3 Green infrastructure and urban water management

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<h1> Introduction

Green infrastructure is well recognized as providing multiple functions and delivering a wide range of benefits. The potential benefits span the environmental, economic and socio-cultural spheres; from reducing flood risk (and the associated costs of flood damage) and cooling high urban temperatures (see Chapter 2), to providing natural areas for wildlife (see Chapter 5), recreation and local amenity (see Chapter 1). Many definitions of green infrastructure also include considerations of blue infrastructure, but this chapter will focus the lens more specifically in this direction. In the context of urban water management, green infrastructure can refer to a process, e.g. using vegetation and soil to manage rainwater at the site as it falls, or to 'an approach that communities can choose to maintain healthy waters, provide multiple environmental benefits and support sustainable communities' (EPA, 2012). We can thus use the 'green' to help us in dealing with a number of contemporary problems with water, the 'blue', hence the phrase 'blue-green infrastructure'.

Water is essential to society and to human life; too much, too little or too poor a quality can make life difficult or impossible for millions of people, as well as destroying billions of pounds-worth of infrastructure and weakening countries' economies and societies. Water is also essential for establishing and maintaining green infrastructure, and so effective management of the 'blue' needs to be one integral element within the management and development of the 'green'.

Green infrastructure can refer to a wide range of installations using plant and soil systems to collect, retain, reuse, treat or encourage the evapotranspiration of stormwater, with an ultimate aim to reduce incidences of flooding and sewer system exceedance, whilst simultaneously providing numerous additional social and environmental benefits. Using green infrastructure for urban water management may offer innovative, cost-effective, socially preferable and environmentally sustainable solutions. There are numerous examples of where green infrastructure is utilized in strategies to meet urban water management goals. These include green roofs across many UK and European cities; bioswales (a form of vegetated rain garden or soakaway) across cities throughout the United States, and constructed wetlands in Australia.

As Fletcher et al. (2015) outline quite comprehensively, green infrastructure used in water management has gained a range of nomenclature and acronyms defining different, or sometimes very much the same, elements, designs and purposes: Low Impact Development (LID); Water Sensitive Urban Design (WSUD); Integrated Urban Water Management (IUWM); Sustainable Urban Drainage Systems (SUDS) or Sustainable Drainage Systems (SuDS); Best Management Practices (BMPs); Stormwater Control Measures (SCMs); Alternative Techniques (ATs) or Complimentary Techniques (CTs); Source Control, and Stormwater Quality Improvement Devices (SQIDs). Fletcher et al. (2015, p. 9) refer to an 'approximately exponential growth' in the use of such terminology in the academic literature from the early 1980s onwards, and the growing interdisciplinarity of these references as the field of interest has expanded from civil engineering to include landscape architects, planners, ecologists and social scientists. A further term 'blue-green infrastructure', which has evolved from the concept of WSUD (Brown et al., 2009) and describes green infrastructure that temporarily turns 'blue' during rainfall events and floods, is the focal point in this chapter.

This chapter will first outline the many challenges water poses in modern society, considering the increasing frequency and severity of flooding and droughts as inevitable outcomes of potential climate change and increasing impermeable ground-cover through urbanization and economic development. It will secondly consider recent suggestions of a paradigm shift in thinking around water management, urban spaces, and the co-development of blue and green infrastructure, thus integrating the different means by which water is managed within towns and cities. Following this, it will look at several shifts in policy and practice that provide examples of how this paradigm shift and support of green infrastructure for urban water management could be finding its way into contemporary urban re/developments. Finally, the chapter will consider the principle stakeholders who will be affected by these changes, arguing that they should be at the heart of new infrastructure developments and brought in as early as possible to ensure the co-construction of sustainable and workable solutions within different contexts embodying different sets of interests and socio-economic pressures. Green infrastructure is increasingly being utilized in strategies to meet urban water management goals, and to help ensure that this process of change advances as quickly and equitably as possible, it is essential that all interested parties are able to contribute to the development of effective solutions.

<h1> The problems with water

Water has always been a crucial factor influencing the location, development and success of urban areas. We require a continual supply of fresh water in order to live and grow food; water is furthermore vital as a means of transportation for certain goods and historically has been even more essential for transporting many more goods as well as people. Yet excesses and shortages of water can also threaten people, whole societies and the urban infrastructures that they have developed.

Whilst flooding has always been a concern for urban settlements situated on floodplains, global flood risk is becoming an increasingly significant concern (Milly et al., 2002). One study by Brenden Jongman et al. (2012) found that almost 1 billion people around the world are currently exposed to flooding, with a corresponding assets-value of $46 trillion.

Jonkman (2005) also found that between 1990-2000, floods (and associated land and mudslides) had directly killed up to 100 000 people and affected over 1.4 billion. It is estimated that approximately 5.5 million properties in England and Wales alone are situated in areas at risk of flooding from rivers, the sea and surface water (Environment Agency, 2009a; 2009b).

With widely anticipated changes to the climate, such as the predicted increase in the frequency and magnitude of extreme precipitation events (IPCC, 2012; Bates et al., 2008), forecasts have been made that flood events will increase in frequency and severity (Allan, 2011; Min et al., 2011; Pall et al., 2011). For example, UK flooding may increase by up to 30 times over the next 75 years, which could end up costing billions of pounds annually (EM-DAT, 2012; Evans et al. 2008). Four of the five wettest years on record for the UK have occurred since the turn of the millennium (2000, 2002, 2008 and 2012; Met Office, 2014). Furthermore, some of the most widespread recent UK flooding occurred in 2007, which prompted the commissioning by the UK government of the Pitt Review (Pitt, 2008). Record-breaking rainfall records in December 2013 - February 2014 led once again to significant flooding across parts of the UK (Met Office, 2014). Climate change is expected to bring significant further shifts in precipitation: a 33 per cent increase in rainfall in the winter months and a 40 per cent decrease in summer in the UK (Abbott et al., 2013), developing further from precipitation changes observed between the 1960s and now (Jones et al., 2012).

At the same time, risks of drought are also increasing around the world (Hirabayashi et al., 2008; Trenberth et al., 2003), along with associated risks such as heatwaves (Van Aalst 2006), wildfires (Westerling et al., 2006) and tree mortality (Allen et al., 2010). In 1999, Nigel Arnell (1999) estimated that by 2025, 5 billion people globally would be living in areas of water stress and this figure is unlikely to have diminished. In Europe, droughts rose by around 20 per cent between 1976 and 2006 (European Commission, 2010), whilst the European heatwave of 2003 has been estimated at causing over 70 000 deaths (Robine et al., 2008). Most of the South East of England is now classified as being under moderate to severe water stress (Weatherhead and Howden, 2009).

The future risks of floods and droughts are likely to be exacerbated by increasing urbanization and economic growth. It is estimated that by 2050, 70 per cent of the world's population will be living in urban areas, up from 30 per cent in 1950 (WHO, 2014). This increasing urbanization is likely to put greater numbers of people, their housing and other urban infrastructure on floodplains (Jha et al., 2012). In the UK, the largest population growth is expected in the South East, increasing by 23 per cent by 2035 (Abbott et al., 2013). Further economic development and urbanization will impact on land-use, and will likely increase the level of impermeable surfaces, as vegetated or soft-surface (permeable, water-draining) areas are replaced by houses, shops, roads and hard-paved areas like car parks and footpaths. This would reduce the space available for surface water to infiltrate naturally into the ground, thereby increasing surface runoff and further heightening flood risk in the built environment (Wheater and Evans, 2009).

Many modern urban environments across the globe are at varying degrees of fluvial, pluvial, coastal and groundwater flood-risk (see Table 3.1), and some of these locations and others are also at risk of drought. Climate change modelling indicates that both flood and drought risk are likely to get worse in the future. In addition, water quality remains a serious issue in many parts of the world as a result of two centuries of industrialization. Further reduction of permeable groundcover in urban areas will make these spaces more vulnerable to flooding and, as shall be argued below, drought. The potential future changes in climate and land-use that we have highlighted make it clear that we need to develop new ways of thinking around how to deal with water. Fortunately, this is beginning to happen, at both research and policy levels, as the next two sections will outline. This new thinking has begun to develop for a number of reasons: the environmental, aesthetic and socio-economic impacts of structural work; the need to adapt urban areas to cope with a changing climate (using fewer resources and emitting less waste); the need to develop water management systems that might cope better with exceedance compared with solid pipes, and an increasing concern for the 'liveability' of cities.

<Table 3.1 Major types of flooding (Source: RGS, 2010)>

<h1> Shifting research focus

Throughout the nineteenth and twentieth centuries, urban water management has focussed on developing and securing a supply of potable water, effective means of disposing of wastewater, and finally, developing a means of disposing of excess (storm) water as quickly and efficiently as possible. This is what Brown et al. (2009) refer to as the water supply, sewered and drained cities. In this way, water was conceived of in three very distinct and separate forms and functions, and so each form has historically been treated in quite a distinct manner. Traditional 'grey' infrastructure (e.g. piped drainage and wastewater treatment systems for pollution control) was predominantly used to manage urban water quantity and quality, and there was a reliance on heavily-engineered projects.

It has been argued that we are now undergoing a paradigm shift towards a system of 'integrated water cycle management … integrating the urban water cycle (including potable water, wastewater and stormwater) into the built and natural urban landscape to provide multiple benefits to society' (Wong, et al., 2013, 11, see also Huang, 2012). Green infrastructure and other non-traditional measures for flood risk management thus aim to reduce the amount of water entering the 'hard' drainage systems, while creating benefits that accrue from naturally storing and processing urban stormwater. The potential for using green infrastructure in urban water management has been, and continues to be, explored by many of the key stakeholders in urban water management, including local governments, institutions, water companies, agencies and academia.

This has led to the development of a series of new concepts and theories, as well as a number of current or recent research projects investigating blue-green approaches to urban water management. First, AUDACIOUS (Adaptable Urban Drainage - Addressing Change In Intensity, Occurrence And Uncertainty of Stormwater), funded by the UK Engineering and Physical Sciences Research Council (EPSRC), looked to provide a comprehensive assessment of urban drainage capacity in the UK with regard to climate change potentialities (Ashley et al., 2008). The project included a significant review of the scope of SuDS to reduce the stress upon wastewater infrastructure. Second, the European Union (EU) funded GRaBS project (Green and Blue Space Adaptation for Urban Areas and Eco Towns, www.grabs-eu.org) focused upon exploring, raising awareness and increasing expertise around how green and blue infrastructure could help new and existing mixed use urban developments adapt to projected climate scenarios. More recently the European Union has funded the Blue Green Dream project (Maksimović et al., 2013). This aims to contribute to the 'service infrastructure' needed to aid the implementation of urban adaptations and retrofit, developing monitoring systems and rating structures such that blue-green initiatives can be reliably assessed and rolled out more widely if they prove to be socio-economically beneficial.

The Blue-Green Cities research project, also funded by the EPSRC, meanwhile aims to develop the mechanisms and procedures for robustly evaluating the multiple socio-economic, environmental and ecological benefits of adopting a blue-green infrastructure approach to managing flood risk. This approach recognizes and accounts for the benefits when the urban system is in flood (blue), and non-flood (green) state (Lawson et al., 2014). A 'blue-green' city aims to reproduce a more naturally-oriented water cycle (Figure 3.1) while contributing to the amenity functions of the urban environment by bringing green infrastructure together with water management concerns (Novotny et al., 2010). This includes restoring natural drainage channels, reducing the extent of impermeable surfaces, increasing infiltration and improving surface storage in natural areas, and thus water quality (Hoyer et al., 2011). The aim would be that blue-green infrastructure would provide a range of services including water supply, climate regulation, air quality and pollution control, production of food, biodiversity and wider socio-cultural services (aesthetics, psychological and spiritual matters).

<Figure 3.1 Comparison of the water-cycle and environmental attributes in conventional (upper) and blue-green (lower) environments (Source: Lawson et al., 2014)>

The Cooperative Research Centre for Water Sensitive Cities (CRC-WSC) in Australia has developed perhaps the most extensive and enveloping conceptual structure with regard to urban water management. This is WSUD, a framework intended to enable progression towards the construction and retrofit of 'Water Sensitive Cities' (WSC) (Wong, 2006; Brown et al., 2009; Wong et al., 2013). Water Sensitive Cities would consider the total water cycle in an integrated manner (stormwater, groundwater, wastewater and potable water supply), with the careful management of catchments, water conservation via stormwater harvesting and recycling of wastewater, and incorporation of green infrastructure. Water Sensitive Urban Design looks to the potentialities of urban design and urban retrofitting to enable this, seeking to minimise the environmental impacts of solutions offered whilst improving their aesthetic qualities and potential recreational benefits (Whelans et al., 1994). Both WSUD and WSC attempt to go beyond this to also consider the socio-cultural and spiritual values of water to people of different cultures, aiming for as an inclusive and sustainable an approach as possible to water for both current and future generations. Water Sensitive Urban Design has gained an international status and the term is now used in New Zealand and the UK (Ashley et al., 2013). The CSC-WSC's work in this area has also led to partnership working across Australian municipalities and has highlighted research priorities further afield, such as in Singapore. In

2006, Singapore's national water agency, PUB, invested in the long-term, strategic Active, Beautiful and Clean Waters (ABC Waters) programme to realise the full potential of its urban water infrastructure and includes WSUD components (Ong et al., 2012). Water Sensitive Urban Design has also been adopted, and further developed, under the SWITCH-EU project (2006-11) (Hoyer et al., 2011) and by CIRIA, the Construction Industry Research and Information Association (Abbott et al., 2013), and numerous international scholars (White, 2008; Green, 2010; Kazmierczak and Carter 2010).

The WSC (Figure 3.2) is an ideal end-point in Brown et al.'s (2009) typology of 'six distinct, yet cumulative, transitional stages in the development of urban water management' (p. 4). The WSC is admittedly still an aspiration: 'there is not an example of a Water Sensitive City anywhere in the world although the concept is attracting attention from scientists and practitioners interested in envisaging potential sustainable water futures' (Brown et al., p. 9). We could assert with reasonable confidence that the great majority, if not all, cities in the world are situated somewhere between seeking to implement or retain Drained City status and Waterways City status.

<Figure 3.2 Urban Water Management Transitions Framework (Source: Brown et al., 2009)>

It is clear that widespread adoption and support for the concepts of a WSC and a Blue-Green City would involve shifts in thinking and behaviour from publics as well as governing bodies and water agencies. Urban design could theoretically reinforce water sensitive values and behaviours, but these would need to be present in the first place to be reinforced. Developing these values and behaviours could involve major changes in thinking and practice for some organizations and people, and so thought needs to be given to ensuring that all parties have a voice in the co-development and implementation of solutions in order to bring as many people as possible into the conversation, as will be discussed in the Stakeholders section.

<h1> Governance level shifts

Governing bodies are taking very seriously the need to deal with the economic, environmental and social threats of an excess, lack and/or poor quality of water. The EU for example has issued its Water Framework Directive and Floods Directive, which commit governments to achieving good quality waters and producing flood risk assessments within their territories. The United States' Environmental Protection Agency (EPA) has invested significant resources in investigating the potential for reducing costs of flooding and stormwater exceedance of combined sewer overflow systems through the use of green infrastructure (EPA, 2007; 2013). In the Netherlands, the 'Room for the River' programme (Rijke et al., 2012) aims to improve flood protection, landscaping and environmental conditions around the country's rivers. UK governments are also beginning to deal differently with the threat of flooding (DEFRA, 2005; 2008; SEPA, 2009); thinking has shifted towards understanding how cities can reduce the probability and consequences of flooding and how they can adapt to the development of new or increased flood risks (Bowker, 2007; Thurston et al., 2008; McBain et al., 2010).

Thinking is similarly shifting away from simple notions of resisting outright inundation and keeping the water out, towards developing resilience to flooding - with phrases such as 'living with water' and 'making space for water' gaining prominence in academic and policy documents (DEFRA, 2005; Bowker, 2007; Pitt, 2008; McBain et al., 2010). In this way, approaches have developed away from establishing increasingly stronger and higher structural defences and towards exploring ways in which water might be managed - channelled, stored, filtered and made use of - moving us from a flood defence mentality to one of flood-risk management (Johnson and Priest, 2008; Butler and Pidgeon, 2011; Porter and Demeritt, 2012).

Such new approaches involve significant shifts in the ways water is managed before, during and after flood events. Channelling water as quickly as possible through engineered drainage systems and pipes, which necessarily have a limited capacity, creates risks of surcharge when capacity is exceeded. Where combined sewer systems are used, this may expel rainwater mixed with sewage into urban rivers and/or streets. Instead, the non-traditional, blue-green approaches aim to develop spaces where water can be stored, or soak into the ground and be filtered by plants and soil before returning to the watercourse at a much slower rate. 'Blue-green' flood-risk management approaches, like WSUD, involve improving green infrastructure, raising water-absorption capacity and promoting natural channelling rather than containing and culverting (Abbott et al., 2013).

In England, the Flood and Water Management Act 2010 has set out regulations for surface water runoff for which the Department for Environment, Food and Rural Affairs (DEFRA) has developed national standards to be followed (UK Government, 2010). In Scotland, the Water Environment (Controlled Activities) (Scotland) Regulations 2011 functions similarly, if not more strictly. In the US, a number of federal requirements drive the EPA and other federal agencies to pursue and demonstrate sustainable stormwater management practices (using green infrastructure). With the CRC-WSC being based in Melbourne, South Australia has somewhat unsurprisingly developed a WSUD policy advising on use of blue and green infrastructure throughout the region.

However despite considerable high-level talk and grand policy declarations, the question remains as to what is actually changing that might encourage our progression along the path from drained cities, to water sensitive ones. In 2009, Brown and Farrelly (2009) produced a paper bemoaning the fact that for all the high-level policy and organizational rhetoric around new approaches to more sustainable water management, there was a 'consistent failure to go beyond ad hoc demonstration projects' (p. 839). They then produced a systematic review of the international literature and an assessment of 53 studies which pointed to twelve types of socio-institutional barriers and inertia points that need to be overcome in order to mainstream WSC thinking. These barriers, selected from an initial list of 36, included an un-coordinated institutional framework; limited community engagement and technocratic path dependency; insufficient resources (both capital and human); unclear, fragmented roles and responsibilities; poor organizational commitment; poor communication, monitoring and evaluation; a lack of political will, and a further lack of any long-term vision or strategy for where incremental changes should lead to. This kind of inertia would continue, they argued, so long as there were no high-level programmes of change targeted at embedded cultures, structures and relationships within and around the industries and legislatures responsible for urban water management.

Whilst this will no doubt be true to some extent and high level programmes of change could effect some significant degrees of change in policy and practice, urban water management requires urgent attention and action in the present day. Incremental shifts in thinking are occurring and innovative solutions and new approaches are being put forward, such as the Baca LiFE project’s take on urban design and planning to reconnect people with the natural water cycle (Baca Architects, 2009). The path to effective change will need to be both top-down and bottom-up, allowing for as many voices as possible to contribute their understandings and perspectives. It is only through the co-development of solutions with people who live and work around them that we can hope to maximise the ‘buy in’ to encourage appropriate behaviour-changes (for example, not littering, cleaning and clearing both green and blue areas) allowing any chance of ’sustainable’ solutions actually being sustainable. It is for this reason that thinking around management of the urban water cycle using green infrastructure needs to have, at its core, consideration of the perspectives of multiple potential stakeholders.

<h1> Stakeholders: Perceptions, motivations and barriers

Engaging all potentially affected stakeholders in negotiations over changes to the way water is managed in the urban environment will need to be absolutely central to the development of plans that can be effective, effectively managed, appropriately treated and so sustainable (Sniffer, 2006; Thorne et al., 2007; Abbott et al., 2013; EPA, 2013). Taking the UK as an example, the stakeholders considered would need to include: local and national government (depending on the scale and location of installations); environmental regulators such as the Environment Agency, Natural Resources Wales, the Scottish Environment Protection Agency (SEPA) and the Northern Ireland Environment and Heritage Service (NIEHS); water companies and water regulators; planning, development and building industries; larger landowners such as industry and farms, if the work were to impact upon their land or alter drainage pathways through their property, and households and businesses who would be at the front end of dealing with any inundation, drought or water quality issues and could be directly impacted by any changes.

Abbott et al. (2013) provide an excellent outline of these stakeholder groups and their perspectives and drivers with a view to helping each group build a case for action. They write of the focus within the UK context upon partnership funding to increase the financial resources available for project work as well as ensuring a greater consideration of the multiple communities that can benefit and the multiple ways in which they can do so. Funding will always be a central issue with any infrastructure development work, and local authorities will be under pressure to demonstrate financial returns on their investments. Bringing different actors together to produce projects that satisfy multiple objectives (water, environment, aesthetics, recreation, biodiversity etc.) would be one way to support partnership funding. Highlighting the multiple beneficiaries of blue-green infrastructure projects could also help to illustrate who might reasonably be asked to contribute towards costs.

Beyond any legislative requirements for pursuing blue-green solutions, water companies operate in the market sector and so may be principally concerned with the financial returns to be made upon investment decisions. A key advantage of blue-green infrastructure to water companies would be the reduction in stormwater entering the sewer system. This may reduce the risk of combined sewer overflows, save running costs by reducing unnecessary treatment of stormwater in treatment plants designed for wastewater, and retain some capacity in existing sewer systems to cope with new residential and commercial developments. In addition, fresh water demand may be reduced (for good or bad; metered users would be using and so paying for less, whilst non-metered users would pay the same but be using less). The wider social, economic and environmental benefits may not fall within the companies' purview beyond advice from governing bodies such as the Water Services Regulation Authority (Ofwat) in the UK. For this reason, to build the business case, cogent economic analyses of the cost and benefit implications of blue-green investments need to be produced and disseminated (see Chapter 4) along with strong advisory pointers from governing agencies and shifts in the way water industries are regulated (allowing for longer-term returns on investment and separation out of potable and non-potable water charges; Abbott et al., 2013).

The built environment sector may also be affected by greater uptake of blue-green infrastructure, with new demands, responsibilities and restrictions placed upon their work. For example, in England, legislation is still pending from the Flood and Water Management Act 2010. Developers will be centrally concerned with returns on investments, but more widely or future oriented actors aware of their corporate social responsibility may realise the potential of blue-green infrastructure to improve reputation as well as liveability and sense of place, which in turn may encourage more people to move into an area, resulting in direct economic benefits. Developers have been argued to have more autonomy than others in the sector and to have a more intrinsically risk-taking nature (Abbott et al., 2013), and so could be considered more likely to try out innovative approaches to urban water management if they were perceived to potentially increase property values. To encourage the pursuit of such opportunities, a more extensive and varied range of well-regarded case studies of successful WSUD implementations could help to build a stronger business case (Abbott et al., 2013).

The role of individuals and communities must also be considered central to the development of WSUD, in an era where individuals are encouraged to assume more responsibility and agency for themselves (reducing the direct responsibility of the state). The potential for citizens to make valuable contributions to the production of knowledge and policy is today widely recognized (Stilgoe, 2009). Households, communities and small businesses may be much less concerned with 'profit', narrowly understood, in considering urban adaptations for water. Avoidance of direct and indirect losses and disruption would of course be a central concern, but beyond this, concerns for sense of place, aesthetics, recreation and leisure opportunities, health and wellbeing, education and a longer-term perspective upon the development of place and community could be strong. Both communities and the governmental bodies that would interact with them may benefit from some capacity-building work to help develop voice and procedures for effective interaction.

It is important to also remember that the sum aggregate of individual household and small business blue-green infrastructure endeavours could make a very significant contribution to reducing flooding and storing water for times of drought. Not all infrastructure assets would need to be 'green'; for example, permeable paving could produce a comparable offset on urban runoff (Wright et al., 2011) and widespread implementation of waterbutts could also retain stormwater, thus helping manage local flood risk and providing storage capacity for later irrigation use in periods of drought. The potential benefits span the environmental, economic and socio-cultural spheres; from reducing flood risk (and associated costs of flood damage) and cooling high urban temperatures, to providing natural areas for wildlife, recreation and local amenity.

<h1> Blue-green infrastructure: Examples of water management systems

This section will look at specific examples of the use of blue-green infrastructure in helping to manage urban water. Due to the specific research interests of the authors, it will focus upon the use of blue-green infrastructure and SuDS in dealing with excess water or flooding. In addition to a number of more hard, structural adaptations such as permeable paving, drainpipe disconnection and waterbutts (rainwater harvesting), SuDS encompass an extensive range of blue-green infrastructure possibilities such as green roofs, infiltration trenches and basins, swales and retention ponds.

<h2> Green roofs

The UK's Commission for Architecture and the Built Environment (CABE 2011, see also Mentens, et al., 2006) found that whilst increasing green space and tree cover in urban areas by 10 per cent might reduce surface water run-off by around five per cent, adding green roofs to all buildings could reduce run-off by up to 20 per cent. If we accept these figures then we should admit that the potential for green roofs is enormous. However the implementability of green roofs will very much depend upon building structures. A number of factors need to be taken into account when considering a building's suitability for green roofing. In some UK cities many historic buildings will have Listed Building status restricting options for adaptation. Beyond this, varying degrees of inclined roofing, the types of materials used in construction, the direction a building faces and overshadowing will all affect their suitability for adaptation (Wilkinson and Reed, 2009).

<h2> Tree-pits

Trees and tree-pits can reduce stormwater runoff in a number of ways. Trees will capture and store rainwater in their canopies; their roots and leaf litter will produce softened and moistened soil conditions that allow for more infiltration of water into the soil, and their root systems will aid water absorption in addition to removing some pollutants from the soil (EPA, 2013). Tree-pits with designed run-ins from surrounding impervious surfaces can provide mini-reservoirs where water can be temporarily stored before being treated by the trees and surrounding vegetation.

<h2> Rain gardens and bioswales

Rain gardens are similar planted depressions with inlets to allow rainwater to enter and be absorbed by the soil and used by plants. As with tree-pits, these plants will absorb some pollutants before the water passes into the groundwater system. In the United States, larger versions of these are frequently referred to as bioswales (EPA, 2013).

<h2> Swales

Swales are broad and shallow grassy channels designed to store and/or slowly convey water, often vegetated to slow down the rate at which the water infiltrates into the subsurface. The sloping and vegetated sides of the swale can make for interesting landscaping usable for recreation purposes during dry periods (Hoyer et al., 2011).

<h2> Retention ponds

Retention ponds and detention basins can be used to provide recreational space, aesthetic aspects and further control and filter stormwater runoff (Jefferies, 2004). Retention ponds are open areas with a regular quantity of shallow water, designed so that they can accommodate excess water from rainfall.

<h2> Detention basins

Detention basins are also open and contain shallow green areas that can store excess water for shorter periods of time. During dry periods, these would function as spaces for recreation and leisure; playing fields and parks for example can very usefully serve this kind of purpose.

Individual, isolated attempts at managing urban waterflows are typically limited in what they can achieve in terms of mitigating stormwater flood risk, filtering waters before they return to the watercourse and providing for times of drought. Because of this, a preferred approach is to develop 'SuDS treatment trains' (Charlesworth et al., 2003; Bastien et al., 2010), whereby the water is gathered, channelled, stored and filtered by a number of different but connected installations, before it leaves the system at a desired rate. Box 3.1 provides an example of this in Stroud, UK. This is argued to produce a more flexible system that can be managed to more efficiently meet the objectives of different stakeholders (Bastien et al., 2010).

<Box 3.1 Examples of a SuDS treatment train: Springhill, Stroud

<h2> Conclusion

The 'greening' of urban surface water drainage infrastructure provides a creative aesthetic opportunity to enhance local planning objectives in addition to offering reduced maintenance requirements for flood and pollution management. An artistic approach to urban landscaping could deliver drainage in a more 'natural' manner consonant with social well-being and local environmental stewardship. Such drainage green infrastructure can promote a sense of place and local distinctiveness, with dynamic and visually stimulating built surroundings encouraging community pride and ownership. (Ellis 2013, p. 10)

This chapter has outlined the case for thinking beyond green infrastructure in and of itself, to consider the use and value of green infrastructure in managing water within the urban environment, and the multiple benefits that could be reaped from adopting more natural, sustainable practices that are embedded in the blue-green infrastructure concept.

We have presented the multiple problems that can be faced by water (too much, too little and too poor a quality), and given a brief overview of how research is now seeking to explore, account for and demonstrate the multiple values of adopting a water sensitive design approach. We have observed how policy-level practices have begun to move in this direction, but argued that much more needs to be done to encourage and enable widespread implementation. We have considered the multiple parties that would need to be brought into discussions of solutions if they were to have any chance of being effective and sustainable.

We then illustrated a few of the many different options that could be considered for implementing blue-green infrastructure, considering the value of these installations in dry periods as well as wet. Finally, we presented an example of a working blue-green infrastructure SuDS treatment train that is both effective and cost-effective within an urban environment.

Urban water management is but one consideration in planning and designing green infrastructure in urban environments. Yet given the increasing frequency and intensity of precipitation observed over the past few decades, as well as the forecasts of possible future climate change which could further worsen the situation, it is a consideration which deserves to be taken very seriously if we wish to ensure that our conurbations are healthy and safe spaces we can enjoy living in.

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