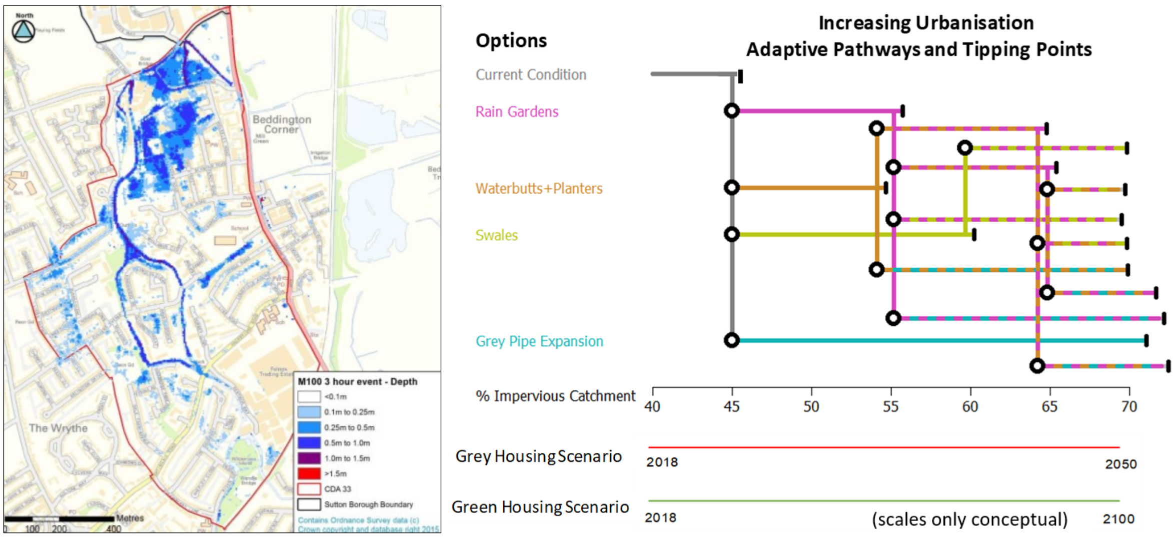
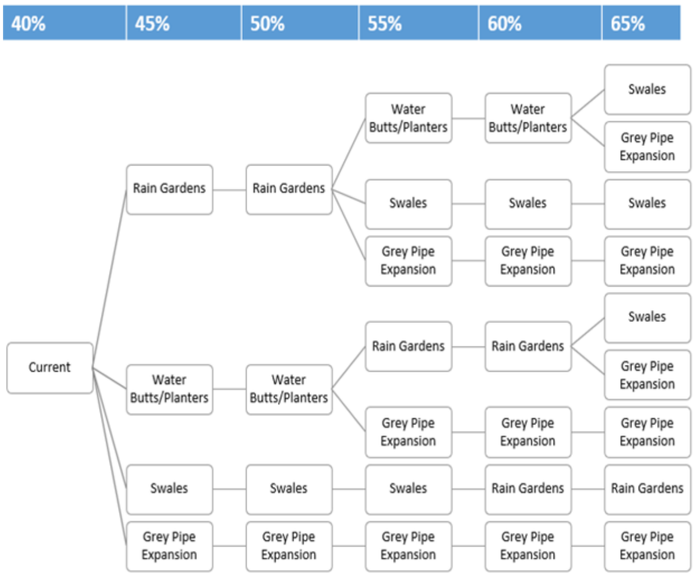


Figure 2.2.1.1: (Left) Flood extent for the Critical Drainage Area 33 in Sutton (JBA, 2015). (Right) Possible interventions to reduce flood risk combined under different pathways. A slow reduction in

impermeable area (green housing scenario) delays the time of intervention (designed with the Deltaris Pathways Generator).



Pathways	Current Criteria	Additional Criteria		
	Standard CBA	Adaptiveness	Ease of Implementation	Multiple Benefits
1	Medium	High	High	High
2	Medium	Medium	Medium	High
3	High	High	Medium	Medium
4	Medium	Medium	High	Low
5	Medium	Medium	Medium	High
6	Medium	High	Medium	Medium
7	Medium	Low	Medium	Low
8	High	Medium	Medium	High
9	Medium	Low	Medium	None

Figure 2.2.1.2: Tree diagram of pathways and their multi-criteria assessment

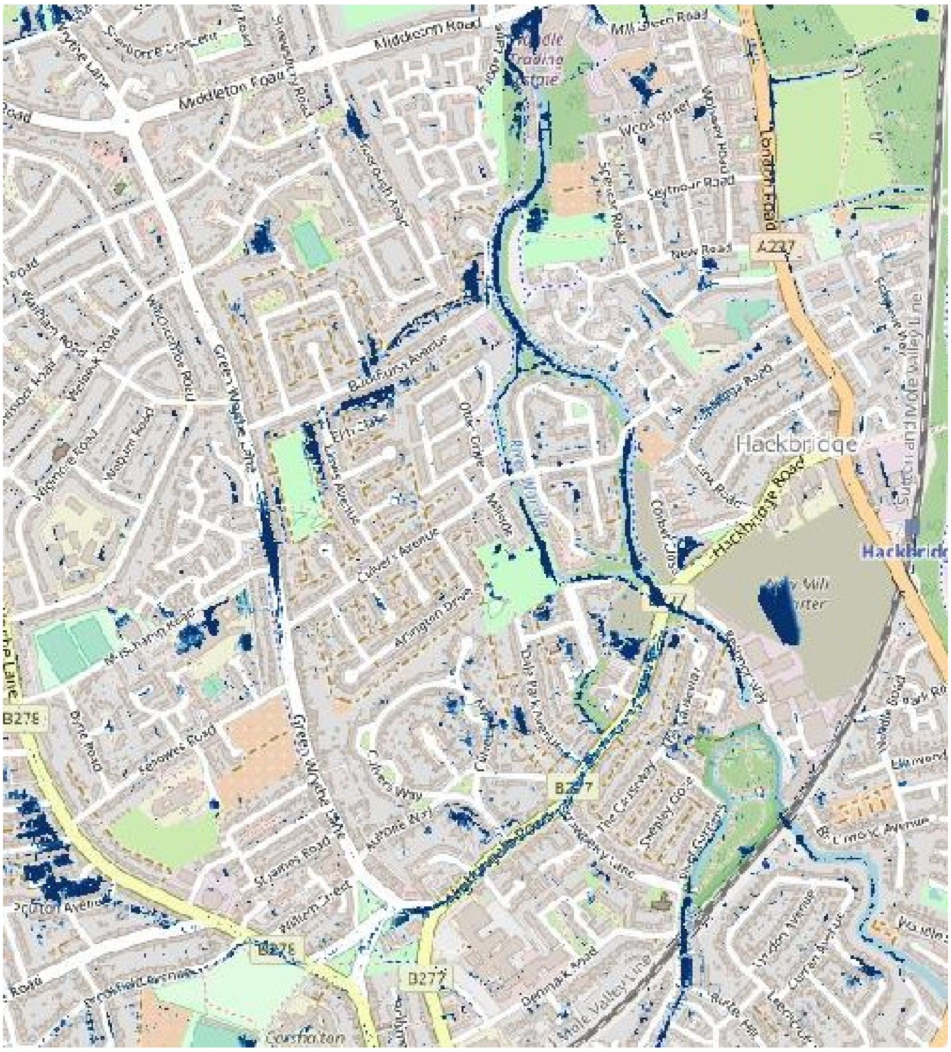


Figure 2.2.1.3: CityCAT simulated water depths greater than 10cm (blue) in Sutton

2. Heriot-Watt University

Work at Heriot-Watt focuses on the co-optimisation of traditional grey and blue-green infrastructure systems and builds on previous work at Heriot-Watt University on sediment, debris and pollutant dynamics in urban drainage systems.

SuDS Retrofit

Working with the Scottish Environment Protection Agency (SEPA), Scottish Water and West Lothian Council we have been investigating the feasibility of retrofitting SuDS to industrial, commercial and office premises at Houston Industrial Estate (Figure 2.2.1.4). This is a large development (over 100 businesses) which drains to a hydraulically-stressed constructed wetland. The specific objectives of the study are:

1. Gauge awareness of SuDS technology and relevant regulations using a specially designed questionnaire
2. Review literature and work with key stakeholders to identify the typical barriers to SUDS retrofit (e.g. financial, space, land ownership, education, etc.)
3. Work with business/land owners and West Lothian Council to understand what types of SUDS would be suitable within the risks and any constraints presented at the site
4. Assess the willingness to install and evaluate the role incentives can play
5. Produce case studies for Houston Industrial Estate which would allow the project findings to be easily transferred to other sites.

Figure 2.2.1.4. Aerial view of Houston Industrial Estate with marked positions for a selection of current study sites

A questionnaire was designed to gauge awareness of SuDS technology and relevant pollution regulations. The questionnaire had a 'Yes/No' format, and contained a checklist of 10 types of SUDS features, asking for a response to two prompts a) is the company familiar with the technique, and b) is there an example of it on their premises at Houston Industrial Estate? Colour images were used to aid recognition of specific features. This questionnaire was posted or emailed to the majority of premises on the estate, and delivered by hand when that was not possible or when no response to the original letter was received. To date, more than 60 responses have been received and analysed. Preliminary analysis of the results revealed that 90% of the companies claimed familiarity with at least one SUDS technology, while the remaining 10% of all companies appeared to be unfamiliar with them (Figure 2.2.1.5). However, the majority of the companies (75%) appeared to be familiar with specific SUDS features illustrated on the checklist, but were unfamiliar with the term 'SUDS'. The majority of these companies (50) were familiar with more than one feature, and many ticked more than half of the SUDS types offered on the list (Figure 2.2.1.5). However, many of the potential plot techniques were unfamiliar to most companies. Experience of flooding did not appear to be a decisive factor influencing awareness of SuDS (Figure 2.2.1.6). Less than a quarter of all companies were aware of general binding rules (GBR) regulating pollution prevention at industrial sites, and ownership of the premises did not appear to be a decisive factor influencing that knowledge (Figure 2.2.1.6).

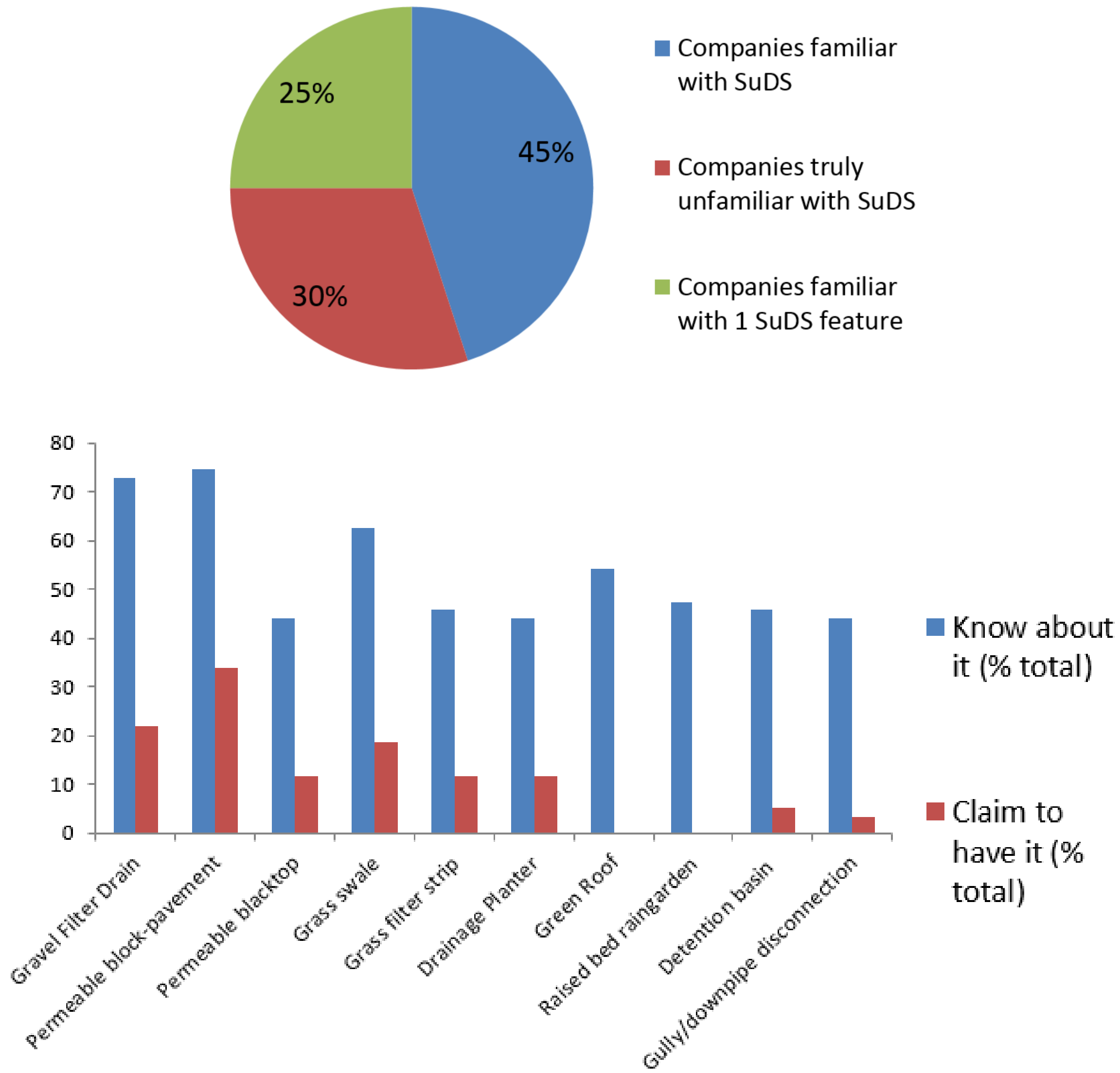


Figure 2.2.1.5. Claimed familiarity with SUDS technology and ownership of specific features at Houston Industrial Estate (n=61).

Our observations, and analysis of the questionnaire results also revealed that some of the newer premises already have SUDS. These are predominantly areas of permeable paving and, to a lesser extent, gravel filter drains. A number of companies also claimed ownership of some other SuDS features (e.g. detention basins), however those claims require to be verified by inspection. There are opportunities for retrofit SUDS features on most of the premises, with space being the principal limiting factor. The exceptions are some of the smaller units where a flow attenuation drain-down vessel is probably the best that could be managed.

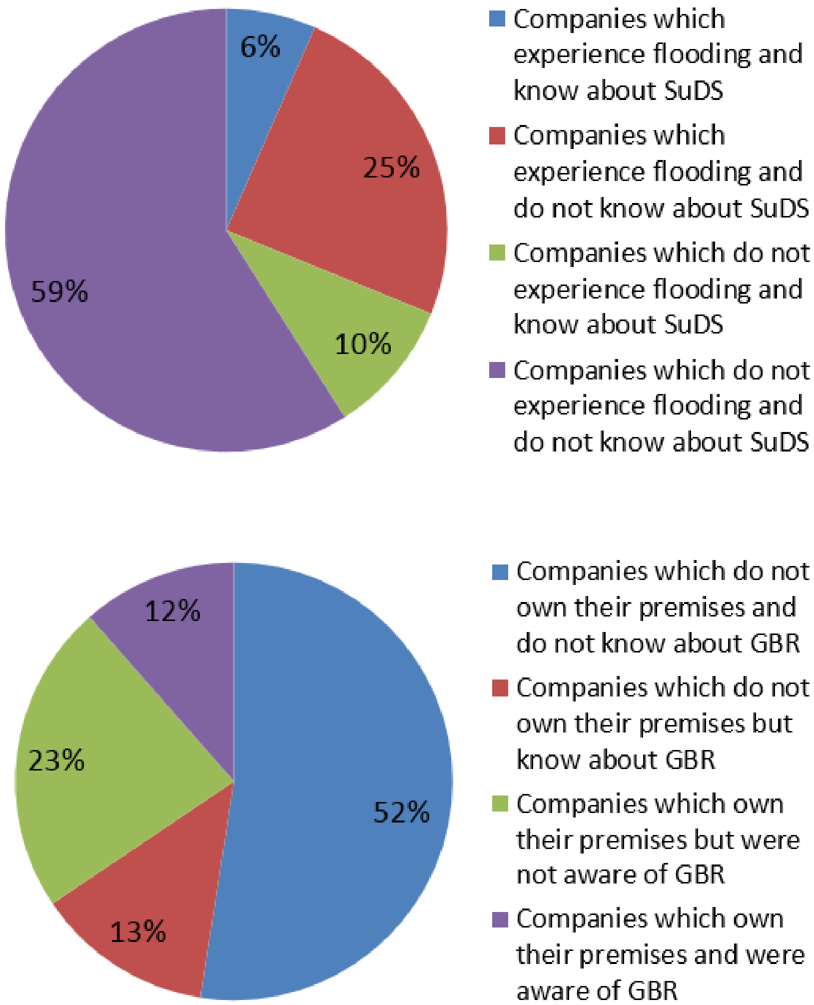


Figure 2.2.1.6. Pie charts illustrating relationships between experience of flooding and familiarity of SUDS (left hand panel), and ownership of premises vs awareness of pollution prevention regulations (right hand panel) (n = 61).

A number of detailed case studies are being carried out to propose specific SUDS retrofits, with companies such as Transcal and NRS actively cooperating. Specific SUDS features recommended in the case studies include raised rain garden planters, trees, flow attenuation vessels, swales, retention ponds and detention basins. A possibility of a public SUDS train terminating in a detention basin next to API Foils has also been identified. This could be linked by a series of swales and a meandering pond to accommodate runoff from a section of public roads, as well as from premises of Transcal, API, Hertz, and Prestige Leisure.

Potential drivers for retrofits identified so far include the potential for reduced water charges, and the scope for capturing rainfall for use in a technological process (including wash waters). Among the initial barriers identified so far are the lack of awareness, time and logistical constraints, branch mentality, and the lack of incentive. A detailed consideration of barriers will be a subject for further work. The preliminary results of the study have been summarised in an abstract submitted to the SUDSnet conference.

Characterisation of suspended sediments in SUDS ponds

A considerable proportion of pollutants in aquatic ecosystems is adsorbed to sediment particles. Suspended sediments also alter the penetration of light, and thus influence the dynamics of primary producers. Hence characterisation of sediments, and in particular of suspended particulate matter, is important for describing patterns of ecosystem dynamics. Therefore, an important part of the project is sediment analysis and particle size distribution. This is being done using gravimetric methods and a Mastersizer instrument at Heriot-Watt University.

This avenue of research is linked to our research within WP2 (see below). In particular, this work will focus on characterising suspended sediments and understanding their impact on water quality and pond ecology. Progress to date has focussed on identifying field sites (described in WP2), establishing a methodology and procuring equipment. Field trials were carried out in early 2018, and were followed by full scale activities beginning in late April. This preliminary work will enable up to 16 months of data collection in the field.

Acknowledgements and further contributions

It should be noted that the activities of Heriot-Watt University team have been undertaken with the assistance of volunteers, as well as PhD and Masters students. The study has also benefitted from valuable inputs from an independent consultant, Brian D'Arcy, who is now a part-time lecturer at Heriot-Watt University. Preliminary findings of the Houston Industrial Estate case study have been summarised in a conference abstract submitted for a SUDSnet conference.

The team have also contributed to the following:

- Presented at The 7th International Conference on Flood Management, Leeds University (September 2017)
- Presented at SUGIR (Scottish University Green Infrastructure Research) conference, Heriot-Watt University (November 2017)
- Presented the preliminary results of Houston Industrial Estate case study at the CREW meeting (Jan 2018)
- Presented at SUGIR conference 'SUDS in the Northern Climate' in SRUC (April 2017)
- Lead preparation of the revision for the final reports on the BG Cities project

3. University of Exeter

Within WP1, the University of Exeter is involved in systematically evaluating urban water system flows in Ebbsfleet, Kent by adopting urban metabolism-based modelling. The quality of the urban metabolism is strongly influenced by its interconnectivity morphology; the modelling, therefore, embraces a whole system perspective that recognises interdependencies between water flows and other flows and fluxes in urban systems including wastewater, energy and material. The urban metabolism concept directly deals with the quantification of the overall flows and fluxes of water, energy, materials, nutrients and wastes into and out of an urban area as well as those converted inside the urban area and track down the environmental impacts on water, air and soil. The impact of growing urban population, a changing climate, and an increase in the frequency of extreme weather events have been strongly reflected through urban water, which emphasises the need for long-term planning and management of urban water resources. The urban metabolism modelling approach allows identifying the system bottlenecks and hotspots in urban water systems, which in turn, enable the definition of better intervention strategies to effectively improve the system performance under extreme events plausibly caused by urbanisation and climate change.

Objectives

1. *Developing an urban metabolism model for Ebbsfleet garden city.*
   The first part of the study is involved in developing an urban metabolism model to represent the urban water system in Ebbsfleet Garden City. An urban water system performance model, WaterMet2, is used in the metabolism modelling. The WaterMet2 model is a simulation, mass-balance-based model which provides fluxes in four subsystems: water supply, stormwater, wastewater, and water resource recovery. The intervention strategies considered in Ebbsfleet Garden city development will be evaluated based on how they can increase the resilience of urban water systems against the different land use and climate conditions.

2. *Integrate household rainwater harvesting (WP2) and grey water recycling on urban metabolism modelling.*
   Ebbsfleet received relatively lower annual rainfall and major contribution of water supply comes from the groundwater resources. It is therefore essential to consider alternative water supply sources and water reuse options for sustainable urban water management in the Ebbsfleet Garden City. The second part of the study focuses on integrating rainwater harvesting and greywater recycling in the sub-catchment and city scales respectively in the Ebbsfleet Garden city, aiming for a more circular urban metabolism.

3. *Contribute to system dynamics model development (WP4).*
   The third part of the study involves the coupling of two work packages; quantitative urban metabolism modelling (WP1) and system dynamics modelling (WP4). WP4 aims to integrate water quality, quality of place, flood risk management, biodiversity and water use optimisation through the system dynamics modelling. The system dynamics model development primarily involves stakeholder engagement to define and conceptualise the problem, build a computer simulation model of the system, test the model and develop policies. Integration of qualitative system

dynamics model with the quantitative urban metabolism model enables to identify the potential blue-green and grey intervention options via initial screening (bottom-up approach) and incorporate them in the urban metabolism simulation (top-down approach).

Methods

In this study, WaterMet² model is adopted for metabolism-based assessment of the integrated urban water system in Ebbsfleet. The WaterMet² model quantify resource flows in the urban water systems and consequent environmental impact categories (Behzadian & Kapelan, 2015). The model allows to undertake sustainability assessment of existing urban water system and the urban water systems modified by future strategic interventions over a pre-defined long-term planning horizon in Ebbsfleet. In the WaterMet², three major subsystems (water supply, stormwater and wastewater) of the urban water systems is represented using four spatial scales (city area, sub-catchment area, local area and indoor area) (Figures 2.2.1.7 and 2.2.1.8) (Behzadian & Kapelan, 2015).

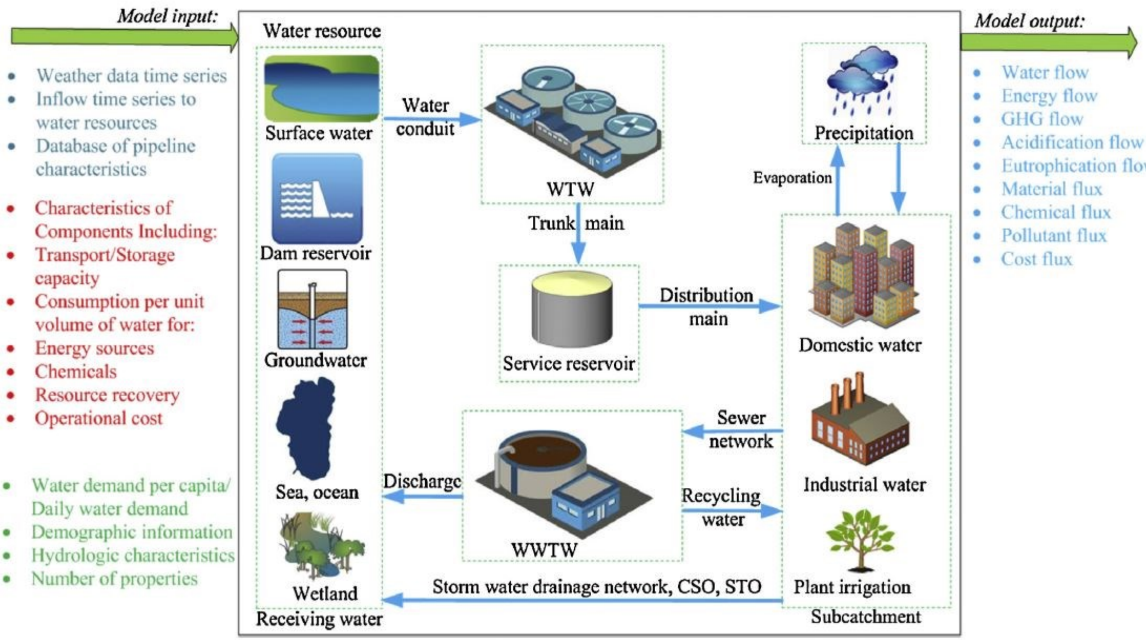


Figure 2.2.1.7 Main components, processes, inputs and outputs of an urban water cycle used for modelling in WaterMet²

As shown in Figure 2.2.1.8, the water supply subsystem in WaterMet² comprises three types of storage components (water resources, water treatment works and service reservoirs) and three types of flow route elements including water supply conduits, trunk mains and distribution mains. Modelling and simulation of the water supply system is carried out in two stages, in the first stage daily water demand starting from the most downstream (sub-catchment level) and aggregating in the upstream direction until it reaches most upstream points (water resources). Having established water demand for each water resource, the second stage involves in distributing water flow in the downstream direction until it reaches sub-catchments.

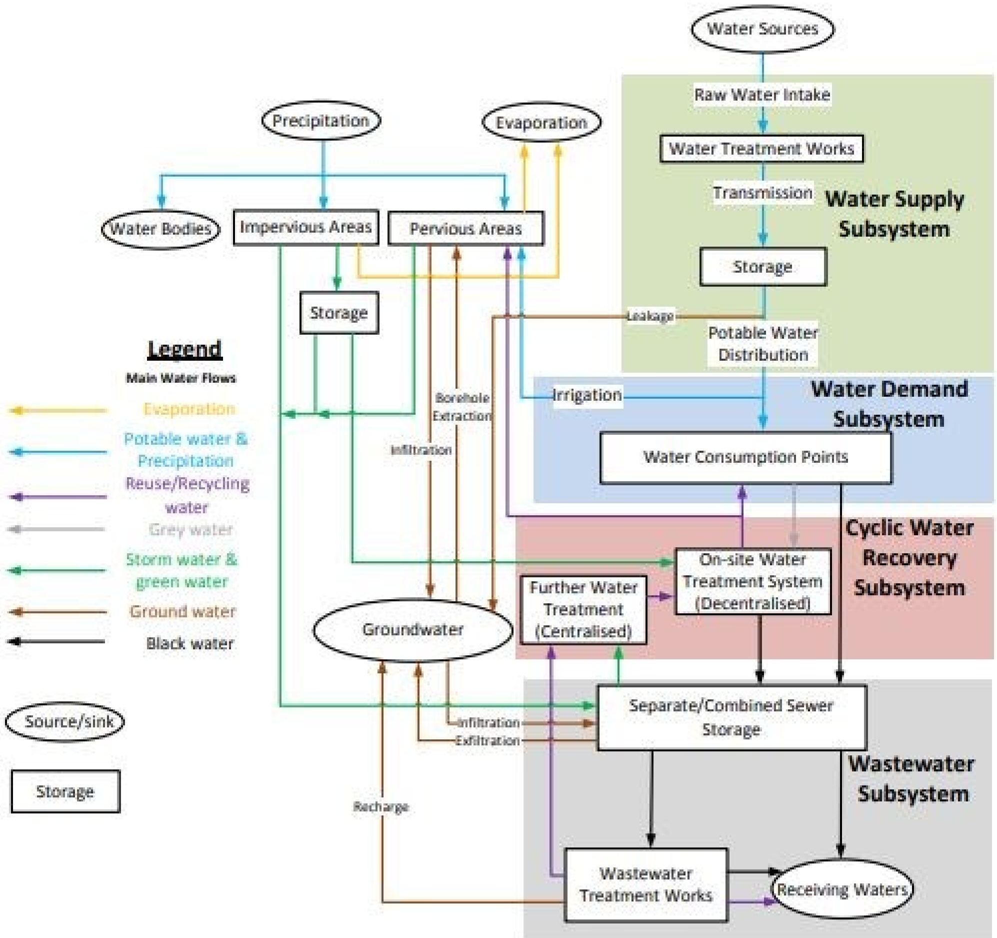


Figure 2.2.1.8 Main flows and storage in the WaterMet² model

Cyclic water recovery subsystem in WaterMet2 divided into two groups, centralised and decentralised facilities. The centralised water recovery such as recycling treated wastewater from wastewater treatment works is modelled at a city scale. The decentralised water treatment facilities such as rainwater harvesting, and greywater recycling are modelled in WaterMet2 in both sub-catchment and local area level. In the wastewater subsystem; wastewater/stormwater flow routes such as separate or combined sewer systems, wastewater treatment works and receiving water are considered. As the aim of this modelling is to support strategic planning in Ebbsfleet, WaterMet2 adopts a daily simulation time step to track down all the modelled flows. Several quantitative key performance indicators such as capital cost of interventions, operational and maintenance cost, the reliability of water supply, the vulnerability of water supply, resilience of water supply, GHG emission, acidification and eutrophication is considered for the subjective judgment of the strategies. In addition, a couple of qualitative key performance indicators such as public acceptance and company acceptance are also considered.

Progress to date

Progress	Lead
Factsheet on SuDS economics published on project website This fact sheet is entitled "Revisiting SuDS Economics: Exploring economic appraisals to identify flexible adaptation pathways" and discusses the different cost elements of SuDS as well as how an adaptation pathways methodology can be useful to adapting a whole-life cost approach.	Cambridge
Draft paper on adaptation pathways for BG/G infrastructure The manuscript entitled "Getting the Blue-Green and Grey infrastructure mix right: Adaptation pathways for long-term urban drainage planning in an uncertain future" is currently being prepared based on the concept of extending the adaptation pathways methodology to G/BG infrastructure (see concept description above)	Cambridge
Placement at Ebbsfleet Development Corporation (L. Kapetas) One week of embedded research at the offices of the Ebbsfleet Development Corporation to establish dialogue with key stakeholders (developers, Kent CC lead drainage authority, water utilities, planners). The objective was to access necessary data sets to conduct aspects of the research programme and to familiarise the researcher with the urban landscape (Hosted by Simon Harrison, Head of Design, Ebbsfleet Development Corporation)	Cambridge
Drainage modelling training Newcastle University organised a 2-day training on CityCat for members of the consortium. This activity supported further integration and understanding of modelling data requirements and capabilities.	Newcastle

Progress on modelling at Newcastle includes testing of the crucially important storm inlet component which links the surface to the pipe network in grey systems (as reported in Bertsch *et al*. (2017) Urban Flood Simulation Using Synthetic Storm Drain Networks. *Water.* 9*,* 925.). Without proper understanding and representation of this component, it is impossible to analyse the impact of blue green interventions.	Newcastle
Secondment with Ebbsfleet Develop Corporation (A. Sangaralingam) Site visits, data collection and networking to understand the future of the Ebbsfleet development and to collate relevant water management plans and strategy documents from the planning consents. Several planning applications are collated from EDC and reviewed to conceptualise the proposed Garden city development.	Exeter
Secondment with Thames Water and Southern Water (A. Sangaralingam) Secondment with Thames water strategic network modelling team in Hampton involves collating water supply plan for Ebbsfleet and historical water supply data sets in the neighbouring distribution mains. Secondment with Southern Water to understand the wastewater disposal and treatment for Northfleet and Ebbsfleet regions. This involves collection of details of the sewer network and the wastewater treatment plant.	Exeter
Preliminary urban metabolism model development by integrating EDC, Thames and Southern Water data sets.	Exeter
Simulating household rainwater harvesting system's performance in Ebbsfleet Garden city (WP2).	Exeter

Key Outputs

Allen, D., Arthur, S., Haynes, H. and Olive, V. (2016). Multiple rainfall pollution transport by sustainable drainage systems: the fate of fine sediment pollution. *International Journal of Environmental Science and Technology.* 14(3), 639-652.

Allen, D., Haynes, H. and Arthur, S. (2017). Contamination of detained sediment in sustainable urban drainage systems. *Water.* 9(5), 355.

Alsubih, M., Arthur, S., Wright, G. and Allen, D. (2016). Experimental study on the hydrological performance of a permeable pavement. *Urban Water Journal.* 14(4), 427-434.

Behzadian, K and Kapelan, Z. (2015). Modelling metabolism-based performance of an urban water system using WaterMet2. *Resources, Conservation and Recycling.* 99, 84-99.

D'Arcy, B., Kim, L-H. and Maniquiz-Redillas, M. (2017). *Wealth Creation without Pollution: Designing for Industry, Ecobusiness Parks and Industrial Estates.* IWA Publishing, 330p.

Kapetas, L. and Fenner, R.A. (2017) Identifying effective Grey / Blue Green drainage solutions through an adaptation pathways approach. TWENTY65 conference, Manchester, 17-18 April 2018.

2.2.2. WP2. Managing stormwater as a resource

Stormwater is frequently considered a hazard leading to a focus on extreme events at one end of the hydrological spectrum which can cause catastrophic flooding, property damage and potentially loss of life. As we enter a more uncertain climate the need to retain and utilise stormwater as a vital water resource comes more sharply into focus. WP2 examines these options and how they interact with the urban system both in the short and long term, and the benefits that can be secured both directly and indirectly (Figure 2.2.2.1).

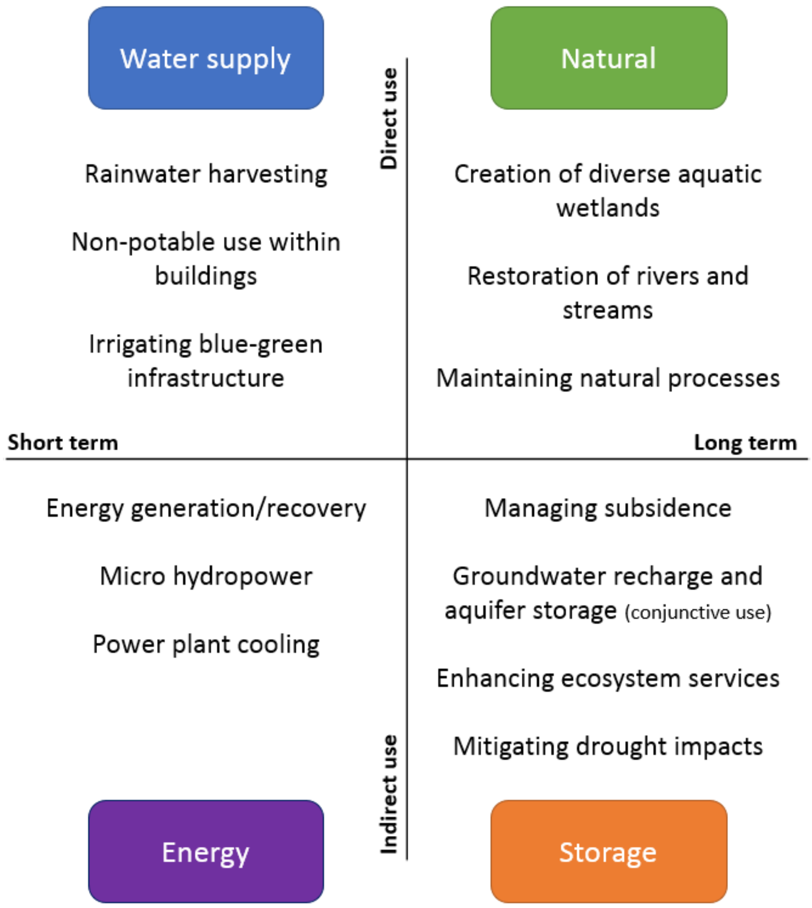


Figure 2.2.2.1: Options for stormwater reuse

The following research question is posed here: how can engineered stormwater management systems be better aligned with natural processes and other physical infrastructure to:

- realise the resource potential of all forms of urban water, with opportunities for storage, recovery and reuse being taken at every stage of the urban water cycle; and
- provide reliable quantities as required so stormwater management becomes increasingly inter-operable with other urban systems (esp. transport, land-use and energy) (WP3)?

Objectives

1. To develop procedures and design methods to derive greater benefit from the management of the urban water environment under flood, normal and drought conditions states through utilisation of stormwater resources.

2. To examine ways of coupling models for urban hydrology, hydrodynamics, stormwater storage and water quality for the purposes of establishing the potential for both direct and indirect use of stormwater in the short and long term.

3. To develop concepts of the 'stormwater cascade' where captured stormwater may be utilised multiple times as it moves through urban catchments, including:

    a. Evaluation of the potential benefits of household rainwater harvesting for water supply augmentation and flood management
    b. Evaluation of the efficacy of the British Standard for rainwater harvesting system design
    c. Demonstrate the potential benefits of rainwater harvesting in large-scale developments

Work Package Team

WP2 is led by Richard Fenner. Research is delivered by four partner universities, with specific responsibilities as shown below:

- Richard Fenner and Leon Kapetas (University of Cambridge): Micro-hydropower, groundwater recharge and urban landscapes
- David Butler, Zoran Kapelan and Sangaralingam Ahilan (University of Exeter): Non-potable use in buildings/Rain-Water Harvesting
- Chris Kilsby and Vassilis Glenis (Newcastle University): Surface and sub-surface interactions
- Vladimir Krivtsov, Scott Arthur, Chris Kilsby and Greg O'Donnell (Heriot-Watt and Newcastle University): Urban stream restoration

Study Approach and Methods

1. University of Cambridge

The potential to recover energy from stormwater is explored by developing a feasibility tool which looks at the key physical/site and climatic characteristics as well as economics. The approach looks at how a retention pond can decouple the problem of intermittent rainfall and energy generation. A comparison is therefore made between existing run-of river (i.e. with no storage) schemes and systems where a pond can slowly release water to generate energy at a turbine carefully selected.

In addition, research is carried out to evaluate the potential for aquifer recharge and storage using stormwater. The work establishes the factors that influence the scheme (climatic, hydro-geologic, water quality, etc.) and the techniques available (e.g. passive infiltration *vs.* well injection). An analysis of the current policies hindering the application is carried out and recommendation will be made.

2. University of Exeter

The aim of is to systematically evaluate potential benefits of Rainwater Harvesting (RWH) on water supply augmentation and urban flood management in the UK cities. Earlier UK RWH studies typically focused on the potential impact of RWH on water supply augmentation only. Whilst, it is still unclear, what benefits can be obtained from a typical household and large-scale RWH systems, what efficiencies are achievable with respect to standard design methods and what is the relationship between water supply augmentation and flood management. WP2 (Exeter University) aims to expand the existing knowledge and methodology on simple purpose RWH system (water supply only) to dual purpose RWH systems (water supply and flood management) through long-term modelling and simulation.

The methodology adopted in the study for the evaluation of rainwater harvesting system is shown in Figure 2.2.2.2. The approach is applied to both household and Northwest Cambridge Development large-scale rainwater harvesting systems.

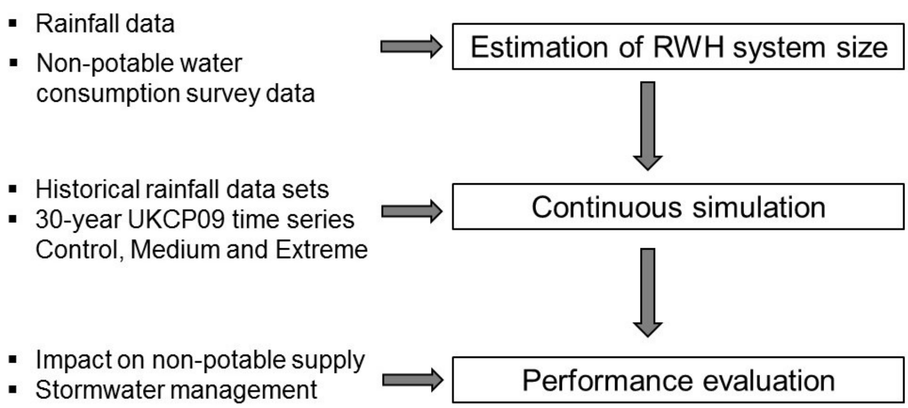


Figure 2.2.2.2: Performance evaluation methodology

In the first stage, the storage volume of the rainwater harvesting (RWH) system is estimated based on the British Standard (BS 8515:2009+A1:2013, simplified, intermediate and detailed approaches). High-resolution micro-components water use data sets of 62 properties across the UK is used to establish household non-potable water consumption patterns in the UK typical 1, 2, 3 and 4-bedroom house.

The second stage involves the continuous simulation of 15 minutes rainfall data sets through the RWH system. Historical rainfall data sets obtained from the Environment Agency and used to account for natural variability in the rainfall on the RWH system's performance over a 30-year simulation period. In addition, 100 equally probable independent UKCP09 hourly rainfall data sets of 30-year time horizon from 2010 to 2039 will also be used in the to account for climate change impact on the rainfall pattern and the system performance. Rainfall ensamples from the three UKCP09 emission scenarios: low, medium and high which correspond to the Intergovernmental Panel on Climate Change (IPCC) scenarios of B1, A1B and A1FI respectively will be considered. This allows inherent uncertainties in the individual climate projection scenarios and the variations amongst the different climate projection scenarios to be accounted for.

Continuous simulation allows evaluation of the system's performance in terms of both non-potable water supply and stormwater attenuation. In the third stage, therefore, a set of non-dimensional indices (e.g. water-saving efficiency, rainfall overflow ratio, reduction in peak overflow) is used to evaluate, compare the impact of differing design storage volumes of the British standard design methods on system performance. Recommendations on the appropriateness of each method will be made.

3. Newcastle University

To understand the potential of rainwater as a resource at the city scale, it is firstly important to gain knowledge of the fate of rainfall. Of importance is the split between green spaces that provide infiltration capacity and impervious surfaces connected to the sewer network, and the extent to which the network is separate or combined. However, reliable quantification of the green areas of our cities is lacking. Previous studies have used relatively coarse resolution satellite data that fail to adequately capture the detail of the urban environment, including gardens (e.g. LCM2015 at 25m; CORRINE at 10m).

The OS MasterMap Topography Layer provides detailed and accurate representations of land use, including individual buildings, roads and other infrastructure. Using this data set, for 26 highly urban catchments located in 6 urban conurbations we have extracted and classified land use into over 10 categories, including roads, buildings, gardens, water bodies and agricultural land. This data set, coupled with knowledge of the combined/separated sewer network, provides information regarding storm water contribution to waste water works. This information can underpin decision-making regarding the potential of blue-green infrastructure to reduce pressure on waste water works, and the benefits of the installation of water butts and other measures to prevent flashy runoff.

In related work, we are gaining an understanding of the impacts of built environment on the seasonal water cycle of highly urbanised catchments. It is not just the impact of urbanisation on hydrological processes that is of importance, e.g. decreasing infiltration, but also the net export of water through the combined sewer network. An analysis of the 26 urban catchments indicates that the seasonal cycle of monthly flows is often dampened, through the export of water in winter and the reduced infiltration in summer. Using this data set we have produced a procedure that can estimate the fraction of the catchment that acts as either "green" (i.e. providing infiltration capacity), or contributes to the combined sewer network or contributes to the separate sewer network. This work is being extended to examine individual storm events, comparing the response of paired urbanised / rural catchments.

These tools are being used to explore the management of surface runoff. A major focus is the Newcastle/Ouseburn catchment, in which the Newcastle Great Park development will provide over 3000 new homes by 2030. SUDS have been constructed downstream of the development, on the floodplain of the Ouseburn, to mitigate flashy runoff. Figure 2.2.2.3 (left panel) shows the partitioning of land use into urban (black), green space (green) and impermeable (brown; e.g. roads and carparks) areas. A satellite image of the area is provided in the right panel. The land use map provides a basis for targeting blue-green interventions to manage excessive flashy runoff.

Figure 2.2.2.3: Newcastle Great Park Development with SUDS. Land cover derived from OS Topography Layer (left hand panel) and Google Map image of the area (right hand panel).

4. Heriot-Watt University

SuDS Pond Water Quality, Biodiversity & Ecosystem Functioning

The work of the Heriot-Watt University team in WP2 aims to study the ecosystem functioning and services/benefits provided by SUDS ponds and compare them with non-SUDS ponds. This avenue of research is linked to our studies within WP1 (see previous section). In particular, this work aims to link the characteristics of suspended particulate matter to their impact on pond ecology. We also aim to study the provision of multiple benefits, including biodiversity and amenity values (Jarvie *et al.* 2017).

Within WP2, it is intended to gather information on the biological community of the ponds and adjacent areas, using a number of ecological surveys (e.g. vegetation, fungi, vertebrates, aquatic invertebrates). We also intend to characterise the planktonic community of these ponds, and in particular the presence or absence of cyanobacteria, and the abundance of diatoms. For that, information on certain nutrient concentrations, in particular N and P, is also being gathered. For chemistry, each pond is being sampled at two points. The water samples are filtered and frozen awaiting further analysis. The intention is to run them for determination of anions and cations using chromatography in the Lyell labs.

Sampling sites

Currently, we are studying nine ponds:

1. Granton Pond, Edinburgh. It is a drainage (SUDS) pond, which provides amenity and biodiversity values. The pond was established in 2005 and is situated in a park, close to a supermarket and a college, with an area of approximately 12,000 m^2. It is managed by Capita Symonds/National Grid.
2. Juniper Green Pond, Edinburgh. It is a SUDS pond, which appears to be a focal point for nearby flats. It is situated in a residential area at Woodhall Millbrae (adjacent to flats 1-12) near the Water of Leith footpath, and has an area of approximately 240 m^2. According to Jarvie *et al.* (2017), the pond was (re)established in 2005, and is managed by James Gibb company.
3. Oxgangs Pond, Edinburgh, is also a SUDS pond providing amenity and biodiversity values. It is located in a residential area adjacent to Firrhill Neuk, and has a surface area of approximately 8,099 m^2. Jarvie *et al.* (2017) give the date of establishment between 2007–2010. The pond is owned by Dunedin Canmore, but management appears to be subcontracted to Water Gems – a landscaper and water features specialist based in central Scotland (https://www.watergems.co.uk).
4. SUDS pond at Eliburn, Livingston is located near a residential area and light industrial units at Appleton Place. The pond is fenced and is not accessible to the public; however, we expect a considerable biodiversity value precisely for that reason. It has a surface area of approximately 1,675 m^2. Jarvie *et al.* (2017) give the date of establishment between 2007–2011. The site is owned by Gladmans.
5. Another SuDS pond in Eliburn is located in nearby Eliburn Park. The pond is fenced off and vegetation in and around the pond is still being in the process of establishment. The site is owned by Gladmans.
6. Blackford Pond is located within Edinburgh Local Nature Reserve. This relatively large pond (surface area 13,500 m^2) provides obvious biodiversity and amenity value, and is enjoyed daily by many visitors. The pond is thought to be natural, and established in the 19th century (Jarvie *et al.* 2017). The pond, however, represents an important component of blue-green infrastructure, having a considerable role in flood resilience.
7. A woodland pond in Goreglen, Midlothian is situated near a main road within a local biodiversity site (LBS) west of Gorebridge. The pond is relatively small (500 m^2 surface area) and is in the floodplain of Gore Water. Creation of the pond dates back to 1794–1861 (Jarvie *et al*. 2017) and was related to coal mining operations in the area. Maps from the period show connections of the pond to the river, but on inspection those are not current, and according to the rangers the pond has not received any surface inflow for the last few years. It is currently owned by the Midlothian Ranger Service. Due to its position within the floodplain, this pond has a role in flood resilience.
8. RBGE pond, Edinburgh is situated within the botanic garden. Being near a residential area, it provides an obvious amenity and educational value. The pond has surface area of 4,560 m^2 and appears to be mainly rainwater and groundwater fed, with no permanent inflow. An outflow pipe connects the pond to the Water of Leith.
9. Inverleith Pond, Edinburgh is situated in Inverleith Park. It has surface area of 43,554 m^2 and supports model boat activities, recreation, and the feeding of wildfowl. The pond appears to be managed by the Local Authority. Historically, it was used for recreation as a boating lake. However, a wetland was retrofitted at the inflow point, and the pond now carries out both pollution prevention and flood resilience functions.

Acknowledgements and further contributions

The activities of Heriot-Watt University team have been undertaken with the assistance of volunteers, as well as HWU postgraduate students, notably Joy Jarvie. The study has also benefitted from valuable input from Professor L. Beavers (Heriot-Watt University). Initial findings on the ponds' valuation have been published in a peer-reviewed journal (Jarvie *et al.* 2017)

The team have also contributed to the following:

- Macroinvertebrate identification (in relation to water quality assessment) workshop in Windermere (September 2017)
- SNH & Edinburgh Living Landscapes GI Practitioners Event, Edinburgh (October 2017)
- LAAs in Dartford (October 2017) and in Ebbsfleet (November 2017)
- Presented at the joint HW-RBGE symposium (March 2018)
- Poster presentation at the TWIC conference in Alloa (April 2018)
- Poster presentation at the Postdoc Symposium in Heriot Watt (May 2018)

Progress to Date

Progress	Objectives Met
Factsheet on energy recovery from stormwater published on website This fact sheet is entitled "Exploring the potential to recover energy from urban stormwater". The fact sheet is based on a publication currently prepared for submission. It presents an easy-to-use screening tool that evaluates site feasibility for microhydropower generation.	1 and 3
Draft paper on energy recovery from stormwater See item above	1 and 3
Research on aquifer recharge and storage of stormwater Currently an MPhil thesis is carried out to evaluate the potential of this approach, establishing the factors that influence recharge/storage and the techniques available (e.g. passive infiltration vs well injection). An analysis of the current policies hindering the application is carried out and recommendation will be made	1, 2 and 3
Blog on Low-Tech Low-Cost Blue-Green Infrastructure published on website This blog discusses some easy to implement SuDS installations done through community leadership. The aim of the blog was to highlight the importance of civil participation on strengthening urban flood resilience. The blog was entitled "Low-cost small-scale blue-green interventions: community led projects enhancing urban flood resilience" and was accessed by more than 500 people within the first 2 months of publication	1
Blog on "The need for Multi-functional design" published on website This blog discusses the need to identify the dominant multiple benefits (focusing on local challenges) and involve specialist in co-designing the solution such that benefits are fully captured.	N/A

[Table continued on next page]

Draft paper on the impact of urbanisation on catchment hydrology A paper is in preparation examining how urbanisation, including the role of the sewer network, has impacted on the seasonal runoff in over 20 catchments, using a paired catchment approach. Additionally, the flashiness of events is being characterised.	In progress
Literature review on rainwater harvesting Compiling and reviewing extensive literature data base on rainwater harvesting research across the globe. Reviewing and formulating British Standard BS 8515:2009+A1:2013 on household rainwater harvesting system design.	3a and 3b
Collating of UK rainfall data Collated finer resolution rainfall data sets throughout the UK from Environment Agency and micro components of the household water consumption data sets of the 62 properties across the UK from Artesia Consulting Limited.	3a and 3b
Development of rainwater harvesting models Developed a mathematical tool and carried out long-term simulation of the performance of rainwater collection and reuse system using historical and projected rainfall (UKCP09) data sets over the 30 years period.	3a and 3b
Collaborations (rainwater harvesting) Site visits, data collection and collaboratively work with South Staffs and Artesia Consulting Ltd on NWCD rainwater harvesting system field study.	3c

Key Outputs

Journal article publication

Fenner R.A. (2017). Spatial evaluation of multiple benefits to encourage multi-functional design in blue green cities. *Water*. 9, 953. http://www.mdpi.com/journal/water/special_issues/Sponge-Cities

Jarvie, J. A., Arthur, S. and Beevers, L. C. (2017). Valuing multiple benefits, and the public perception of SUDS ponds. *Water*, *9*(2).

Conference participation and proceedings publication

Ahilan, S., Melville-Shreeve, P., Kapelan, Z. and Butler, D. (2018). The influence of household rainwater harvesting system design on water supply and stormwater management efficiency. *11th International Conference on Urban Drainage Modelling*, 23-26th Sep, Palermo, Italy.

Butler, D., 2018. From Rainwater Harvesting to Rainwater Management Systems. *11th International Conference on Urban Drainage Modelling*, 23-26th Sep, Palermo, Italy. (Key note presentation).

Fenner R.A. (2017). A spatial evaluation of multiple benefits from Blue Green infrastructure. *Twenty65 Conference*, 4-5 April, Manchester, UK.

Fenner R.A. and Hoang L. (2017). Institutional perspectives on impacts and benefits of an urban flood management project, Portland, Oregon; *Proceedings of 14th International Conference on Urban Drainage*, Prague, September 15-20 2017.

Fenner R.A., O'Donnell E. (2017) Overcoming barriers to Blue-Green infrastructure through multiple benefit evaluation. *7th International Conference on Flood Management*, September 5-9, Leeds, UK.

Kapetas L. *et al*. (2017). Linking extreme weather intensification to socioeconomic trends via a participatory urban resilience assessment: A case study on Thessaloniki. *14th International Conference on Urban Drainage (ICUD)*, IWA/IAHR (Prague, Czech Republic, 10-15 September 2017) Conference Proceedings pp 2023-2031.

Melville-Shreeve, P. and Butler, D. (2018). Quantifying Long-term Benefits of Multi-Purpose Rainwater Management Systems. *11th International Conference on Urban Drainage Modelling*, 23-26th Sep, Palermo, Italy.

Books and book chapters

Fenner R.A. (2017) Water: essential resource and critical hazard. Chapter 5 in Building Sustainable Cities of the Future: from small urban centers to megacities (Ed Bishop JK.) , pp 75-98 (Springer) ISSN 1865-3529 ISBN 978-3-319-54456-4 DOI 10.1007/978-3-319-54458-8

Technical reports

Fenner R.A. (2017) Using Green Infrastructure to achieve multi-functionality in urban stormwater management, CitiBank Global Perspective Solutions: Water (https://www.citivelocity.com/citigps/ReportSeries.action?recordId=61)

2.2.3. WP3. Inter-operability with other systems

The aim of work package 3 (WP3) is to investigate how interoperability between different urban infrastructure systems (i.e. multi-system functionality) can provide a practical approach to move towards more integrated forms of urban flood risk management (figure). WP3 aims to produce the knowledge and approach necessary to facilitate interoperability in flood risk management, i.e. the active management of connections between infrastructure systems, to increase the functionality of the whole system (i.e. a city) to deal with exceedance events (e.g. SUDs).

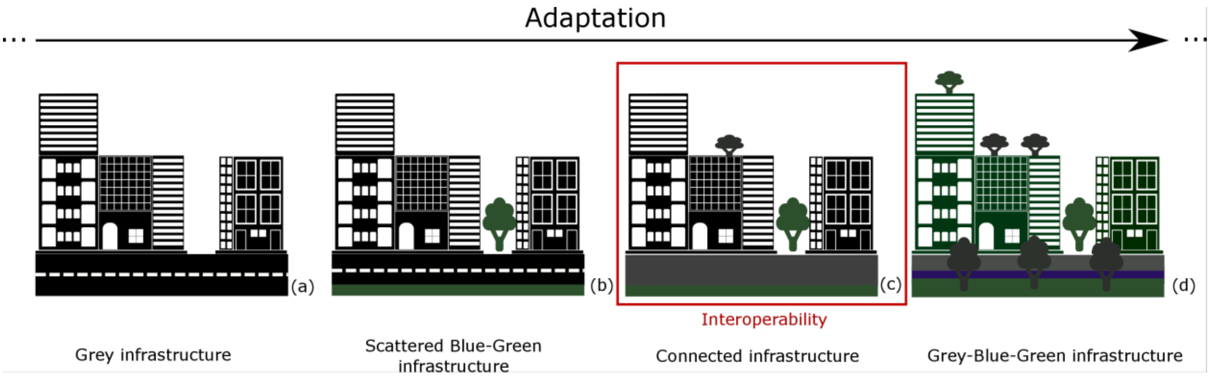


Figure 2.2.3.1: Interoperability as step towards flood resilient Blue-Green cities

Objectives

WP3 has three main objectives:

1. Define interoperability: The first step is to clearly define what interoperability means in the context of urban flood resilience and flood risk management, to demonstrate the rationale behind it, and to provide real-world examples.

2. Collect (spatial) data: An important aspect of integrating multiple systems in the urban environment is a good understanding of what information is needed to move towards interoperable design solutions. Therefore, data will be collected on what aspects are important to consider, based on scientific literature as well as discussions with stakeholders.

3. Develop spatial analysis framework: There is currently no systematic way to integrate multiple infrastructure systems and other available information related to flood risk (e.g. physical characteristics, socio-economic impacts, stakeholders, etc.) to do a suitability analysis for urban planning and where to implement interoperable solutions. We therefore investigate how to use (freely) available spatial information to screen urban areas to locate hotspots for connecting existing systems and identifying interoperable possibilities.

Work Package Team

David Dawson (University of Leeds) leads WP3 and the research is carried out by by Kim Vercruysse (University of Leeds). Input is also provided from Nigel Wright (De Montfort University), Chris Kilsby (Newcastle University), Richard Fenner (Cambridge University). Collectively, they have extensive interdisciplinary capacity in the field of flood management and resilience. Specific expertise of the team includes flood simulation/modelling, hazard analysis, evaluation of flood benefits, climate change, adaptation economics, urban and infrastructure resilience, and system approaches to flood risk.

Study Approach and Methods

First, a literature review is being performed to produce a synthesis of systems-thinking in flood risk management and resilience, progress made is the last decades in terms of assessing flood risk and vulnerability, and to identify current knowledge gaps towards achieving urban flood resilience at the system-level.

Building further on the literature review, a spatial analysis framework will be developed to enable planners and practitioners to identify suitable locations for interoperable solutions and to visualise the complexity of multi-system approaches for flood risk management. The framework will be based on datasets freely available/accessible to all stakeholders (as much as possible) to enhance application in other cities, and to allow stakeholders to include site-specific criteria in the framework. The spatial analysis will be based on the weighted overlay function in GIS software ArcGIS, and is based on a set of physical, socio-economic and infrastructural criteria which influence the suitability of interoperable solutions (see illustration of end result in figure). We aim to weigh (or define the importance of) different criteria for interoperability by including knowledge and insights from other WPs, by talking with SAB members, and by having discussions with stakeholder groups. The framework will be applied to the case study cities Newcastle and Ebbsfleet.

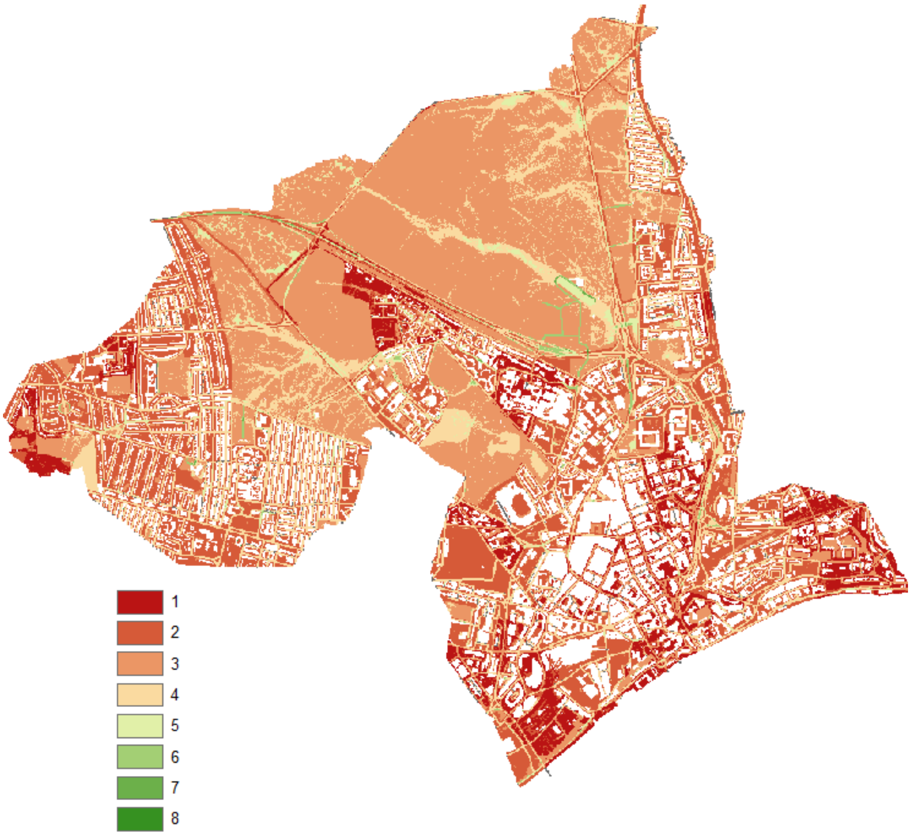


Figure 2.2.3.2: Simplified illustration of suitability analysis for interoperability, applied to the urban core in Newcastle. Flood hazard (CityCAT) and population density are used together with the road network and green spaces. High values (green) indicate locations most suitable for interoperability between the road and green space network (combination of high flood risk, low population density, minor road and close to park).

Progress to Date

Progress	Objectives Met
Briefing note distributed among SAB members The briefing note was distributed after the QPM in January 2018 and feedback was received from SAB members. This feedback was used to refine the focus of the research.	1
Factsheet published on website defining interoperability for flood resilience After consulting with team members of WP3, a factsheet was published on the website which aimed to set the scene of the research. It outlines the rationale behind the need for interoperability and provides some concrete examples.	1
Draft paper on interoperability A first paper draft is produced which further discusses the rationale behind interoperability in flood risk management. The manuscript synthesises the current knowledge and gaps in flood risk management from a systems perspective and will also outline the concept for the analysis framework.	1, 2 and 3
Gathered spatial data on Newcastle Available spatial data on Newcastle has been collected, including: a) Flood risk information (CityCAT) b) Socio-economic data (census data) c) Infrastructure systems (OS Mastermap) d) Traffic and air pollution (Urban Observatory) This data will be used to test the methodological approach.	2
Methodological approach development (As outline above)	3

Key Outputs

Publications

- Factsheet on website which defines Interoperability in the context of urban flood resilience
- A more detailed briefing note was also produced to inform SAB about the rationale of the WP

Meetings

- CityCAT induction day + meeting at Urban Observatory (01/02/2018, Newcastle)
- Meeting with David Wilks at Arup about interoperability (08/02/2018, Leeds)
- WP3 skype chat with Dick Fenner and Leon Kepatas (feedback factsheet and linkages WPs) (15/02/2018)

Talks and conferences

- Presentation at SCOTTS Flood Group Meeting (through SAB buddy Dave Gowans) (22/02/2018, Glasgow)
- European Geosciences Union – presentation at session "Urban Resilient Studies" (10/04/2018, Vienna)

Invitation for a presentation at British Water Surface Water Management Focus Group (24/05/2018, London)

Research Impact

Once the methodology is complete we plan to engage stakeholders with the approach. The final year of the WP will be focused on impact related activities; Ebbsfleet remains a primary focus of this.

2.2.4. WP4. Citizens' interactions with B/G+G infrastructure

The aim of WP4 is to develop our understanding of how attitude and behaviour change amongst flood professionals and urban residents might be achieved, to encourage greater co-development of B/G+G infrastructure such that devices put in place are more appreciated over the longer-term. This should in turn hopefully improve *felt* amenity benefits, behaviour and people's willingness to get involved with voluntary lay-maintenance and clearing. This should improve functioning and reduce maintenance costs to developers and Local Authorities, making devices more sustainable.

Objectives

The aim of WP4 in relation to the wider research project is to gain access to core groups within communities, to gain an understanding of their feelings towards blue-green and grey device; working with these groups to survey community preferences, trial community interventions to raise awareness,; and build transferable principles of community engagement. Its specific objectives are to:

1. Establish baseline data. WP4 will need to first understand who the communities living around and using (or not using) devices are, what their feelings about the B/G+G devices are and whether or not they feel they achieve what they are intended to, in terms of both reducing flood risk and providing multiple benefits. WP4 can then look to understand the strengths and weaknesses of contemporary modes of engagement, how well communities and professionals feel these have worked in raising awareness, encouraging engagement and improving behaviour.

2. Understand community preferences. Beyond the preferences of a core group of participants, WP4 will need to gather data more widely from communities around the B/G+G devices. WP4 will also need to try to get beyond people providing what they perceive to be the more 'socially acceptable' answer of 'liking' all green infrastructure, using contemporary social psychology tools. WP4 will work alongside the core group to co-develop processes and means of effectively engaging wider communities, to gather their views.

3. Evaluate and assess the effectiveness of different interventions. WP4 will work with the core group to develop and implement interventions to affect community awareness, engagement and behaviour. WP4 and participants will be positioned to assess the efficacy of these different tools in context.

4. Develop transferable principles of B/G+G FRM community engagement. Lessons learnt from established B/G+G infrastructure and communities will be transferable to future developments. For this reason, case studies from each site (detailed in following section) will be developed to demonstrate how citizens' priorities and the reality of their lifestyles, communities, and neighbourhoods shape their understanding, preferences and behaviour in ways that will impact upon the ongoing costs and sustainability of B/G+G devices.

Work Package Team

Dr Jessica Lamond (UWE) will lead WP4 with input from Karen Potter (OU) and Colin Thorne (Nottingham) supported by Glyn Everett (UWE), Emily O'Donnell (Nottingham), Shaun Maskrey (Nottingham) and Tudor Vilcan (OU). UWE will lead on the analysis of existing data and design of engagement tools with the support of Nottingham and OU. UWE and OU RAs will focus on the engagement activities in situ in Bristol and Milton Keynes with Nottingham RA focussing on IAT (Implicit Association Test) and social media engagement activities.

Study Approach and Methods

WP4 will look to extend and deepen public involvement through a Critical Communicative Methodology, encouraging understandings and approaches to the research to be developed with 'the researched' (Gómez et al., 2013; Rodríguez et al., 2013; Flecha and Soler 2014). In this way, WP4 will pursue a Participatory Action Research (PAR) approach to community engagement (Brydon-Miller et al., 2003), looking to facilitate the empowerment of communities and develop their voices within the city.

This might in turn help to encourage behaviour change, hopefully cultivating 'cultures of enthusiasm' (Geoghegan, 2012) whereby the development of interests and skills work in tandem, with and through local communities, to encourage people taking ownership of B/G+G devices within their area.

The aim will be mutual awareness-raising, for all (researchers, professionals and community members) to engage and learn from their involvement, sharing knowledge and understanding, upskilling participants and making maximum use of both lay and professional knowledge, skills and capacities.

PAR emphasises equal-standing and collaboration between 'researchers' and 'the researched', combining research with action and looking to make a tangible difference to participant's lives (social change) as well as producing useful and transferable knowledge. To this end, specific research questions will remain necessarily under-defined at the beginning of the project, because community input may change the focus; questions will emerge from conversations.

Engagement could include: raising awareness of flood-risk and different possible means to counter this, and discovering different community priorities and preferences around a portfolio of B/G+G strategies. A further stage of engagement would involve learning about and reflecting upon helpful and unhelpful behaviours in the wider community, and reflecting upon opportunities for encouraging behaviour-change that might enable the better performance of B/G+G infrastructure.

Three sites have been chosen around Bristol and one in Ebbsfleet; the Bristol sites were selected following conversations with Bristol City Council and South Gloucestershire Council to be Emersons Green, Hanham Hall, the ongoing Southmead SuDS development work. The Site in Ebbsfleet was selected based on consultation with the Ebbsfleet Development Corporation.

Progress to Date

Progress	Objectives Met
Implicit Association Test (IAT) A literature review into eliciting of implicit preferences was conducted by Emily O'Donnell at Nottingham. This literature review informed the development of the Implicit Association Test (IAT). An IAT has been developed to run on both a laptop/tablet (utilising the FreeIAT software) and online by Emily O'Donnell, Shaun Maskrey and Anush Poghosyan with support from Jessica Lamond. Having the two versions gives the greatest flexibility for use across different work packages. A trial IAT has been developed at Nottingham by Shaun Maskrey (with technical support from Anush Poghosyan) to explore residents' perceptions of sustainable urban drainage systems (SUDS) in public green spaces (parks, etc.). In this IAT, the respondent is presented with a series of photographs of public green spaces with and without SUDS features. The IAT records how quickly the respondent associates these images with positive and negative descriptive words taken from a word bank. The word bank contains 150 words, which are organised into three sub-categories: tidiness, attractiveness and safety. This IAT will be used with communities in Bristol (and potentially at other sites) in spring and summer 2018. In this trial, the IAT will be used alongside self-reporting measures such as the feeling thermometer and Likert scale to compare and contrast the preferences elicited. Self-report measures have been developed by Shaun Maskrey for the IAT trial. The IAT will be able to be used across multiple work packages, addressing a range of research questions in relation to blue-green and grey infrastructure, with a range of different communities.	2, 3 and 4
Identify and develop links with local community groups Sites were selected based on the need to consider a variety of developments and installed features. Retrofit, mature development and new development sites have been selected and the focus is on features that are visible in the urban space. An assessment of local interest groups was undertaken. Documentary evidence has been gathered on the developments and	

engagement relating to them. Dialogue with key stakeholders has been initiated. Links have been developed with local groups where they exist in Emersons Green, Hanham Hall and Ebbsfleet. Links with key individuals in such groups and in the stakeholder organisations involved in planning and managing schemes have been made. This is still an ongoing process as the initial baseline analysis has revealed further stakeholder groups.	
Papers on understanding the strengths and weaknesses of contemporary modes of engagement This is being approached through extensive literature review and from the dialogue around study sites. The literature review has been presented at a conference and is now summarised into a journal paper and briefing note. Initial findings around the Bristol Case study sites has been summarised into a conference paper.	1 and 3
Conduct Initial observations with local community groups Site visits and observations have been conducted at the three Bristol sites. A research participants group has been established at Hanham Hall; Events have been attended at Emersons Green and a blog has been posted to the *Friends of* group, and further contacts have been gathered, and observations have been conducted at Embleton Road in preparation for approaching parents of the road's school in July.	1, 2 and 3
Collecting and analysing data around existing BG+G devices Using data previously collected around retrofit devices in Newcastle and Belfast a social practice theory approach has been taken to understanding different perspectives and ownerships of practice communities. This has been presented as a conference paper and is now being developed into a journal paper.	1, 2 and 4
Analysing attitudes to potential BG+G devices Analysis of attitudes of commercial property occupiers towards retrofit of small scale SUDs has been conducted based on interviews conducted in Newcastle Central Business District. This has been presented at the Newcastle Learning and Action Alliance and published as a journal paper.	2 and 4

Key Outputs

Publications

Adekola, O., Everett, G. and Lamond, J. (2018). A Proposal for a Community Engagement Framework for Co-Developing Blue-Green Infrastructure (BGI) in the Built Environment. *Health: The Design, Planning and Politics of How and Where We Live*. Bristol: Architecture Media Politics Society.

Everett, G. and Lamond, J. (2018). Considering the value of community engagement for (co)-producing blue-green infrastructure. *Flood Recovery Innovation and Response VI.* Southampton: WIT Press.

Everett, G. and Lamond, J. (2018). Green roofs: Perceptions in the Newcastle, UK CBD. *Journal of Corporate Real Estate*. ISSN 1463-001X [In Press].

Everett, G., Lamond, J., Morzillo, A. T., Matsler, A. M. and CHAN, F. K. S. (2018). (submitted). Point of Opportunity Interactions (POI) for Understanding Opinions about Green Infrastructure. *Society & Natural Resources*

Everett, G. (2017). *SuDS and human perceptions.* In Charlesworth, S. and Booth, C (Eds.). Sustainable surface water management. Oxford: Wiley-Blackwell.

Everett, G. and Lamond, J. (2017). 'Everyone loves a bit of nature … I think it's a great idea' : Business perspectives on increasing BGI in Newcastle's CBD. *Newcastle LAA relaunch.* Newcastle on Tyne.

Everett, G. and Lamond, J. (2016). SuDS and human behaviour: co-developing solutions to encourage sustainable behaviour. *E3S Web Conference (3rd European Conference on Flood Risk Management).* 7, 15pp.

Lamond, J. (2018). Water: a world issue. *Watermarks- architecture in a fluid world.* Portmeirion, Wales: Royal Society or Architecture Wales.

Tools

Three versions of the IAT tool: laptop, tablet and web-based.

Research Impact

Participatory Action Research has impact on the communities participating throughout the project. Groups around the case study sites in Bristol and Ebbsfleet are learning about the flood risk management aspects of blue-green infrastructure and developing deeper appreciation as a result.

Findings from the Newcastle Central Business District have been presented to the Learning and Action Alliance and informed ongoing planning for interventions in the City.

The community of architects in Wales have developed an improved understanding of the importance of engaging with blue-green infrastructure to enhance design principles towards aesthetic enhancement of urban spaces.

2.2.5. WP5. Achieving urban flood and water resilience in practice

WP5 is divided into two linked sub-WPs;

1) Putting flood risk management at the heart of planning, and

2) Demonstration case studies.

WP5.1. Putting flood risk management at the heart of planning

Research for WP5.1 attends to the investigation of the socio-political context of the urban land-use planning system and this system's impact on the wider governance arrangements of water management. A clear conclusion from the Blue-Green Cities research project was that reducing scientific uncertainties alone is insufficient in unlocking the potential for widespread uptake of BGI; stronger cross-sector integration and partnership working being key to overcoming the barriers (Thorne *et al.*, 2015; O'Donnell *et al*., 2017). However, the requirement to work in partnership with engineers/hydrologists and facilitate the delivery of integrated sustainable water management sits on the planner's priority list alongside a plethora of other environmental, social and economic issues and concerns – the majority of these issues and concerns being as complex and convoluted as the delivery of integrated water management (Potter *et al.*, 2011). More fundamentally, it is alleged that sustainable flood risk management is not a task for which planning is constitutionally well equipped; political and economic forces have powerfully shaped the profession from the push for the development in the 1960s and through ongoing decades against which planners have struggled to mainstream what is often fundamentally 'aspirational' policy regarding sustainable development (Howard, 2009; Potter *et al.*, 2016).

To meet the overall aim of this multidisciplinary proposal to make urban flood resilience achievable nationally, it was recognised by the Consortium that further research is required to target the ongoing restricted connectivity between land-use planning and sustainable water management policy. Through an action research orientated approach, WP5.1 works closely with practitioners to deepen the understanding and affect change at a practice level - how planners engage in a collaborative process with flood risk managers and other water-sector stakeholders, to develop integrated policy and strategies to broaden the uptake of B/G+G infrastructure.

The aim of WP5.1 is therefore to examine how the collaborative planning and decision-making process must evolve between responsible authorities and stakeholders (e.g. planners and developers responsible for urban form, engineers and scientists who design optimal water management solutions for specific locations and the communities at risk of flooding) to enable cities to achieve sustainable flood resilience and water security.

Objectives

1. Identify institutional barriers, and 2. Interpret institutional barriers to innovation within the planning process, to further understand the socio-economic context, in which planners must operationalise policy and take planning decisions that affect the sustainable flood resilience of cities

3. Role of planners and design process. To investigate how planners may play the crucial collaborative role and achieve consensus in strategic land-use decisions on B/G+G with and against various other planning objectives and other institutions' policies, whilst maintaining land values and enhanced development opportunities.

Work Package Team

WP5.1 is led by Karen Potter and Tudor Vilcan (The Open University), and assisted by Colin Thorne (Nottingham), Jessica Lamond (UWE), Emily O'Donnell (Nottingham), Shaun Maskrey (Nottingham) and Glyn Everett (UWE).

Study Approach and Methods

Action research should be, as asserted by Somekh (2005), the approach of choice for social science researchers focusing on innovation, due to its capacity to deepen understanding on the barriers and enablers to change – in this case, the barriers within the planning and development process. Action research can be particularly pertinent when a new phenomenon is introduced to bring about improvement (e.g. BGI), but because of the socio-economic and institutional complexity, attempts at change and implementing novel policy can often be frustrating and frequently not possible to implement as originally planned or intended. The Action Research methodology integrates social science inquiry with participants' own practical action aimed at dealing with real world problems and issues. Through the adoption of this approach, the research will seek to bring about change in an iterative, cyclical process of 1) data collection on the topic under investigation, 2) analysis and interpretation of the data, 3) planning and introduction of strategies to bring about change with 4) further evaluation of these attempts at change through the collection of further data. Whilst much research can claim to be applied and driven by real world problems, the important characteristic of action research is this linking of knowledge first generated by researchers being applied by practitioners, with a view to altering practices in a beneficial way (Denscombe, 2009).

Stage 1 - The first stage of the research will essentially seek to understand what is happening already in the collaborative planning process between responsible authorities and stakeholders. Through the process of data gathering, the institutional, socio-political and procedural (including gaps in knowledge and data) barriers to UFRM innovation will be identified, through: a) a critical interpretative review of the academic and practitioner literature relating to the barriers in the planning and water management domain; b) a secondary analysis of the data and findings from the Blue-Green Cities project that also identified socio-political barriers to the implementation of BGI, c) interviews and observation in relevant planning meetings with the case study stakeholders, participatory observation with the LAAs in Ebbsfleet and Newcastle, and d) complemented with exploratory discussions and interviews with key national participants in the flooding policy field.

Stage 2 - It is important that the first stage of the research does not merely empathise with participants and offer up a mirror to their experience, as is alleged of much 'qualitative' research (Silverman, 1993). 'Theory', as defined by Silverman (1993), is a set of explanatory concepts offering ways of looking at the world and which are essential in defining the research problem, to shed light and add insight to the meaning of the social processes witnessed in the planning and flood risk management domain. For example, the theory of Collaborative Governance is a practice based theory about the management of collaborations, structured in themes representing issues identified repeatedly by practitioners, e.g. differences in the operational and decision making procedures of an organisation, the misunderstandings and tensions created through the different values and language of a profession or discipline (Vangen and Huxham, 2012). The second stage of the research will seek to interpret the barriers to innovation – in an iterative process, comparing the initial data and observations with previously developed theory to develop an analytical framework; further collection and coding of data based on this framework and lastly, a return to the literature to refine the research concerns and theory.

Stage 3 - Action research seeks to go beyond merely describing a situation, analysing and theorising social practices – it also seeks to work in partnership with stakeholders to reconstruct and transform certain practices (Somekh, 2005). This will be operationalised through the LAAs in the case study cities (WP5.2). The general aim of innovation is to produce some form of change and to do things differently through the adoption and implementation of new ideas and policy (Hartley, 2012; Sørensen and Torfing, 2011 in Diamond and Vangen, 2017). Again, there is a rich body of literature providing theory and insight into transformative change. Although there are complex institutional and socio-economic factors and rigid structures and processes, working in collaboration provides important opportunities for public sector practitioners to lever opportunities that can emerge from working across sector boundaries, recombining concepts and practices from different disciplines to develop new learning and approaches.

Practical information/data needs for enhanced decision making will be identified and methods by which they can best be addressed will be determined, e.g. through data analytics (Krioukov *et al.* 2011), meta-learning or data mining (Spielman and Thill, 2008). Through the process of *Cognitive Modelling 4* systematic diagrams of aspects of the decision making process will allow for design of decision support systems that bring together the required data and knowledge. Comparative research will also be undertaken in other contexts to understand and demonstrate how identified barriers have been overcome.

Three major qualitative methods will be triangulated within the research stages above to reconstruct both the discursive and organisational aspects of the planning and flood risk management policy arrangement: through an analysis of documentation (e.g. planning policy and strategy, minutes of meetings); observation/participatory observation; and interviews and/or focus groups. Participant observation allows the distinctive opportunity to perceive reality from the viewpoint of someone 'inside' the case study, or as phrased by Silverman (1993), sharing in people's lives whilst attempting to learn and understand their world. Interviews are considered one of the main data collection tools in capturing the perceptions of actors and generating data which gives an authentic insight into people's experiences (Silverman, 1993). One of the hallmarks of focus groups is the explicit use of the group interaction to produce data and insights that would otherwise be less accessible without such interaction found in a group, stimulating participants in making explicit their views, perceptions, motives and reasons (Punch, 2013). The overall characteristic of qualitative research is that it is naturalistic and fundamentally depends upon watching and studying people and events in their territory and natural settings (Punch, 2013). Action research as a particular strategy works within the system, but also engages participants/stakeholders to own the problem, issue or concern and be involved with the research process – to be collaborators in the research rather than be watched and studied (Denscombe, 2009).

Progress to Date

Progress	Objectives Met
Identify institutional barriers Comprehensive literature review across planning, water management, governance and green infrastructure to capture the barriers/challenges known to date (or inferred); detailed examination of policy documents; analysis of the data arising from the published written evidence appended to the 6th Report of the Post-legislative scrutiny: Flood and Water Management Act and the Government's response to the report Participatory observation with Ebbsfleet Development Corporation and Kent County Council, including key stakeholder and design meetings with developers. Interviews with officers and employees of EDC. Analysis of drainage applications, together with a greater understanding of the nature and technicalities of the process Participatory observation with the Ebbsfleet Learning and Action Alliance (see section 5.2)	1
Interpretation of institutional barriers Literature review to examine the potential for innovation through theories of collaborative governance, interpretation of current suboptimal policy outcomes in the context of governance theories (e.g. Hajer's institutional void). Analysing the role of state planning and the implications from an interventionist role, to 'steering' and enabling development to unequivocally 'facilitating' economic growth	2 (ongoing)
Comparative analysis of SuDS policy in England and Wales Initiation of comparative analysis between the English and Welsh implementation of SuDS policy – if and how the consideration of positive policy outcomes is contingent on the choice of regulations, i.e. through the implementation (Wales) or non-implementation (England) of Schedule 3 of the Flood and Water Management Act (2010). Two focus groups with Welsh planners (and other stakeholders) at the RTPI's Wales Planning Conference	2

Key Outputs

Publications

- Draft paper on the 'Ditching' Schedule 3 of the Flood and Water Management Act (2010) and Delivery of SuDS through the English Planning System: a Proposed Case of Policy Void
- OU Blog - Placing Flood Risk at the Heart of Urban Planning (http://www.open.ac.uk/research/news/placing-flood- risk-management-heart-urban-planning)

Conferences/Workshops

- Workshop hosted at the RTPI Wales Planning Conference, Cardiff, 7 June 2018
- Guest speaker at the Urban Flood Resilience in Newcastle Workshop, Newcastle University, 2016
- Guest speaker at the National Environment Agency 'Sustainable Places' Specialist CPD/Conference, Nottingham, 2017
- Presentation and ongoing engagement with Defra/EA/WG/NRW Thematic Advisory Group (TAG) for Flood Risk Management Policy, Strategy and Investment, will inform and support the Defra/EA/WG/NRW Joint Programme of flood and coastal erosion risk management research and development regarding planning and flood risk management

Research Impact

- Participation as member of the CIRIA Project Steering Group for 'Delivering successful integrated water management through the planning system' (CIRIA RP1057), providing specialist advice to CIRIA's Project Manager on the project, including objectives, scope and the work programme, reviewing progress and outputs
- Response written and submitted to the Welsh Government Consultation on the implementation of sustainable drainage systems (SuDS) on new developments (15 February 2018)
- Development of case study material for the 'Collaborative Leadership' undergrad module, The Open University Business School.

WP5.2. Demonstration case studies

This section of WP5 is based in our two case study cities. The first case study will build on foundations laid and substantial progress already achieved by the Blue-Green Cities Consortium in Newcastle. Specifically, the Newcastle study will investigate how urban flood resilience can be achieved in practice in the contexts of urban renewal and expansion (i.e. through retro-fit, redevelopment and new build in developments at the urban fringe). The Ebbsfleet study will investigate how urban flood resilience can be achieved in the context of planning and developing an entirely new 'garden city'. Both cities were named in the successful proposal, submitting letters of support for that proposal and are committed to collaborating with the Consortium throughout its 3-year lifespan.

Newcastle Upon Tyne

Newcastle is a natural choice for the first case study. In their letter of support, Newcastle City Council noted that, across the world, the co-benefits of natural flood risk management approaches, such as green infrastructure are being realised and the frameworks to drive activity are being created, citing as an example how the European Commission's Covenant of Mayors on Sustainable Energy and its 'Mayors Adapt' scheme - of which Newcastle was one of the first signatories - are being brought together.

During the Blue-Green Cities project, key stakeholders in Newcastle developed tools and governance structures that built confidence that re-imagination of the City's existing approaches to flood risk and water management was *possible*. Crucial in this process was the Learning and Action Alliance (LAA), which the Blue-Green Cities project established. The LAA provides a safe forum to explore advanced UFRM modelling and best practice in flood risk management, as mentioned in the Local Flood Risk

Management Plan (Newcastle City Council, 2016). The LAA also helps develop consensus on the options available and appropriate to implementing innovation and change, as well as beginning to broaden horizons with respect to inter-operating urban water systems with other urban systems, such as transportation.

The potential for transformative change in Newcastle already existed prior to establishment of the LAA through individual contacts and networks between stakeholders, including, crucially, Northumbrian Water Ltd., Newcastle University, the Environment Agency and the City's primary water contractors, Arup and Royal HaskoningDHV. Having a dedicated forum where these and other institutional stakeholders could learn, unlocked the potential to turn these informal networks into an advocacy coalition that could move from envisioning a better water future for the city to implementing the first steps necessary to realising the latent ambition to make Newcastle a 'Blue-Green City'. For example, flood researchers at Newcastle University had already developed ideas for how road junctions and profiles could be modified to improve surface water drainage and reduce the vulnerability of the urban transport system to paralysis during heavy rain events like the 2012 'Toon Monsoon', which brought traffic to a halt just 35 minutes into the downpour. When academics from Newcastle University and other partners brought to the LAA ideas on how BGI could be incorporated into the streets of Newcastle they found a receptive group of like-minded professionals among the membership of the LAA.

The LAA process culminated at the Blue-Green Cities' Primary Knowledge Exchange and Research Dissemination Event at Newcastle's Centre for Life on 18th February, 2016, when key stakeholders signed a pledge setting out their shared intention to make a 'Blue-Green City'.

Collaborative research will continue in Newcastle between now and 2019, as the City moves forward with 'Blue-Green' approaches, align its actions with the work Arup and Newcastle University are currently undertaking on a global review of financing green infrastructure, to help move the City forward in realising its ambition to become a 'Blue-Green City'. In this continued cooperation, it is hoped that the geographical scope of the work will be expanded to the wider metropolitan area by bringing into play the North East Combined Authority's Green Economy working group as a mechanism for broadening learning and spreading it more widely.

The vehicle for participatory research in Newcastle will be a continuation of the Newcastle LAA, with a reshaping of the vision, strategic objectives and stakeholder group, developed through 2017 and beyond.

Ebbsfleet

Ebbsfleet Development Corporation (EDC) welcomed the Consortium's invitation to partner with us, particularly because the role and use of landscape to support a wide range of environmental, social and economic outcomes is a defining aspect of the emerging vision for Ebbsfleet as a 21st century Garden City (the EDC are charged with delivery up to 15,000 new homes in North Kent in the next few years).

The aims and objectives of EDC's strategy for delivering the Garden City align closely with aspects of the Consortium's activities and intended outcomes, and it is clear that their involvement in the research will add to our understanding of how planning and development can be re-envisioned to navigate the Blue-Green Cities approach and ensure flood and water resilience in Ebbsfleet despite uncertainties that cloud our view of the UK's climate and socio-economic futures.

The geography and terrain of the locale guarantee challenges to flood and water security that provide a testing context for the creation of integrated B/G+G treatment trains and SuDS. The area to be developed features large, abandoned quarries (some with open water bodies), a massive landfill, a heavily impacted and incised watercourse (the River Ebbsfleet), an unintentionally flooded, but richly biodiverse marsh (created by water leaking from a former cement works) and a range of other former industrial sites interspersed with patches of farm land and relatively undisturbed countryside. The area slated for development is bordered by the existing communities of Swanscombe, Greenhithe and Northfleet, which have their own Local Authorities – each with its own planning agenda.

This backdrop will not only challenge but inspire us to support EDC in achieving its goal of bringing forward, “high quality housing with smart, sustainable and renewable technologies”.

It was agreed when members of the WP5 research team visited Ebbsfleet for a start-up meeting with representatives of EDC that the initial approach in Ebbsfleet will be to establish a LAA. EDC are perfectly placed to assist with this as they are already networked with landowners, developers, builders, utility providers and statutory partners in delivering the Garden City. EDC have facilitated contact and dialogue with key stakeholders through their existing channels and working groups, inviting them to join and participate in the LAA. They are also willing to share the results of their own baseline studies – which will provide a useful starting point for our research and have offered to commission additional explorative work where this would be mutually beneficial in moving the programme forward.

The demonstration case studies research in Newcastle and Ebbsfleet will inform, take-up and apply research in WPs 1-4 to establish, within the project’s lifetime: a) how resilient UFRM service delivery can be put at the heart of urban planning, and b) how barriers to innovation can be overcome despite uncertainties in future urban climates, land-uses, development patterns/trajectories and political leadership.

Objectives

1. Facilitate partnership working. Make the aspirations of multi-objective planning policies deliverable in mainstream practice by bringing together engineers, stakeholders and Local Authorities with an enhanced understanding of collaborative partnership working (LAAs), linking with WP5.1.

2. Build relationships and create connectivity. Facilitate integration of urban flood and water planning and management systems to support multiple functions while balancing trade-offs and facilitating positive interactions between:

   a) engineered assets;
   b) advances in water technology;
   c) natural processes in restored urban streams and drainage systems, and;
   d) the preferences and behaviours of the citizens and communities that benefit from systems of B/G+G infrastructure.

Work Package Team

WP5.2 is led by Colin Thorne Shaun Maskrey and Emily O’Donnell (University of Nottingham), supported by Tudor Vilcan and Karen Potter (Open University). Tudor Vilcan is leading on the Ebbsfleet LAA, where Shaun Maskrey, through the modelling expertise developed in his previous research, has had a pivotal role in developing the System Dynamics model that is currently the central activity of the group.

In addition to specific inputs planned from staff at OU and Nottingham, WP5.2 is heavily supported by the expertise of many other RA's from across the Consortium. The most important contributions come from Leon Kapetas (Cambridge), Vladimir Krivtsov (Heriot-Watt), Sangaralingam Ahilan (Exeter), Glyn Everett (University of the West of England), Kim Vercruysse (Leeds) and David Dawson (Leeds).

Study Approach and Methods

The demonstration case studies present an opportunity for continuous knowledge exchange with WPs 1-4 concerning challenges such as technology lock-in, maintenance concerns, institutional silos with differing goals, leadership concerns, and financial limitations. By participating in WP5, researchers and practitioners co-produce knowledge to modify their approaches and gain traction in delivering innovation.

In addition, WP5 uses *Action Research* (Gómez et al., 2013) that engages researchers in the urban planning process as this has been demonstrated to accelerate uptake of innovation (Potter *et al*. 2011; Cettner *et al*. 2013). *Action Research* starts through the LAA approach, which represents current best practice (Newman *et al*. 2011; van Herk *et al*. 2011; Ashley *et al*. 2012; O'Donnell *et al*. 2017).

LAAs are open arrangements where participants with a shared interest in innovation and implementing change create a joint understanding of a problem and its possible solutions based on rational criticism and discussion (Ashley *et al.* 2012). LAAs promote cooperation between diverse stakeholders from different disciplines and backgrounds. They aim to break down barriers to both horizontal and vertical information sharing and accelerate the identification, adaptation and uptake of new information (Batchelor and Butterworth, 2008). They encourage stakeholders to bring their knowledge and expertise and talk freely outside the constraints of existing formal institutional settings. An atmosphere of trust and mutual ownership facilitates the identification of innovative ideas for the solution of complex socio-technical problems.

The Newcastle LAA has built on that set up in 2014 as part of the Blue-Green Cities research project. With some members of the previous LAA having left their posts, the scope and purpose of the new LAA differs sufficiently from that of its predecessor. For example, LAA membership now includes land-owners and developers - powerful interest groups hitherto relatively neglected in UFRM research.

The Ebbsfleet LAA has at its core the network already established by EDC, while benefitting from the inclusion of other stakeholders suggested by Consortium researchers on the basis of social theory and the specifics of the Garden City, its constituents, citizens and their neighbours in the adjacent, established communities of Swanscombe, Greenhithe and Northfleet.

Research findings and practitioner feedback align, and periodically re-align, research in WPs 1-4 with end-user needs in the case study cities, throughout the project. In this context, distinguishing features of the case studies element of WP5 include:

a) responsiveness to practitioner needs,
b) a focus on empowering local champions,
c) co-production of new knowledge needed to meet technical challenges and overcome social, institutional and political barriers to innovation in sustainable urban flood and water management,

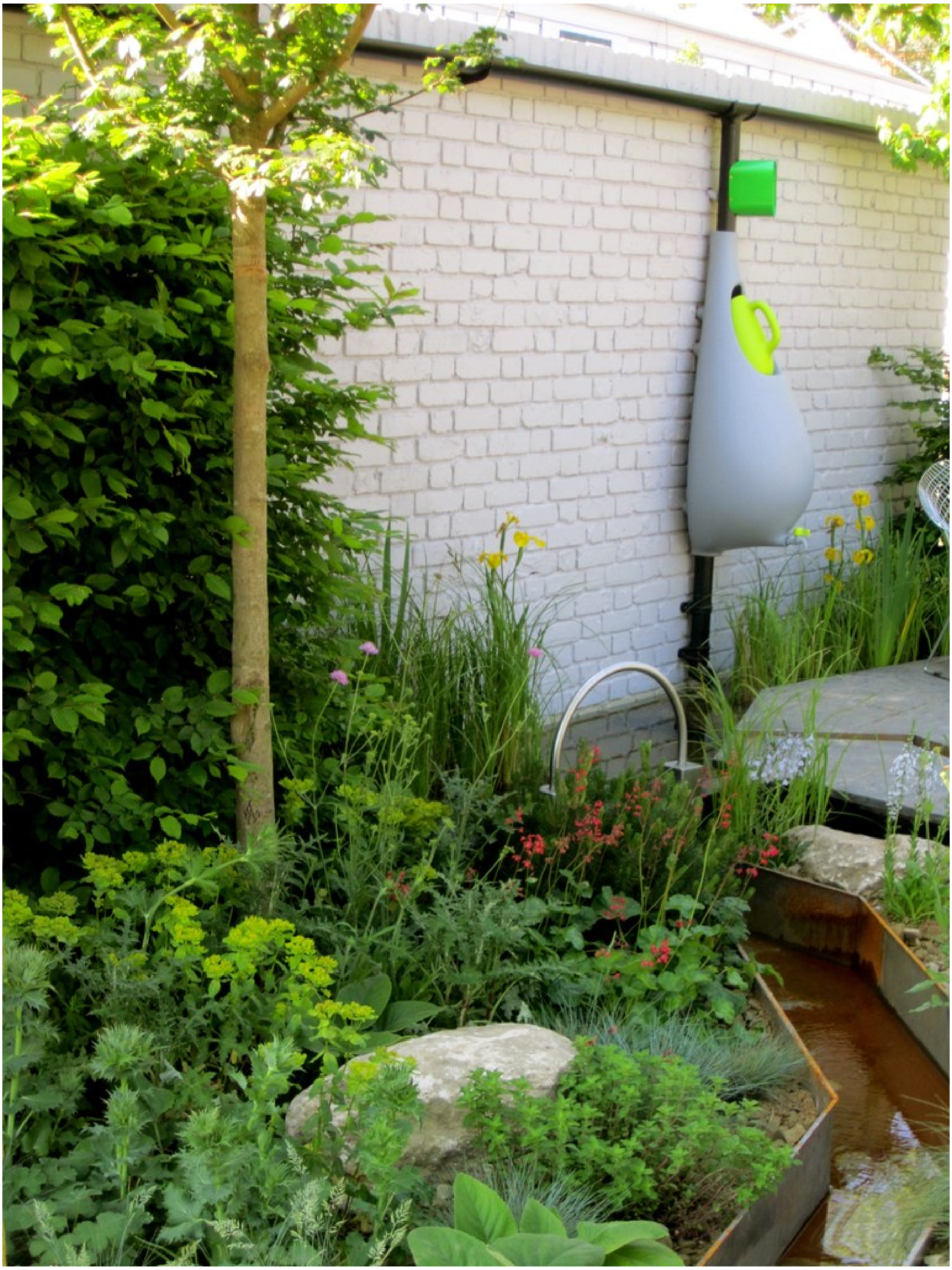
delivering urban flood and water resilience in practice, in the contexts of retrofit, redevelopment and peripheral development in a core city and new build in a Garden City on overcoming barriers to innovation.

Progress to Date

Progress	Objectives Met
LAA Launch Events Emily O'Donnell (Nottingham) facilitated the start-up meetings for Ebbsfleet LAA and the re-launch of the Newcastle LAA shortly after the Urban Flood Resilience project started. The start-up meeting for Ebbsfleet took place on 17th November 2016 and was highly encouraging. The Consortium were represented by Colin Thorne, Karen Potter and Emily O'Donnell. Simon Harrison and Paul Boughton from the EDC were in attendance. The next meeting in Ebbsfleet (to identify LAA members) will be in early 2017. The start-up meeting in Newcastle took place on 14th December 2016. Colin Thorne, Chris Kilsby, Karen Potter, Emily O'Donnell, Vassilis Glenis, Glyn Everett and Greg O'Donnell represented the Consortium. John Robinson, Kelly Graham, Darren Varley and Justin McLaughlan attended on behalf of Newcastle City Council.	1
Ebbsfleet LAA The Ebbsfleet LAA has met every two months since its launch. The focus in Ebbsfleet is on building relationships between local stakeholders, as well as the knowledge/institutional capacity to ensure that blue-green devices feature prominently in future design, planning and development of the area. In September 2017, the Ebbsfleet LAA embarked on a project to better understand sustainable water management in the area by co-constructing a system dynamics model. This model will be built by the research team and the LAA participants in tandem across a series of 5-6 workshops throughout 2017/18. At the first 'modelling workshop' the stakeholder identified six problem dimensions around which to base their model: a) flood risk, b) biodiversity, c) water quality, d) water use, and e) quality of place;	1 and 2

while at the second they developed their thinking by identifying a range of model variables that form the cause > effect relationships within each of these dimensions. It is the intention that presentations and activities from LAA and Consortium members will be interspersed with modelling activities schedule during 2018. For example, at the last LAA on the 3rd of April 2018, Paul Kent from Southern Water gave a presentation on Southern Water's water use strategy in Ebbsfleet. The Ebbsfleet LAA will continue to meet every 6-8 weeks. RAs and Co-Is from WPs 1-4 will attend LAA meetings as appropriate to meetings themes and the specific topics to be discussed. Consortium members will describe and present the interim results of their research to date and outline the next steps, as relevant to the case study location. They will receive feedback from LAA members concerning the utility of their research in the context of challenges faced by the case study cities. This will help ensure that the research outcomes are relevant to a range of practitioners, in addition to generating excellent science. Shaun Maskrey and Tudor Vilcan are also looking to develop a framework to provide future LAA organisers with a toolkit for ensuring consistency. By using the concept of *capacity building*, they aim to complement the social learning that happens in LAAs with an emphasis on developing long-term capacities of stakeholders that endows them with the required ability to enact institutional change.	
Newcastle LAA The Newcastle LAA have continued to meet every 6-8 weeks following the launch. There are around 40 members of the LAA, of which 15-25 regularly attend meetings. Since July 2017, Shaun Maskrey (Nottingham) has facilitated the LAA, and encouraged partner organisations to take turns hosting meetings. Since July 2017, meetings have been hosted by Newcastle University (2), Newcastle City Council (1) and the Environment Agency (1). The lead partner sets the agenda for the LAA with support from Shaun Maskrey in a facilitation role. A full list of LAA meetings can be found at on our project webpage at: http://www.urbanfloodresilience.ac.uk/learning-and-action-alliances/newcastle-laa.aspx	1 and 2

Meetings have tended to showcase best practice work of key partners, encourage input (and knowledge sharing) from members into existing or proposed (re)developments, and provided opportunities for members of the consortium to disseminate their research. The Newcastle LAA has recently partnered with the EU Naturvation project, which is exploring nature-based solutions to environmental issues affecting urban environments. See https://naturvation.eu/ The Naturvation project similarly uses Newcastle-upon-Tyne as its UK case study location. A joint meeting was held in March 2018, hosted by the Environment Agency. Consortium members are invited to continue to contribute to LAA meetings going forwards. Presentations, visits, demonstrations and other workshop-style activities with a focus on retrofitting blue-green features into an urban environment are encouraged. From July 2018 onwards, Emily O'Donnell (Nottingham) will resume facilitation of the Newcastle LAA.	
Newcastle Blue-Green Declaration Group The Newcastle Blue-Green Declaration Group continues to run alongside the LAA, meeting quarterly. Formed during the blue-green cities project, the group consists of key city decision-makers, who take findings and outcomes from the LAA meetings, and integrate these with citywide blue-green thinking at a strategic level. The group is currently chaired by Darren Varley (Newcastle City Council).	1



FUTURE RESEARCH PLANS AND IMPACT

3.1. Consortium Impact and Outputs

This project has the potential to enable a step change in protecting UK cities and the national economy against risks due to increased storminess caused by climate change, without constraining urban renewal and development. It can do so by envisioning and making deliverable a different water future: one based on resilient cities where flood and water management is planned, developed, designed and operated in ways that are truly sustainable. Our international networks and profiles mean that, as our new science emerges, it will be brought to the attention of the city leaders and populations not only in the UK, but worldwide.

The new science and knowledge created through our research will be of direct utility to academics, practitioners and organisations engaged in UFRM worldwide. Achieving the project aim will certainly help make the case study cities (Newcastle and Ebbsfleet) more resilient to future floods despite uncertainties concerning climate and socio-economic changes. Our research also has the potential to help make cities throughout the UK more livable; better able to manage future extremes of both flood and drought. The same is true for cities worldwide that are receptive to innovations needed to deliver integrated B/G+G and SuDS systems. Our research has the potential to inform public debates on urban planning, development and flood risk, to empower practitioners who recognise the need for transformative change and to increase confidence among UFRM decision makers.

Knowledge, insights and understanding of urban flood resilience generated by the Consortium will be useful not only to organisations and practitioners responsible for urban flood risk management, but also people living and working in cities throughout the UK and beyond, including Councillors, voters who elect them, tax payers who fund flood risk management and people and communities at risk of flooding.

We are committed to conveying our findings in ways accessible to professionals and decision makers, as well as the people and communities they serve. Specific impact groups and outcomes are shown overleaf in Table 3.1.1.

From the outset, impacts will extend outside academia because policy makers, planners, developers, engineers and communities in Bristol, Newcastle and Ebbsfleet will be actively engaged in our research. Our website and use of social networks, plus blogs, webinars, press briefings and appearances on the broadcast media will:

a) reduce the lag between production of new knowledge and impact outside academia, and
b) enable us to inform debate in real time on how to make cities flood resilient places where people live better and work more productively.

Table 3.1.1: Consortium impacts

Social impacts	Economic and environmental impacts
Civic society and governance • Enhanced planning policy • Sustainable urban growth and development • Improved public health and well-being • Wider stakeholder engagement in city • Planning and governance	*Urban economies* • Reduced flood losses and business disruption • Multiple benefits between floods from B/G+G spaces and corridors • Increased water security • More productive workforces • Competitive edge over rival cities that are not flood resilient, regionally, nationally and globally
Citizens and communities • Urban renewal • Reduced flood anxiety • Neighbourhood uplift • Increases in flood and water literacy • Flood and water citizenship • Improved quality of life	*Urban environments* • More urban green spaces and corridors • Managed flooding during extreme events that exceed capacity of piped/surface drainage system • Improved water quality • Improved air quality • Reduced urban heat island effects • Improved soil and soil water quality • Higher resilience to floods and drought

3.2. Work package reports

3.2.1. WP1. Resilience under change

Academic Outputs

The research carried on extending adaptation pathways for planning under uncertainty will lead to the preparation and publication of two research articles in international scientific journals. The first article will focus on description of the approach and will present results from the analysis as well as recommendation on how it can be applied by interested stakeholders (lead flood authorities, practitioners, water companies). The second article will discuss the modelling methodology (used in the former article), the opportunities and limitations of the technique from the perspective of the flood modeller.

In Exeter, the aim is to publish two journal papers from this research. The first paper will focus on quantitative urban water system performance modelling using WaterMet[2] in Ebbsfleet Garden City. Colleagues will contribute to a paper focusing on system dynamics modelling, which is led by the University of Nottingham. There are plans to present urban metabolism simulation results at suitable conferences and LAA meetings in Ebbsfleet.

Practitioner Outputs

Research produced in this work package has significant take-up potential by practitioners including water companies, consultants, government, and flood authorities. Therefore, research will be disseminated in the form of factsheets and conference presentations which will make the approaches more accessible. The opportunity to produce a technical report with CIRIA will be explored (see the forthcoming Blue-Green Cities Project Reports, CIRIA).

a) Estimates for long-term BGI flood and water quality performance in the context of UKCP09 climate change forecasts as well as urbanisation trends.
b) Understanding of the feasibility of BGI and SuDS retrofit in residential, commercial and industrial areas
c) Model of dynamics of key retrofit asset types
d) An approach which supports the comparative evaluation of the costs and benefits of alternative UFRM solutions
e) An approach to evaluate urban drainage system resilience and the effect of multi-functional enhancement strategies which take into account the optimum mix of design options over time and under uncertainty.

Public Outputs

Blogs and factsheets produced by the consortium provide the most suitable dissemination pathway for a broader public. In particular, advocacy groups and engaged citizens will find objective information about the potential and limitations of SuDS as part of our urban infrastructure.

Other Outputs

Interactions with other work packages

The adaptation pathways methodology investigates a series of SuDS interventions. Intervention preferences will be informed through discussion with local stakeholders in Sutton. This is linked to investigation into stakeholder interaction with urban drainage infrastructure (WP4). The same approach can be followed using the LAA platforms in Ebbsfleet and Newcastle (WP5).

The case study at Houston Industrial Estate used a ‘Discussion Group’ technique (to identify barriers and incentives for SuDS retrofit) during a business breakfast seminar. This methodology is relevant to the techniques used in LAAs (WP5).

The case study of sediment dynamics in ponds is linked to the investigation of the ponds’ ecology, biodiversity and multiple benefits (WP2).

3.2.2. WP2. Managing stormwater as a resource

We will continue publishing in appropriate, peer-reviewed international journals, such as the Journal of Flood Risk Management, ICE Water Management Journal, the Urban Water Journal and Water Research. Articles already published have been highlighted in the previous section.

The draft article on “Micro-hydropower recovery from stormwater” will be published in a scientific journal to disseminate this feasibility methodology (mid 2018). The research work currently in progress looking at the potential for groundwater recharge and aquifer storage of stormwater is also expected to lead to a publication (mid 2019).

Academic Outputs

WP2 (Exeter) aims to publish the two journal papers from research into rainwater harvesting. The first paper will be based on objectives 3a and 3b, by evaluating performance of household rainwater collection and reuse systems in Newcastle and Ebbsfleet (Dec 2018). The second paper will be based on objective 3c, focusing on large-scale development site at the Northwest Cambridge development site (June 2019).

Practitioner Outputs

a) Practical and efficient solutions for recovery, recycling and re-use of stormwater as a resource to increase water security in a future characterised by more intense and frequent storms and longer more stressful droughts
b) Re-evaluate the efficacy of the British Standard of rainwater harvesting system design
c) Enhanced design tools for sizing recovery systems and models to appraise their performance on the management of stormwater flows and quantification of benefits from each recovery option
d) Open source tools such as the enhanced RWH tool will be made available in the public domain to all relevant stakeholders
e) Demonstrate potential benefits of rainwater harvesting in large-scale development site

Public Outputs

a) Dialogue with stakeholder groups about perceptions of stormwater re-use and mitigation of concerns
b) Dialogue with other utility operators (e.g. electricity sector) for joint (co-ordinated) action across the water-energy nexus
c) Dialogue with water companies and EDC on efficiency of household rainwater harvesting on water saving
d) Dialogue with consultancy companies on impact of large scale rainwater harvesting on reduction in water consumption
e) Practical pathways for potential enhancement and maintenance of urban green spaces

Local authorities or engaged citizen groups who wish to explore the possibility of generating renewable energy from their stormwater will find this research of particular value. This research has already been disseminated in a factsheet and simple case study examples will be developed in the future to support the applicability of the feasibility assessment.

Other Outputs

Feedback into WP2, potential impact of household rainwater harvesting on urban metabolism modelling.

Interactions with other work packages

The investigation of the ponds' ecology and biodiversity (WP2) is linked to the case study of water quality and sediment dynamics (WP1). This study also investigates amenity value and multiple benefits of BGI, and benefits from the input of volunteers – hence a clear interconnection with WP4.

3.2.3. WP3. Inter-operability with other systems

Academic Outputs

WP3 will produce at least two publications (refereed journal articles or conference-related publications); and at least two conference presentations (including European Geosciences Union 2018).

Practitioner Outputs

Presentations or workshops will be given to different stakeholder groups (e.g. British Water Surface Water Management Focus Group) to disseminate and discuss the idea of interoperability in flood risk management, and identify possible challenges. The GIS tool will also serve to support decision-making around interoperability. Alongside the tool, a guide can be produced. Specific for the case studies Newcastle and Ebbsfleet, application of the tool in collaboration with stakeholders will provide guidance on systems-thinking in flood risk management.

Public Outputs

Factsheets on defining interoperability and further research results will be available on the website to present the main outputs in an engaging way.

Interactions with other work packages

The outputs of the WP3 will allow system wide evaluation interoperable infrastructure design solutions. In doing so it could provide additional input for the GIS-toolbox [WP1b, Year 3], and help evaluate the resulting benefits of interoperable designs solutions [WP1a, Year 2]. Feedback on the acceptability and utility of the new design approaches will help inform and steer the societal and stakeholder research as it progresses [WP4] and the outputs will contribute directly to the project's case studies in Newcastle and Ebbsfleet [WP5]. Equally, system performance improvements and benefits from using stormwater as a resource (WP2) and citizen interaction (WP4) could provide added input for system evaluations. Peoples' perspectives of interventions; acceptance of disruptions, irrationality in decision making, health benefits – financial decision making may also help us explore the notion of risk transfer i.e. flooding fields to save cities.

3.2.4. WP4. Citizens' interactions with B/G+G infrastructure

Academic Outputs

WP4 will produce at least three publications (refereed journal articles, book chapters and/or conference-related publications); at least one book contribution and four conference presentations.

Practitioner Outputs

WP4 will produce a range of outputs for different practitioners, format depending upon feedback as to what would be most useful. Possibilities include:

a) A CIRIA guide on B/G+G devices and community engagement
b) A Local Authority guide to community engagement strategies around B/G+G devices
c) An app, for use by professionals in engaging communities as well as gathering data
d) A Digital Testimonials resource toolkit for professional development purposes and wider engagement around effective approaches to engagement

Public Outputs

a) Social media platforms for engagement around devices in people's local community (Facebook, Twitter, Instagram, etc.)
b) An app, to provide local residents with voice and open up more immediate communication around likes, dislikes and issues

Other Outputs

The app and social media platforms that WP4 produces, and the public-facing elements of the data gathered by these, will provide an evidence-backed model for translation and transference to a wide range of issues and locations by a number of parties (governmental, non-governmental, voluntary, etc.).

Interactions with other work packages

WP4 will engage in productive conversations and knowledge-exchange with other WPs throughout the programme.

- Findings from WP1a and WP1b (design optimization and GIS assessment of B/G+G approaches) can feed into conversations with the core group, and the IAT, to explore lay citizens' perceptions of benefits and barriers
- Discussions with WP2 and WP3 will develop thinking around un/productive uses of, and potential for developing, citizen engagement regarding data collection around stormwater management and inter-operability of B/G+G assets

WP4 will have a close and ongoing relationship with WP5, developing tools for data-collection and analytics as well as strategies for engagement, and learning from case study city LAA feedback to continue developing the WP4 research focus.

a) From the work of WP4 with local communities, models of best practice for community engagement and effective knowledge exchange will be developed that will be shared with WP5, to try to ensure that local voices are listened to throughout the planning process

b) WP4 will provide the tools to collect the citizen data that will be required for WP5 data analytics. Through ongoing knowledge exchange and discussion, WP4 will both learn from WP5 thinking and contribute to the development and implementation of the WP5 programme

c) The WP4 data analytics work will further help to embed community perceptions, values and behaviours into thinking around:
   i. More innovative, adaptable and sustainable UFRM designs [WP1a]: with an improved understanding of what people need and want (in terms of dealing with excessive water flows, keeping spaces hydrated, providing cleaner water and amenity values through the provision of green spaces, recreation, relaxation and flora and fauna), designs of UFRM will be able to be tailored more specifically to the particular exigencies of different communities
   ii. What local residents want to know about B/G+G functions and how this interest might be utilised in studies [WP2 and 3]; through conversation with residents and WP-leaders, possibilities for citizen science engagement will be explored

d) WP4 case studies will offer information to professionals on what forms of engagement are and are not felt to work with different communities (WP5)

e) WP4 will supply key inputs to WP5, while benefitting from feedback from case study city LAA members that will help align and re-align research in WP4 as it progresses

3.2.5. WP5. Achieving urban flood and water resilience in practice

Academic Outputs

We will publish research in peer reviewed journals, such as the Journal of Flood Risk Management, Environmental Science and Policy, and ICE Water Management, and present our research at international and national conferences, including Flood and Coast 2017 and the International Conference on Flood Management 2017.

Practitioner Outputs

Demonstration case studies research will offer recommendations to enhance planning policy and guidance, widen stakeholder engagement in city, and begin to transform planning and governance in Newcastle and Ebbsfleet, and potentially other Core Cities.

Public Outputs

Public outputs in the case study cities (Newcastle and Ebbsfleet) include evidence to support:

a) Sustainable urban redevelopment, renewal, growth and development
b) Improved public health and well-being
c) Wider stakeholder engagement
d) Reduced flood anxiety
e) Neighbourhood uplift
f) Improved quality of life
g) Multiple co-benefits between floods from Blue-Green infrastructure, spaces and corridors

Other Outputs

Our research into the benefits and impacts of multifunctional B/G+G infrastructure will generate knowledge to help stakeholders in Newcastle and Ebbsfleet to:

a) Reduce flood losses and business disruption
b) Increase water security
c) Produce a more productive workforce
d) Generate a competitive edge over rival cities that are not flood resilient, regionally, nationally and globally
e) Create more urban green spaces and corridors
f) Manage flooding during extreme events that exceed capacity of piped/surface drainage system
g) Improve water quality
h) Improve air quality
i) Reduce urban heat island effects
j) Improve soil and soil water quality
k) Create a higher resilience to drought

Interactions with other work packages

a) WP1: information on urban water cycles, green spaces and green corridors in the case study cities (to inform coordinated management of the stormwater cascade (WP2)); insight into the opportunities and challenges to installing SuDS in the case study cities, and opportunity to interact with end-users to consult with WP1 to help build a GIS Toolbox to support comparative evaluation of the costs and benefits of alternative UFRM solutions

b) WP2: opportunities for assessing the resource value of stormwater in the case study cities

c) WP3: information on confidence, uncertainty and decision-making relating to infrastructure interdependencies

d) WP4: opportunities to test on-line systems to canvass and potentially shift citizens' and professionals' attitudes and behaviours with respect to B/G+G assets in the case study cities, and; provision of citizen data from case study cities needed for data analytics that embed community perceptions, values and behaviours into innovative and adaptable UFRM designs

3.4. Dissemination Plan

Managing the risks of urban flooding to individuals, communities, businesses, property, infrastructure, commerce and the environment in cities, lies at the heart of this project. The project objectives include studies of the impact on, and feedback from, stakeholders including not only UFRM planners and decision-makers, but also individual citizens, community leaders, and businesses. In this respect, co-production of knowledge is integral to the research and the dissemination of our findings will begin on day 1. For example, the objectives of the project include to:

"*Make the objectives of multi-objective planning policies deliverable in practice by bringing together engineers, stakeholders and Local Authorities in partnership working*"

and,

"*Create connectivity in urban flood and water planning and management systems to facilitate positive interactions between: engineered assets; advances in water technology; natural processes in restored urban streams and drainage systems; and the preferences and behaviours of the citizens and communities that benefit from systems of B/G+G infrastructure*"

Further, case studies are central to this research and engagement with practitioners and communities throughout the project using *Participatory Action Research* provides an ideal pathway for dissemination of co-produced knowledge, data, analyses and methods. This will be led by WP5 who will align research in WPs 1-4 with end-user needs based on practitioner feedback on research findings at regular LAA meetings. This will enhance the reliability of the project outputs, ensure user buy-in and uptake of the project's user-focused deliverables.

In addition to engaging with end-users in co-production of knowledge and outcomes through WP5, further steps to ensuring impact through dissemination include:

1. Engagement with key stakeholders beyond those involved directly in the project through fieldwork, meetings and workshops that will include:

    a) Statutory authorities such as the DEFRA, EA for England and Wales, SEPA, and the Northern Ireland Department for Infrastructure (DfI), based on links that already exist between the team and these bodies and as well as new contacts;

    b) Built environment professionals such as architects, civil engineers, urban planners, transport and highways bodies and their professional institutions;

    c) Local Authorities in the case study cities (Newcastle and Ebbsfleet);

    d) Citizens through engagement with Non-Governmental Organisations (NGOs) such as the Rivers Trusts, National Flood Forum and appropriate local social enterprises.

2. Research in the project draws on the procedures already adopted by practitioners in designing urban fabrics, spaces and green corridors including, amongst others, the SuDS Manual, the RRC Manual, FRA Channel Design Options, Foundation for Water Research FR/R0014, Defra FD2619 and relevant CIRIA Reports. This means that the project's outputs will be set in a framework that is readily usable by practitioners. For example, CIRIA (Paul Shaffer), Mark Naura (RRC) and Jenny Mant (Ricardo) have been contracted to form a Pathways to Impact Team, to provide dissemination support through their networks and will help with planning, advertising and organising delivery of the impact activities and outputs.

3. We have put in place a Strategic Advisory Board (SAB) made up of senior professionals in UFRM including representatives of the Environment Agency, Water Companies, consultants, City Councils, Public Health England and UKWIR (**Error! Reference source not found.**1).

4. Each RA will spend at least two weeks at the beginning and end of the project on secondment to relevant organisations in one of the case study cities. The initial secondment will embed the project with stakeholders (e.g. Local Authorities, Water Companies, Environment Agency, Development Corporations), give RAs insights regarding barriers/opportunities for building flood resilience, and establish communications with practitioners. The final secondment will facilitate knowledge exchange and encourage uptake of project deliverables designed to help practitioners overcome challenges and implement innovation needed to achieve flood resilience

5. We will engage with professional associations such as the IWA and ICLEI internationally and CIRIA, the RTPI and TCPA nationally.

6. We will present work at national and international conferences such as the biennial International Conference on Flood Management (ICFM). In the later stages of the project we will publish in appropriate, peer-reviewed international journals, such as the Journal of Flood Risk Management.

7. Internationally, we are engaging with other projects such as the Delft Flood Resilience Group (www.floodresiliencegroup.org), ICLEI and the Resilient Cities Leaders Forum (http://resilientcities2016.iclei.org/), and Ceres: Building Climate Resilient Cities (https://www.ceres.org/). International dissemination will culminate with a closing workshop held at the Royal Society of London (as was highly effective for FRMRC II).

8. Research outcomes of immediate relevance to practitioners will be published by CIRIA with assistance from the RRC. Production of four CIRIA reports will be guided by our SAB. Paul Shaffer (CIRIA), Mark Naura (RRC) and Jenny Mant (Ricardo) will assist the team in matching the content to the needs of practitioners (as they have done for reports by FRMRC and Blue-Green Cities). RRC involvement will extend our reach to professionals in the restoration of urban streams and wetlands, assuring wide dissemination, uptake and impact.

9. We will communicate the research on an on-going basis through internet-based tools including a project website, Twitter feed and LinkedIn group maintained by Emily O'Donnell and Shaun Maskrey.

The team all have prior experience of working with end-users in other projects. In particular Colin Thorne and Nigel Wright have been involved in generating user-focused research outputs in FRMRC. In this context, Colin Thorne was deputy Chair (Dissemination) for the FRMRC and he chaired FRMRC's Dissemination Committee. The University of Nottingham were responsible for the two user-focused deliverables produced during FRMRC I and have been involved in producing three of four CIRIA Reports coming out of FRMRC II. In this respect, the professional and stakeholder networks already developed under FRMRC will bring a large group of end-users to this project.

In addition, Colin Thorne and Emily O'Donnell were responsible for dissemination of user-focused research outputs from the Blue-Green Cities project, which included a successful website (45,977 views by 35,609 unique visitors), social media (168 LinkedIn Group members, 1325 Twitter followers), project blog (7490 views by 6139 unique visitors), Wikipedia page (over 16,000 views) and project factsheets (850 views of 16 factsheets) (statistics from 04.01.17). The Blue-Green Cities project culminated in a dissemination event in the demonstration city of Newcastle in February 2016 where the 'Newcastle declaration on Blue and Green Infrastructure' that was launched by Newcastle City Council (http://www.bluegreencities.ac.uk/bluegreencities/documents/blue-green-declaration-signed.pdf). The declaration was signed by six major public and private organisations actively involved in flood and water management and committed signatories to; the prioritisation of BGI in managing flood risk; the importance of changing working practices towards greater collaboration; working with developers to maximise BGI in new developments; raising awareness and building capacity amongst communities to develop and maintain BGI; and piloting new way of working to realise the multiple benefits of BGI. It is our ambition in the new Consortium to use experience gained during the Blue-Green Cities project to increase the number of people outside academia that engage and interact with us by at least one order of magnitude.

Other co-investigators are involved in a variety of related, funded projects (EU, Research Councils, etc.) both in the UK and internationally that will ensure two-way engagement with this project.

3.5. Key Performance Indicators (KPIs)

The performance of the Consortium will be monitored by the PI in relation to key performance indicators (KPIs). Each of the Project's WPs have their own time line, milestones and outputs, which will be used to gauge and assess the successful and timely completion of each element of the research programme. Comparison between research progress and the agreed timelines will alert the PI if any tasks are late so that timely corrective action can be taken. The need for and, when necessary, the nature of changes to the work programme will be identified and fully documented. Indicators of progress and success within the WPs that may be used by the management committee include:

- Manuscripts submitted to peer reviewed journals
- Conference papers
- Technical reports
- New collaborations
- Interactions with stakeholders and users
- Interactions with elected representatives and other decision makers
- Interactions with the international research community
- Generation of additional, related research funding
- Outreach activities

Additional KPIs to be monitored by the PI include:

- Interest in the Consortium website (e.g. number of hits and queries/contacts)
- Interest expressed in urban flood resilience more generally, for example through interest in other websites
- Highlights on wider societal and/or ethical components of the project, such as public outreach activities
- Collaboration and data exchanges with groups and organisations outside of the UK
- Overall quality and efficiency of the "external" communication strategy of the Consortium and level of European and International recognition of the Project's research, as evidenced by co-citation, referencing, requests for information received by Project Administrator, invitations received by the Partners, etc.

- Management of intellectual property and commercialisation of research output: as evidenced by management reporting
- Capacity of the Consortium to meet financial targets and to deliver results on time and on budget: as formally reported to the EPSRC
- Progress towards delivering the stated outputs and outcomes

3.6. Science Audit

The quality of the science being developed by the Consortium within the project will be assessed using standard EPSRC peer review procedures. The international relevance of the work will be assessed with the help of the SAB which will provide written feedback and recommendations after each SAB meeting and full science audit at the end of Year 3.

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LIST OF ACRONYMS AND ABBREVIATIONS

AHP	Analytical Hierarchy Procedure
ASC	Adaptation Sub-Committee
B/G+G	Blue/Green and Grey
BGI	Blue-Green Infrastructure
BS	British Standards
CBA	Cost-benefit analysis
CEDR	Centre for Effective Dispute Resolution
CIRIA	Construction Industry Research and Information Association
Co-I	Co-Investigator
Defra	Department for Environment, Food and Rural Affairs
DfI	Northern Ireland Department for Infrastructure
DGT	Data-Gathering Technology
EA	Environment Agency
EDC	Ebbsfleet Development Corporation
EPSRC	Engineering and Physical Science Research Council
FRMRC	Flood Risk Management Research Consortium
FESSUD	Financialisation, Economy, Society and Sustainable Development
GIS	Geographical Information Systems
IAT	Implicit-Association Test
iBUILD	Infrastructure Business models, valuation and Innovation for Local Delivery
ICFM	International Conference on Flood Management
ICIF	International Centre for Infrastructure Futures
IPR	Intellectual Property Rights
ITRC	Infrastructure Transitions Research Consortium

IWA	International Water Association
LAA	Learning and Action Alliance
LWEC	Living with Environmental Change
NGO	Non-Governmental Organisations
PAR	Participatory Action Research
PI	Principal Investigator
PTST	Probabilistic tank-sizing tool
RA	Research Associate/Fellow
RRC	River Restoration Centre
RTPI	Royal Town Planning Institute
RWH	RainWater Harvesting
SEPA	Scottish Environmental Protection Agency
SuDS	Sustainable Urban Drainage Systems
SPT	Social Practice Theory
TCPA	Town and Country Planning Association
UFRM	Urban Flood Risk Management
UKcric	UK Collaboratorium for Research on Infrastructure and Cities
UKWIR	UK Water Industry Research

ANNEXES

Annex I: Membership of the SAB

Name	Organisation
Bridget Woods-Ballard	HR Wallingford
Chris Digman	MWH
Dave Gowans	Sweco
David Wilkes (co-chair)	Arup
Fola Ogunyoye (co-chair)	Royal Haskoning DHV
Hans Jensen	UKWIR
Hayley Bowman	Environment Agency
John Robinson	Newcastle City Council
Kit England*	SNIFFER
Mark Stranaghan	Department for Infrastructure, NI
Martin Buckle	RTPI and Independent Planning Consultant
Peter Drake	Water Industry Forum
Simon Harrison	Ebbsfleet Development Consortium
Simon Spooner*	Atkins
Steena Nasapen-Watson	Northumbrian Water

*corresponding member