EDITORIAL

**Managing urban flood risk in Blue-Green Cities; the Clean Water for All initiative**

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Portland, Oregon USA, demonstrates many best practice examples of sustainable stormwater management that embrace the *Blue-Green* ideal of reconfiguring the urban water cycle to more closely resemble the natural water cycle. For more than a decade the City of Portland has invested widely in Blue-Green infrastructure (BGI) to help reduce the number of combined sewer overflows (CSO), in the context of a state-wide plan to restore Oregon's watersheds, recover fish and wildlife populations to sustainable levels and provide ecological, cultural and economic benefits [*Yeakley and Dunham*, 2014]. These ongoing efforts have produced more than 2000 street bioswales, over 600 ecoroofs, tens of thousands of street trees, and supported extensive efforts involving culvert removal, reintroduction of native vegetation and animals (including beaver), land purchasing from willing sellers and floodplain reconnection and restoration [*BES*, 2018]. As Portland progresses towards becoming a *Blue-Green City* (where pre-development hydrology is mimicked through the restoration of natural drainage channels, improvements to water quality, increased infiltration and surface storage), a strong scientific evidence base has been compiled to support the implementation of multi-beneficial, multifunctional Low Impact Development (LID) and BGI. The abundance and range of implemented BGI assets and restoration schemes, combined with the relative age of some assets (over 10 years old) and consequential likelihood that they are increasingly viewed as 'normal' within the urban landscape, made Portland an ideal demonstration case study under the EPSRC's 'Clean Water for All' (CWfA) research initiative (2014-15).

The interdisciplinary research project led by the University of Nottingham that formed the basis for this Virtual Special Issue represents a collaborative effort between academic institutions in the UK, US and China, under the themes of Water Engineering, Resilience and Sustainability. In addition to academic outputs, co-location research in the UK and US aimed to build long-term, collaborative partnerships between: UK academics working on the EPSRC research consortium "Delivering and Evaluating Multiple Flood Risk Benefits in Blue-Green Cities"; American colleagues engaged in the National Science Foundation (NSF) funded Portland-Vancouver ULTRA (Urban Long-term Research Area) research project, and; Chinese academics researching flood risk and water management in Sponge Cities. The overarching aim of this interdisciplinary research was to provide an enhanced evidence base to justify adoption of BGI, while developing a greater understanding of design modifications needed to co-optimise multiple co-benefits. To meet this aim, objectives were set to:

1) Investigate the environmental and social impacts and benefits arising from implemented BGI and river habitat restoration, and;

2) Identify the challenges and barriers that continue to hamper Portland's continued progression towards *Blue-Green City* status.

The CWfA research programme comprised three phases; start-up and planning, co-location research in Portland and data analysis, and write up and dissemination. The programme culminated in a Knowledge Exchange Workshop and Symposium in Ningbo, China, 15-18th June 2015. Research was performed as a closely integrated and carefully sequenced set of five themes that ran in parallel and provided a stable framework for the execution of the diverse activities involved in delivering the project. Much of the research focused on Johnson Creek, a free flowing stream that originates in the foothills of the Cascade Mountain Range and flows west for 42 km, crossing through the southeast Portland metropolitan area before its confluence with the Willamette River. The 134 $km^2$ rural-urban watershed is subdivided into numerous smaller sub-catchments of varying size (0.006-0.7 $km^2$). Approximately 75% of the catchments convey stormwater to Johnson Creek through a piped network and a series of outfalls. In the lower reaches, river restoration activities funded through extensive public and private investment over the last three decades have gradually reconnected parts of Johnson Creek to its floodplain. This includes the East Lents Floodplain Restoration Project, within the 280 ha Foster Floodplain Natural Area in lower Johnson Creek. This scheme has successfully reduced the occurrence of 'nuisance flooding' (<1 in 10 year events) that frequently blocked Foster Road (a major commuter thoroughfare) while providing BGI that generates multiple co-benefits as part of the wider Johnson Creek Restoration Plan [*BES*, 2001].

The papers included in this Virtual Special Issue demonstrate that while a range of barriers to BGI still exist in Portland, the benefits of the Blue-Green approach to urban flood and water management extend far beyond the hydrological sphere, leading to improvements in water and sediment quality, habitats and biodiversity, recreation, amenity and neighbourhood aesthetics. The key research outputs from each theme are now summarized and related research papers are signposted.

**Theme 1. Identifying and dealing with uncertainty as a barrier to the adoption of BGI**

Despite the abundance and diversity of BGI in Portland a multitude of uncertainties act as barriers to widespread implementation. Theme 1 investigated how institutional stakeholders in the City of Portland identify and deal with biophysical and socio-political uncertainties. A Relevant Dominant Uncertainty (RDU) approach was piloted to establish the RDUs and areas of low confidence that are responsible for challenges and concerns that currently limit progress towards the Blue-Green idyll [*Thorne et al.*, 2018]. Socio-political RDUs, which refer to a lack of confidence that decision makers and communities will continue to support, understand, and pay for BGI (including RDUs such as public preferences, stewardship of BGI and appropriate responses to the impacts of climate change), were found to exert the strongest negative influences on BGI decision making in Portland. Biophysical RDUs, which include maintaining infrastructure performance and provision of services, impacts of climate change and modelling, were recognised by stakeholders but found to hamper decision making to a lesser degree. Thorne et al. (2018) advocate a concerted approach to identifying and managing both the socio-political and biophysical RDUs in order to broaden the implementation of BGI that is both supported by local stakeholders and scientifically sound. Notably, post-project monitoring and evaluation of infrastructure service delivery following implementation is essential to assess whether the design standards are fit for purpose, and provide further information on long-term functionality.

**Theme 2. Hydro-morphodynamic modelling of flow and suspended sediment**

As highlighted in Theme 1, a key uncertainty (i.e. RDU) affecting the long-term sustainability of a Blue-Green City concerns service provision and maintenance of infrastructure, particularly as BGI assets age and environmental conditions change. Theme 2 investigated the functionality and maintenance requirements of a major piece of BGI by evaluating the short and long term performance of a lowered floodplain and channel re-meandering project at East Lents in lower Johnson Creek. A 2-dimensional, hydro-morphodynamic model was employed to simulate flow and suspended sediment dynamics, and investigate the capacity of the project to lower flood peaks and retain sediment. Simulations demonstrate that the downstream flood peak for a 30-year return period event can be attenuated by up to 23% owing to the large capacity and geomorphic features of the floodplain [*Ahilan et al.*, 2018]. The floodplain also acts as a sediment sink, trapping ~20-30% of flood sediments generated further upstream. These are significant results in a stream where 'nuisance flooding' from short return period events is a chronic problem and retention of sediment is a deficiency due to past straightening and hard-lining of the channel. Sediment retention in the floodplain also reduces the cumulative sediment load supplied to the Willamette River, a key watercourse for listed and endangered salmonids, so demonstrating the wider impacts of the East Lents floodplain restoration. Ahilan et al. (2018) further investigated the effectiveness of this floodplain project for larger floods (115 $m^3$/s, 500-year return period), resuspension of sediment during long-term simulations, and the impact of sedimentation on floodplain storage capacity. They found a 28% flood peak reduction for the 500-year flood event, challenging the common assumption that floodplain storage is only effective up to medium flow (50-year) events. This finding is attributable to the large extent of the lowered floodplain and its high storage capacity. Sedimentation was found to have no adverse impact on floodplain water storage over engineering timescales, as volumes of deposited sediment are insignificant compared with floodplain storage capacity. Fine-grained flood sediments are known to be contaminated by heavy metals and other pollutants and hence there may be the potential for contamination levels in the floodplain to rise over long time periods. However, there is no evidence of rising levels of contamination to date, and the dense and vibrant vegetation on the floodplain gives it a high capacity to absorb and process pollutants safely. In summary, Ahilan et al., (2018) conclude that the East Lents floodplain restoration provides flood resilience, sediment reduction and water quality benefits.

**Theme 3. Sediment, contaminants, morphology and riparian restoration**

The type of sediment, and concentration of attached pollutants and heavy metals, are important factors in evaluating the success of an urban stream restoration scheme. Theme 3 focused on fine sediment heavy metal deposition by investigating the sources and pathways of contaminated sediment in Johnson Creek, and the potential for different land use, e.g. BGI, to reduce pollutant levels. In a *short communication*, Chang et al., (2018) investigate relationships between sediment-related, heavy metal concentrations and sub-basin characteristics and find that the delivery of contaminated sediment in the heterogeneous, rural-urban Johnson Creek catchment is more complex than that found in situations where land use is more clearly segregated. This questions common assumptions regarding sources and delivery paths of flood-related sediment pollutants. The authors invite interested parties to download the full dataset at https://rdmc.nottingham.ac.uk/handle/internal/32 to further investigate the relationship between sediment heavy metal concentrations and sub-basin characteristics in Johnson Creek.

A large proportion of runoff entering Johnson Creek from the North side of the catchment is transported through complex pipe networks that discharge into the creek. Stormwater pipes that discharge into watercourses are acknowledged as point sources of toxic contaminants in urban rivers. Recent advances in stormwater management promote infiltration and pollutant removal by routing stormwater through vegetated structures, natural flood management structures or restored riparian zones (green stormwater infrastructure). In Johnson Creek and its tributaries, which traverse rural and urban sub-catchments, green stormwater infrastructure has been widely implemented to reduce flooding and improve water quality. This includes setback outfalls that discharge piped stormwater outflows into a pocket wetland or swale prior to reaching the main channel. The increased hydraulic roughness in these features causes flow velocities to decrease, encouraging deposition of polluted sediment. Lower pollutant levels were observed at setback outfalls compared with direct outfalls into Johnson Creek [*Janes et al.*, 2016]. River restoration activities (in-stream and riparian features) along the study reach of Johnson Creek were also found to reduce pollutant levels and create additional benefits such as habitat for species listed as at risk or endangered. Higher levels of habitat quality (determined by River Habitat Survey (RHS) assessment methods) and lower levels of channel modification were associated with higher removal efficiency of several pollutants (Fe, Ba, Sn, Mg, P, K). Janes et al., (2016) conclude that setback outfalls and river restoration represent passive stormwater treatment measures that reduce the sediment pollutant input into Johnson Creek from the surrounding urban catchment.

**Theme 4. Community perceptions: the social dynamic**

Moving away from biophysical uncertainties (i.e. RDUs) to socio-political uncertainties, Theme 4 investigated the concern of several City of Portland institutional stakeholders regarding negative perceptions of BGI by local residents and communities. Perceptions of BGI have a direct impact on citizens' understanding of the effectiveness and future willingness to pay for, and help maintain, such assets [*Everett et al.*, 2015]. Theme 4 investigated the social dynamic and evaluated citizens' perceptions of bioswales as an example of a highly visible BGI intervention. Residents' appreciation and acceptance of the bioswales was strongly dependent on their awareness of the purpose of the asset and its functionality, their community values (e.g. environmental attitudes), and other site-specific variables such as physical bioswale characteristics (plant choice, maintenance regime and level of perceived 'untidiness' and littering) [*Everett et al.*, 2018]. Some residents possessed general knowledge of the primary functionality of the bioswales, but this was by no means universal or even commonplace. Everett et al. (2018) suggest that greater consultation and co-construction of solutions during the development phase should be explored as a means to improve local awareness and satisfaction, and thus, encourage a change in public perceptions and behaviour. Greater promotion of the social and ecological benefits of BGI may also improve local acceptance of assets.

**Theme 5. Multiple benefits of BGI**

Discussion of the multiple environmental, ecological and social benefits of BGI and river restoration is a common thread covered by all Themes. For instance, river and floodplain restoration has been shown to generate flood risk reduction benefits (flood peak attenuation, increased water storage and infiltration, reduced runoff velocities) while also improving instream sediment quality and habitats, and reducing pollutant concentrations (Themes 2 and 3). Residents were generally aware of the flood risk management and water quality improvement functions of bioswales but other, less visible, co-benefits, such as carbon sequestration (as part of climate change adaptation objectives), were less widely acknowledged (Theme 4). Similarly, recognition of the multiple benefits of BGI was identified as a socio-political uncertainty (i.e. RDU) that can act as a barrier to widespread implementation of BGI (Theme 1). Communicating the multiple benefits of BGI could, therefore, increase confidence in blue-green approaches as preferred strategies. Theme 5 identified and evaluated the multiple benefits created by the East Lents Floodplain Restoration Project and developed a GIS tool capable of overlaying a range of biophysical benefit layers (habitat connectivity, recreational accessibility, traffic movement, noise propagation, carbon sequestration and $NO_2$ trapping) to illustrate the benefit profile, intensity and dependency [*Hoang et al.*, 2018]. These impact categories reflect examples of the types of benefits from such a restoration scheme and were selected based on the initial aims of the East Lents project [BES, 2014]. They are by no means definitive and, in future research, determining the pollutant trapping rate of, for example, NOx and particulates could provide a more comprehensive evaluation of the ability of BGI to trap airborne pollutants. Hoang et al., (2018) conclude that in addition to providing flood storage during a flood event (its primary function), the East Lents project contributes positively beyond the project area by improving landscape connectivity, amenity accessibility and habitat accessibility when it is not flooded. Carbon sequestration and noise reduction were found to have declined immediately following construction of the project; however, these are expected to be temporary impacts due to removal of vegetation during the restoration works.

## Knowledge Exchange in Ningbo and China's Sponge City programme

CWfA research outputs were disseminated via a Knowledge Exchange Workshop and Symposium hosted by the University of Nottingham Ningbo China (June 2015). This event brought together UK-US-Chinese academics and Ningbo City officials to facilitate the exchange of knowledge and experience on the advantages of using integrated drainage systems, best management practices and BGI to provide sustainable and resilient urban water, flood risk and environmental management. Ningbo is a rapidly urbanising delta city facing challenges regarding the management of water and flood risk coupled to extensive economic development and growth. As Tang et al. (2018) note in their paper on the opportunities to integrate BGI into current city development in Ningbo, there is history of natural flood management and Blue-Green drainage techniques employed to help manage urban water. Systems of ponds, rivers and wetlands supplied Ningbo with freshwater for drinking and irrigation, and are still visible in western parts of the city. In addition, agricultural practices, such as growing rice in paddy fields, were reliant on the flooding of arable land in the floodplain to support growth of semi-aquatic species of rice. Modernisation during the late 1970-90s saw an increase in subsurface piped drainage infrastructure and the building of large mountain dams to store freshwater and supply the growing city. China has experienced a recent shift in water management due to recent floods and severe droughts, launching the 'Sponge Cities' campaign to promote self-sufficiency in water management and resilience against extreme weather events through sustainable urban drainage and water sensitive urban design. In September 2015 the Chinese government approved the development of 16 model 'Sponge Cities' in urban districts including Wuhan, Chongqing and Xiamen, involving the retrofit of existing cities and introduction of BGI and sustainable urban drainage to facilitate the absorption and reuse of rainwater. This has now been extended to 30 cities, including Shanghai. This campaign encourages the development of strategies to simultaneously tackle five of the pressing water management issues (water pollution remediation, flood mitigation, waterlog elimination, freshwater preservation and water consumption conservation). Strong political will to implement 'Sponge Cities' that is apparent creates an abundance of emerging opportunities for China and helps overcome one of the key socio-political challenges to widespread implementation [*Tang et al.*, 2018].

## Concluding remarks

In summary, the CWfA research initiative has contributed to the growing evidence base supporting BGI and river restoration as urban flood risk and stormwater management strategies that generate a multitude of environmental, ecological and social benefits to a range of beneficiaries. Evaluation of the benefits of Portland's stormwater management and river restoration helped justify adoption of BGI while developing a greater understanding of design modification to co-optimise multiple co-benefits. Lessons learned and concepts developed under the CWfA research programme have been employed by the Blue-Green Cities team in UK case studies, demonstrating the value of the evidence base created in Portland for future research. For instance, the Relevant Dominant Uncertainty (RDU) approach was adapted to investigate the barriers to implementation of BGI in Newcastle, UK, supporting Thorne et al., (2015) in the conclusion that socio-political uncertainties and barriers exert the greatest negative influence on Blue-Green decision making [*O'Donnell et al.*, 2017]. The multiple benefits GIS assessment tool created by Hoang et al., (2016) was further developed into the Blue-Green Cities Multiple Benefit Toolbox (available to download from http://www.bluegreencities.ac.uk/publications/multiple-benefit-toolbox.aspx). This toolbox evaluates the spatial distribution and relative significance of six BGI benefits (flood damage reduction, noise mitigation, air pollution reduction, carbon sequestration, access to greenspace and habitat connectivity, and it has been used successfully in several case studies in Newcastle [*Morgan and Fenner*, 2017; *O'Donnell et al.*, *2018*]. Finally, the 2-dimensional, hydro-morphodynamic model developed for the East Lents study has also been employed in investigations of fine sediment dynamics in the Newcastle Great Park development, concluding that these stormwater ponds can effective attenuate the flow peak and trap fine sediment, thus helping manage urban water quantity and quality [*Guan et al.*, 2018].

The CWfA research demonstrates that while a range of barriers to BGI still exist, most notably socio-political uncertainties and public perceptions, the benefits blue-green flood risk and stormwater management extend far beyond the hydrological sphere and can lead to improvements in water and sediment quality, habitats and biodiversity, recreation, amenity and neighbourhood aesthetics. Overcoming the socio-political and biophysical barriers through extended scientific and humanities research, confidence building, social learning and community engagement can help cities such as Portland and Newcastle, and those involved in the Chinese Sponge City campaign, to achieve *Blue-Green City* status.

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