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Evaluating the multiple benefits of a Blue-Green Vision for urban surface water management

Session 1, paper 1

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Abstract

A Blue-Green City aims to recreate a naturally-oriented water cycle while contributing to the amenity of the city by bringing water management and green infrastructure together. The Blue-Green approach is more than a stormwater management strategy aimed at improving water quality and providing flood risk benefits. It can also provide important ecosystem services, socio-cultural benefits and adaptability to future (uncertain) changes in climate and landuse. However, quantitative evaluation of the benefits, their spatial distribution and co-dependencies are not well understood.

The Blue-Green Cities Research Consortium has adopted an interdisciplinary approach to quantitatively evaluate the benefits of Blue-Green infrastructure (BGI) and their relative significance. A new ArcGIS evaluation tool has been developed which can identify the spatial distribution of different benefits and normalise benefits onto a uniform scale. This allows the local impact of multiple benefit types, benefit dependencies and dis-benefits to be directly compared, helping decision makers to co-optimise the benefits from the outset of project planning. The tool was successfully piloted in 2014 in Portland, Oregon, a city with a Blue-Green Vision and extensive investment in green infrastructure, primarily to help reduce the number of combined sewer overflows and improve water quality.

This paper also reports on the application of the benefit evaluation tool in Newcastle (UK). Here, hydrodynamic models have been developed to simulate pluvial flood inundation and the movement of water through BGI. An overland flow model has been integrated with the subsurface drainage network to handle discontinuous free surface and pressurised flows. This allows the simulation of mixed flows in pipes and realistic modelling of sewer outflow events. A hypothetical future is presented for a residential area of Newcastle where all pavements and back-alleyways have permeable paving and all gardens are greenspace. Modelling shows that the BGI provides temporary storage and helps alleviate the burden on the subsurface system.

The Blue-Green Vision for Newcastle was developed by the Learning and Action Alliance (LAA), an open arrangement where participants create a joint understanding of a problem and its possible solutions based on rational criticism and discussion. The LAA encourages cooperation between a diverse range of stakeholders from different disciplines and backgrounds, including local authorities, major landowners, water companies, academia and environmental groups, and represents a novel approach to facilitate the negotiation of a Blue-Green Vision that addresses strategic objectives, public realm improvements and, not least, the management of urban surface water.

Introduction

Flooding is widely recognised as one of the World's most serious hazards and can have devastating impacts on social, economic and environmental systems. In England alone, over 2.4 million properties are at risk of fluvial or coastal flooding, with a further 2.8 million properties susceptible to surface water flooding (Bennett, 2013). Those living in cities are particularly vulnerable. Urbanisation and economic growth, and the consequential reduction in permeable (green) surfaces, combined with a changing climate and greater frequency and magnitude of intense precipitation events, act together to increase the urban flood risk and damage potential (Bates et al., 2008). There is therefore a demand for new and innovative responses to reduce both the probability and consequence of urban flooding by making cities more resilient and able to adapt to changing flood risk (Wilby and Keenan, 2012).

Blue-Green Cities are designed to use surface water as a resource, embracing the concept of Water-Sensitive Urban Design (WSUD), recreating naturally-oriented water cycles in urban environments and combining water management and green infrastructure objectives. This approach moves on from the predominantly engineering and technical focus of traditional grey infrastructure design. Issues of flood risk management do not fit into a single discipline, nor do the potential benefits of the Blue-Green approach, which span the environmental, social, economic, ecological and cultural spheres, and hence, require an interdisciplinary team to fully evaluate. 'Blue-Green Cities' is an interdisciplinary research project funded by the Engineering and Physical Sciences Research Council (EPSRC, February 2013-February 2016). The Consortium comprises academics from nine UK institutions and numerous disciplines; geography, hydrodynamics, geomorphology, ecology, physics, social sciences, engineering, and environmental economics. The Consortium aims to develop new urban flood risk management strategies as part of wider, integrated planning intended to achieve urban renewal and environmental enhancement in which the multiple benefits of Blue-Green Infrastructure (BGI) are rigorously evaluated and understood. Since the project inception in 2013, the Consortium's research has addressed one of the pivotal challenges around the implementation of Sustainable Drainage Systems (SuDS) and BGI; that of creating a sound evidence base to support the business case for a Blue-Green approach to flood risk management and the generation of multiple environmental, social and ecological benefits when the system is in both flood and non-flood states. Without strict regulation and legislation, a business case is invaluable in order for the wider value of SuDS and BGI to be taken into account (Ashley et al., 2015).

This paper introduces the Blue-Green Cities Research Project and the novel interdisciplinary resilience framework that places people, society and their interactions with flood risk management policy at the heart of the research. Using hydroinformatics tools and a clear Blue-Green Vision, the procedures for the robust evaluation of the multiple functionalities of BGI components within flood risk management strategies have been developed and tested in two case study cities; Portland, Oregon (USA), and Newcastle (UK). This paper will begin by defining the concept of a Blue-Green City and the development of a Blue-Green Vision for Newcastle with the Newcastle Learning and Action Alliance (LAA). The paper will then outline the key physical science and socio-political uncertainties and barriers that limit widespread implementation of BGI and possible strategies to overcome such barriers, including the robust evaluation of the multiple benefits of BGI. The paper will then introduce the novel GIS tool that is being developed to identify, characterise and quantify the multiple benefits, and the sophisticated hydrodynamic modelling tool that is being used to determine the specific flood risk reduction benefits of hypothetical Blue-Green futures.

The Blue-Green Cities Concept

BGI and SuDS are increasingly recognised as vital components of urban flood risk management. This moves on from the traditional approach to urban surface water and flood risk management which aims to remove surface water as quickly and efficiently as possible via the subsurface drainage system, treating water as a nuisance rather than a resource. Surface water may be routed quickly into the nearest watercourse, placing an increased demand on the confined watercourse to accept extra water. During heavy rainfall events, this increased volume of runoff discharging rapidly into the watercourse could increase the flood peak and risk of overbank flow. Alternatively, surface water may enter the combined sewer systems where there is a risk of sewer surcharge if the capacity is exceeded during high rainfall events. Sole reliance on the subsurface infrastructure places a significant burden on the piped network and waste water treatment works, many of which are experiencing capacity issues which are likely to be exacerbated with future urban expansion and growth. Grey infrastructure fulfils a vital role in protecting people, infrastructure and assets from some of the larger storm and flood events (e.g. the Thames Barrier saved low-lying areas of London from severe flooding during the winter 2013/2014 floods (Thorne, 2014)). However, grey infrastructure typically fails to provide significant social and ecological benefits which represent a key section of the 'SuDS triangle' for systems design that encourages the consideration of water quantity, quality and biodiversity/amenity.

A Blue-Green City aims to recreate a naturally oriented water cycle while contributing to the amenity of the city by bringing water management and green infrastructure together (Hoyer et al., 2011). This is achieved by combining and protecting the hydrological and ecological values of the urban landscape while providing resilient and adaptive measures to deal with flood events (Figure 1). Key functions include restoring natural drainage channels, mimicking pre-development hydrology and improving water quality, reducing imperviousness, and increasing infiltration, surface storage and the use of water retentive plants (Novotny et al., 2010).

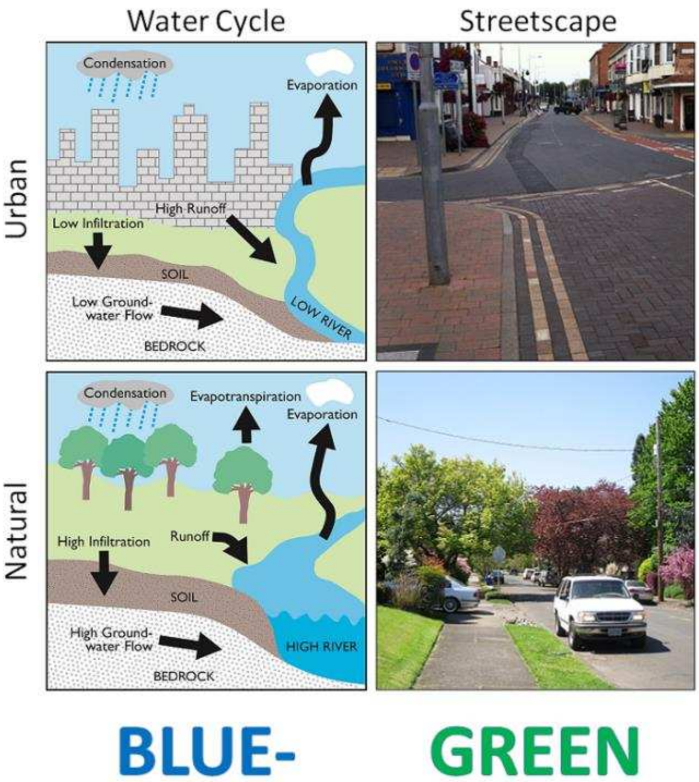

Figure 1 Comparison of the hydrologic (water cycle) and environmental (streetscape) attributes in conventional (upper) and Blue-Green Cities. Source: (Lawson et al., 2014).

Blue-Green Cities and other international sustainable water management concepts such as Water-Sensitive Urban Design (WSUD) seek to develop urban water and flood risk management that holistically considers the environmental, social and economic consequences of different strategies, and reduces the reliance on the subsurface drainage system. Such approaches are gaining increasing support as efforts are made to better integrate the water cycle with urban design and development needs, protect urban water resources, and generate multiple benefits from multifunctional landuse (Ashley et al., 2013; Wong and Brown, 2009).WSUD regards urban surface water runoff as a resource and multiple benefits may be achieved at lower costs if water services are linked with other urban infrastructure systems (Potter et al., 2011). WSUD, SuDS and BGI are relatively new in England yet advances in the US (BES, 2010), Australia (Brown and Clarke, 2007), Europe (Stahre, 2008) and Scotland (Bastien et al., 2012) provide illustrative exemplars and lessons learned that may help such non-traditional approaches to urban water and flood risk management gain acceptance and support.

The Blue-Green Vision

Research projects such as 'Blue-Green Cities' and 'Blue Green Dream'(Maksimović et al., 2013) are helping advance the paradigm shift away from grey infrastructure alone to a combination of grey plus Blue-Green. However, widespread implementation requires negotiation of the Blue-Green Vision by all representative stakeholders, and subsequent ownership and championing of that vision. Although specific to the locality where it is developed, the Blue-Green Vision will be founded on the changes in culture and practice to allow urban environments to follow the principles of Blue-Green Cities by maximising the opportunities to achieve multiple benefits of Blue-Green approaches to surface water and flood risk management. Blue-Green design can be used to create an urban environment where multifunctional surface water management schemes bring a range of benefits to the environment, society and economy. For instance, the integration of water management, urban green space provision and connected Blue-Green space makes areas better places to live. Natural assets enhance the visual quality of the urban environment in the time between floods; communities are more healthy and quality of life is improved; social capital is enhanced through better relationship with water and the interaction with the natural environment/urban space; water quality is improved by natural processes and treatments; and schemes are designed to be sustainable by making them resilient and adaptive to future changes, e.g. in climate and landuse. It is no longer sufficient to consider water and flood risk management in isolation from other urban systems and services, rather to take an integrated and synergistic perspective in order to get 'more from less' in any investment. For this to be effective, the place of water management within land use, urban design and city planning needs to be properly acknowledged by all involved and the opportunities exploited from managing water in a way that brings it more into the open within green and blue spaces. As an example, the Philadelphia Water Department has developed a Green Infrastructure Vision designed to protect and enhance their watersheds by managing stormwater runoff with innovative green stormwater infrastructure throughout the City, while also maximizing economic, social, and environmental benefits for the wider Philadelphia area (Philadelphia Water Department, 2015). Portland, Oregon, has a similar vision centred on using green infrastructure for stormwater management, illustrated by the $55 million 'Grey to Green' project (2008-2013) which included citywide construction of green streets, installation of eco-roofs, purchasing land to create green assets, removing culverts, planting thousands of street trees and educating local residents and communities about the functioning and benefits of green assets (BES, 2010, 2015).

Developing a Blue-Green Vision for Newcastle with the Learning and Action Alliance

A Blue-Green Vision was developed for Newcastle, one of the Consortium's case study cities, during meetings of the Newcastle Learning and Action Alliance (LAA). Newcastle was selected as a demonstration city as it encompasses hydrological, topographic, urban density and socio-economic conditions that are representative of those found more widely in UK cities and has experienced recent major flooding events, e.g. the 'Toon Monsoon' June 2012 (Newcastle City Council Overview and Scrutiny Committee, 2013). Much of the city centre is impermeable and vulnerable to pluvial flooding and there is a risk of sewer surcharge during extreme rainfall events. Newcastle has examples of BGI/SuDS as part of recent residential developments, such as Newcastle Great Park (Figure 2), and there is keen interest in BGI for flood risk management and public realm improvement from key stakeholder groups plus active research into climate change adaptation and mitigation and urban greenspace (Newcastle City Council, 2015).

Figure 2 SuDS/BGI in Newcastle (photo credit: Emily Lawson)

The Newcastle LAA (www.bluegreencities.ac.uk/bluegreencities/research/learning-and-action-alliance.aspx) was established in February 2014 and regularly meets to discuss strategies to promote the Blue-Green Vision and encourage uptake. 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; Lawson and Lamond, 2014). LAAs encourage cooperation between a diverse range of stakeholders from different disciplines and backgrounds. In Newcastle, this includes members of the local authority, major landowners, water companies, academia and environmental groups, and represents a novel approach to facilitate the negotiation of a Blue-Green Vision. Such collaborative working between a group of individuals or organisations aligns with recommendations in the Floods and Water Management Act 2010 and Surface Water Management Plan (Defra, 2010). The aim of the LAA is for stakeholders to bring their knowledge and expertise and talk freely outside the constraints of existing formal institutional settings, challenge restrictive regulations and explore novel solutions. The LAA provides an effective way of integrating academic research with the needs of key stakeholders, practitioners and end-users.

To help create the shared vision, the Newcastle LAA began by identifying potential demonstration projects within the Newcastle administrative boundary, separating projects into; 1) those that are delivered and hence, may offer opportunities for learning; 2) those that are in the planning and designing stage and where it might be possible to influence the direction of the project to incorporate BGI; and 3) those that are totally visionary and do not have any funding allocated or strong designs but are situated in areas where potential projects could make a large difference to surface water management and the provision of multiple benefits. The LAA then looked specifically at the Newcastle urban core and, through a series of interactive workshops, created a hypothetical ‘Blue-Green future’ founded on local knowledge of the hydrological systems, positioning of assets and other infrastructure, social characteristics of the area and thoughts on potential areas for regeneration. This included ideas around where it may be possible to implement BGI and SuDS, and the type of assets that could be implemented based on the multiple benefits that they could provide. Local policy documents such as the Surface Water Management Plan (Gateshead and Newcastle Councils, 2012) and the Core Strategy (Newcastle City Council, 2015), which outlines green infrastructure and urban renewal objectives, were used to increase the realism of the hypothetical Blue-Green future. The Blue-Green Cities Consortium are currently modelling some of the hypothetical BGI schemes, prioritised by the LAA, to assess the change in flood risk if such schemes were implemented, and to determine the range of other benefits that could potentially accrue.

Despite the growing recognition and support for BGI, there are a myriad of uncertainties, challenges and concerns that hamper implementation and the fulfilment of the Blue-Green Vision. Many urban flood risk management professionals still perceive uncertainties concerning service delivery to be greater for BG compared to grey infrastructure. Similarly, urban planners and decision makers may question the appetites of communities and their elected representatives for increasing a city or neighbourhood’s reliance on BGI (Thorne et al., 2015). Inter-agency working is an example of a socio-political barrier that may be overcome through initiatives such as the LAA. The next section of this paper explores these barriers and potential strategies to overcome them.

Barriers and Uncertainties that hamper the Blue-Green Vision

The widespread adoption of BGI is currently limited by uncertainty regarding its hydrologic performance and lack of confidence in political acceptability and public preferences (Thorne et al., 2015). The barriers to implantation of BGI were investigated via semi-structured interviews with institutional stakeholders in Portland, Oregon, a city with a strong Blue-Green Vision and recognised as a leader in green stormwater management (Water Environment Research Foundation, 2009). Uncertainties were separated into two distinct types; physical science (biophysical) uncertainties and socio-political uncertainties. Biophysical uncertainties include: modelling, climate change, natural hazards, downscaling climate projections, impacts of climate change (e.g. the detrimental impact of increased air temperatures and/or changing precipitation regimes on river health), and maintaining infrastructure performance and provision of services (as the asset ages and environmental conditions change). Notably, the number of socio-political uncertainties was found to be much higher, suggesting that they currently play a greater role in limiting BGI implantation in Portland. Socio-political uncertainties include: public preferences, stewardship of BGI, population, urban/economic development, economic resilience to climate change, level of inter-agency working, capital costs, appropriate responses to the impacts of climate change, and recognition of the multiple benefits of BGI. Ultimately, to widen implementation of BGI, both the socio-political and biophysical uncertainties and barriers must be identified and managed because key stakeholders involved in designing and delivering sustainable urban flood risk management projects must have greater confidence that BGI components are both scientifically sound and supported by communities and their elected representatives (Thorne et al., 2015). Consultation regarding BGI during planning and installation phases, and continued dialogue afterwards, could help improve residents' understanding of the existence and function of BGI and increase local awareness, which may in turn improve the public perceptions of BGI (Everett et al., 2015), thus addressing one of the socio-political uncertainties.

A similar set of semi-structured interviews were carried out in Newcastle (April-May 2015, Lawson et al., (in prep.)) to compare and contrast uncertainties and barriers, and strategies to overcome such barriers, in a US and UK context. Analysis of the Newcastle interviews illustrated 17 different categories of barriers to the implementation of BGI, including lack of knowledge and awareness, funding and costs, maintenance and adoption, legislation and governance and identifying and quantifying (and monetising) the multiple benefits. Interviewees commented that:

> "I think it's quite good to green up cities, I suppose, but I guess one caveat on that from our point of view as well is being able to demonstrate and have evidence of the benefit enough to be able to justify funding."
>
> "…the real challenge is being confident that blue-green is value for money over the alternative."
>
> "…natural flood risk management systems, it's really hard to quantify the benefits, which means it's really difficult to get the funding for it"

A prominent strategy to overcome the barriers to BGI, as inferred from the Newcastle interviews, was to promote multifunctional space and (quantitatively) asses the multiple benefits. Interviewees commented that:

> "We started to realise that there are flood risk management, it is an avenue for green infrastructure, public health is a value is an outlet, you kind of look at the different funding streams, and then what you start to see is green infrastructure is a mechanism to achieve the benefits that we, with all the eco-system services that we're trying to achieve."

> "Then if it is similar in cost, but you can highlight all these other benefits that link with our sustainability strategy, our air quality improvements, then straight away they would be happy to sign it off as a project."

Evaluating the Multiple Benefits of BGI

Quantitative evaluation of the benefits of BGI and SuDS, their spatial distribution and co-dependencies are not well understood. Multiple benefit assessment is gaining increased traction within academia and industry and new tools are being developed, such as the CIRIA BeST (Benefits of SuDS Tool, W045) tool, which enables cost-benefit analysis through a structured assessment to help quantify and evaluate each benefit (CIRIA RP 993, 2015). In parallel, a new GIS evaluation tool has been developed by Blue-Green Cities Consortium members at Cambridge University. The tool can identify the spatial distribution of different benefits and normalise benefits onto a uniform scale, allowing the local impact of multiple benefit types, benefit dependencies and dis-benefits to be directly compared, helping decision makers to co-optimise the benefits from the outset of project planning (Hoang et al., in review). The tool uses physically-based methods and models to calculate the benefits (where possible) to avoid using value transfer methodologies. Significantly, this method of benefit evaluation recognises the importance of the relative significance of benefits in relation to the surrounding environmental and socio-economic context; for instance, a green infrastructure installation in a highly impermeable, concrete built up area will provide a greater benefit than the same green infrastructure installation in an area that already has significant greenspace.

The GIS tool was successfully piloted in 2014 in Portland to evaluate some of the multiple benefits of the East Lents Floodplain Restoration Project, a large scale restoration project that was completed in early 2014 to help reduce the impacts of 'nuisance' flooding (flooding of high frequency, e.g. 1 in 10 yrs, which causes public inconvenience) by reconnecting Johnson Creek to its floodplain (BES, 2001). The tool was used to evaluate six potential benefits of the scheme (in addition to the main intended benefit of flood risk reduction); habitat connectivity, recreational accessibility, traffic movement, noise propagation, carbon sequestration and NO_2 trapping (the detailed methodology in computing each benefit can be found in Hoang et al., (in review)). The East Lents Floodplain Restoration Project is shown to provide benefits to habitat connectivity, recreational accessibility and traffic reduction, in addition to meeting the primary function of reducing flood risk. The tool can also illustrate the spatial extent of the benefits, which in this case, spread beyond the project boundary. This is a significant finding as benefits may accrue to other stakeholders, such as those living in proximity to the project area, rather than just the asset owner. This study also discusses how benefits may be incremental and/or cumulative, recognises a potential time-lag to benefit accrual, and address the potential non-linearity and interaction between different benefits. This study also addresses the idea of benefit trade-offs. For instance, a scheme that creates large flood risk reduction benefits by allowing controlled inundation of a restored floodplain may create disbenefits to carbon sequestration during the inundation period. The level of benefit is also likely to change over time as the environment is modified by natural and human processes. For instance, hydromorphodynamic modelling work has demonstrated that the gradual accumulation of sediments from the wider watershed within the restored floodplain may reduce the storage capacity of the flood basin over time (Ahilan et al., 2015). This stresses the importance of adequate maintenance to maintain the initial high level of flood reduction benefit.

The tool is currently being refined for use in Newcastle and focuses on several case study areas, including a dense residential area of terraced housing within the Wingrove ward, and the area around the Newcastle Great Park SuDS schemes near the Ouseburn watercourse. Here, effective field tracing methodology is also being used to determine transport, deposition and resuspension characteristics of sediment within SuDS ponds (Allen et al., 2015), which may have implications for maintenance requirements.

Flood risk reduction benefit

A hydrodynamic model that simulates pluvial (and fluvial) flood inundation and the movement of water through BGI has been developed by Blue-Green Cities Consortium members at Newcastle University (Glenis et al., 2010; 2013). Outputs from the model will be used as inputs to the multiple benefits GIS tool to calculate the flood risk reduction benefits of specific strategies within the Blue-Green Vision. The City Catchment Analysis Tool (CityCAT) for urban flood assessment realistically represents the urban environment (land use and terrain) in its complexity. CityCAT uses standard, readily available datasets, such as a Digital Terrain Model (DTM) for the topography and OS MasterMap to delineate the urban features (buildings, roads and permeable surfaces). CityCAT enables rapid assessment of combined pluvial and fluvial flood risk and is enhanced by efficient algorithms for grid generation and robust and extremely accurate solutions of flow equations. Current capabilities for modelling BGI include permeable paving, green and blue roofs, water butts, and swales (currently being coded into the model). CityCAT comprises an overland flow model integrated with the subsurface drainage network to handle discontinuous free surface and pressurised flows, and thus accurately simulates mixed flows in pipes. The model was validated against laboratory measurements for mixed and pressurised flows and showed good agreement. CityCAT can simulate pluvial flooding due to blocked sewers as well as flooding from sewers due to insufficient capacity.

CityCAT is being used by the Blue-Green Cities Consortium to compare flow velocity, depth and inundation extent before and after the adoption of BGI in select areas of the urban environment. As proof of concept, simulations have been run to determine the flood risk reduction benefit for a residential area of Newcastle (Wingrove). A business as usual simulation has been run to illustrate the current flood risk. Using the same design storm, a suite of simulations has been run, each with different Blue-Green modifications to the environment. For instance, one simulation re-classified all of the pavements and back-alleyways as permeable paving and all of the gardens as greenspace. Another simulation included water butts (300 L capacity) on each of the properties. Preliminary modelling output shows that the BGI provides temporary storage and helps alleviate the burden on the subsurface system, and is particularly effective for small-scale rainfall events (5-30 yr return periods). This creates a flood benefit which can subsequently be incorporated into the GIS tool as a specific benefit layer. CityCAT capabilities are currently being developed to include large swales (with connection to subsurface drainage systems) and will be tested in a range of scenarios for the Newcastle urban core (business as usual and hypothetical Blue-Green futures) before the project finishes in February 2016.

Concluding remarks

The Blue-Green Cities Research Project adopts an interdisciplinary approach to identify and rigorously evaluate the multiple flood risk benefits of natural flood risk management strategies and Blue-Green infrastructure. This paradigm shift from traditional grey infrastructure designed to remove water as quickly as possible from the urban surface is in line with WSUD and urban water management that holistically consider the environmental, social and economic consequences of flood risk management strategies.

- The Blue-Green Vision is for urban environments to follow the principles of Blue-Green Cities by maximising the opportunities to achieve multiple environmental, social and economic benefits of Blue-Green approaches to surface water and flood risk management.
- Learning and Action Alliances may be a platform for collaboration and vision development, as demonstrated by the Newcastle LAA (established in 2014) and may help overcome some of the uncertainties and barriers to BGI, such as inter-agency partnership working.
- Uncertainties and barriers to the adoption of Blue-Green infrastructure span the biophysical and socio-political spheres, and while some can be reduced, addressed and overcome, others we can only talk about and included in our risk assessments.

- Barriers can be overcome by promoting multifunctional space and assessing multiple benefits, improving education and communication, partnership working, better data, changes in legislation and through best practice exemplars, such as the ‘Grey to Green’ initiative in Portland, Oregon.
- Multiple benefit GIS assessment tools can be used to quantify and value a range of selected benefits and identify where, when and to whom the benefits accrue. A new GIS evaluation tool has been developed by Blue-Green Cities Consortium members at Cambridge University and can identify the spatial distribution of different benefits and normalise benefits onto a uniform scale, allowing the local impact of multiple benefit types, benefit dependencies and dis-benefits to be directly compared, helping decision makers to co-optimise the benefits from the outset of project planning. This tool is one of the key outputs from the Blue-Green Cities Research Project.
- Hydrodynamic models can illustrate the role of Blue-Green infrastructure in reducing flood risk and managing surface water. The Consortium are using CityCAT, a hydrodynamic model that simulates pluvial (and fluvial) flood inundation and the movement of water through BGI, to determine the specific flood risk reduction benefits of hypothetical Blue-Green futures.

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