A Review of Current Knowledge

Surface Water Management and Urban Green Infrastructure

A review of potential benefits and UK and international practices

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Editor: T.D. Evans

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This review is one of a series of Reviews Of Current Knowledge (ROCKs) produced by FWR. They focus on topics related to water supply, wastewater disposal and water environments, which may be the subject of debate and inquiry. The objective of each review is to produce concise, independent scientific and technical information on the subject to facilitate a wider understanding of the issues involved and to promote informed opinion about them.

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"Traditional Norwegian green roof more than 300 years old"

The buildings date from the second half of the 17th century. The roof a waterproof layer of birch bark covered with turf, which protects the waterproof membrane, insulates the building and also modulates run-off; just like a modern green roof.

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Abbreviations

BAP	Biodiversity Action Plan
BCA	Benefit Cost Assessment
BMP	Best Management Practice
BRE	Building Research Establishment
BREEAM	Building Research Establishment Assessment Method
CABE	Commission for Architecture and the Built Environment
CIRIA	Construction Industry Research and Information Association
CIWEM	Chartered Institution of Water and Environmental Management
CNT	Center for Neighborhood Technology (USA)
CSO	Combined Sewer Overflow
CWSC	Centre for Water Sensitive Cities (Australia)
DCLG	Department for Communities and Local Government
DTLR	Department for Transport, Local government and the Regions (now defunct)
DTI	Department for Trade and Industry (now defunct)
EA	Environment Agency
FWMA	Flood and Water Management Act 2010
FWR	Foundation for Water Research
GI	Green Infrastructure
GSI	Green Stormwater Infrastructure
KTN	Knowledge Transfer Network
LDF	Local Development Framework
LEED	Leadership in Energy & Environmental Design
LID	Low Impact Development
LIUDD	Low Impact Urban Design and Development
LLFA	Lead Local Flood Authority
MEF	Maximum Extent Feasible
Ofwat	The Water Services [financial] Regulation Authority for England and Wales
ONS	Office for National Statistics
PHS	Priority Hazardous Substances
PMSEIC	Prime Minister's Science and Engineering Innovation Council (Australia)
PPG	Planning Policy Guidance
PPS	Planning Policy Statement
RBMP	River Basin Management Plan
RCEP	Royal Commission on Environmental Pollution
ROCK	Review of Current Knowledge
RTPI	Royal Town Planning Institute
SAB	SuDS Approval Body
SEA	Street Edge Alternatives
SuDS	Sustainable Drainage Systems
SWMP	Surface Water Management Plan
TCPA	Town and Country Planning Association

UKCP	United Kingdom Climate Projections
UKWIR	United Kingdom Water Industry Research (Ltd)
USEPA	United States Environmental Protection Agency
WERF	Water Environment Research Foundation
WFD	Water Framework Directive
WSUD	Water Sensitive Urban Design

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Glossary and Definitions

Best Management Practice (BMP): Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the discharge of pollutants to waters of the United States. BMPs also include treatment requirements, operating procedures, and practice to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage. (USEPA, 2003).

Bioretention area: Vegetated areas that collect and temporarily store runoff with the express purpose of treating it through engineering soils and vegetation.

Combined Sewer Overflow (CSO): Flow from a combined sewer system in excess of wastewater treatment or interceptor carrying capacity released to a receiving water body (IWA, 2004).

Detention basins: may have permanent but very shallow water, or more usually dry until it rains. Usually retain some solids.

Green Infrastructure (GI) defined in the USA as: "*a network of decentralized stormwater management practices, such as green roofs, trees, rain gardens and permeable pavement, that can capture and infiltrate rain where it falls, thus reducing stormwater runoff and improving the health of surrounding waterways*" (Center for Neighborhood Technology, 2010). Note there are a number of alternative definitions (e.g. Benedict & MacMahon, 2006).

GSI Green Stormwater Infrastructure: is a term used by Seattle Public Utilities to denote the use of the green infrastructure elements of BMPs for stormwater management (Open Space Seattle, 2010).

Green roof: Covering all or part of a roof with vegetation over layers of drainage and protection/waterproofing/insulation.

Grey Infrastructure: constructed assets that occupy land, such as motorways, factories, or sewers (NENW, 2009).

Heat Island Effect: A metropolitan area which is significantly warmer than its surrounding rural areas, mainly due to urban development which generates and retains heat.

Infiltration basin: Depressions in the ground to retain runoff and also allow infiltration. Can be landscaped to provide amenity value.

Low Impact Development (LID): An approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible. LID employs principles such as preserving and recreating natural landscape features, minimizing effective imperviousness to create functional and appealing site drainage that treat stormwater as a resource rather than a waste product. (http://www.epa.gov/owow/NPS/lid/)

Pervious/permeable surfaces: allow rainwater to infiltrate and be stored for re-use, infiltration or release to surface water.

Raingarden: A planted depression that allows rainwater runoff to be temporarily stored and or infiltrate from impervious urban areas like roads, roofs, driveways, paths and car parks.

Resilience: The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks. Note that there are a number of definitions of the term, this is the one used here.

Retention pond: permanently retaining water held in a depression for the purpose.

Street Edge Alternatives: designed to provide drainage that more closely mimics the natural landscape prior to development than traditional piped systems. (on-line tour: http://www2.cityofseattle.net/util/tours/seastreet/slide1.htm)

Sustainability/Sustainable Development: Has many definitions, the one most often quoted is "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland Commission of the United Nations, 20th March, 1987).

Sustainable Drainage Systems (SuDS): This acronym has had different meanings since emerging in the UK in the 1990s; this is the current term and is defined as: approaches to stormwater management that minimise the impacts from the development on the quantity and quality of runoff and maximise the amenity and biodiversity opportunities (CIRIA, 2007).

Swale: broad, shallow channel covered with grass or other suitable vegetation. Designed to convey and/or store runoff, can also infiltrate water.

Triple Bottom Line: expands the traditional reporting framework to take into account ecological and social performance in addition to financial performance.

Water Framework Directive: European Community Directive (2000/60/EC) of the European Parliament and Council designed to integrate the way water bodies are managed across Europe. It requires all inland and coastal waters to reach "good status" by 2015 through a catchment-based system of River Basin Management Plans, incorporating a programme of measures to improve the status of all natural water bodies.

Review of Current Knowledge

1 Introduction

The UK and many other countries are facing unprecedented challenges from financial stress, climate and demographic change, lifestyle expectations and a growing realisation that the practices of the past will no longer be fit to tackle these challenges and the future needs of society. The separate management of our urban water systems, traditionally considered apart from other urban systems by specialists will no longer be affordable or sensible in the future world. Increasingly, there is a need to find ways to elicit multiple benefits from the way in which we provide such services and associated infrastructure. Joining urban water management practices to other urban planning and design practices to achieve multiple benefits can be readily achieved provided those involved are willing to change their current approach and to cooperate (e.g. MWH, 2011). For example, current initiatives in urban planning to promote the use of green infrastructure (GI) can be linked with stormwater system management to provide synergistic opportunities that can benefit society and keep costs down (e.g. Green Infrastructure North West, 2011).

Green Infrastructure (GI) has been defined in the USA as: "a network of decentralized stormwater management practices, such as green roofs, trees, rain gardens and permeable pavement, that can capture and infiltrate rain where it falls, thus reducing stormwater runoff and improving the health of surrounding waterways" (Center for Neighborhood Technology, 2010) and is now "more often related to environmental or sustainability goals that cities are trying to achieve through a mix of natural approaches" (Foster et al., 2011). Thus GI challenges popular conceptions about green-space planning and protection as GI emphasises the importance of open and green space that are protected and managed for the ecological benefits they provide. The value of GI in relation to urban stormwater management has become apparent and many US and other practitioners have begun to promote the co-management of stormwater and GI (e.g. USEPA, 2010; CIWEM, 2010; Center for Neighborhood Technology, 2010; Green Infrastructure North West, 2011) and examples are given in Section 5 which provide conclusive evidence that using GI for stormwater management is considerably more cost effective than traditional approaches.

Using GI to reduce the rate at which rainwater falling on urban areas reaches and runs off surfaces ('Rainwater GI') is a multi-value option for adapting to the predicted effects of climate change that is in widespread use in many parts of the world (e.g. Rutherford, 2007; Sylwester, 2009) and interest is growing in GI in the UK although not necessarily from a stormwater management perspective (e.g. CABE, 2010a). The use of GI helps take pressure off underground drainage networks and reduces the risk of sewer and stormwater flooding. It reduces climate change emissions of wastewater management because with less water entering the underground network, less energy is used in pumping and treating. Evapotranspiration leads to evaporative cooling by the elements of GI which then counteract the heat island effect of cities, which improves the quality of life, reduces stress and reduces the need for air-conditioning (Georgi & Dimitriou, 2010). It also has many other benefits to human living not least bringing biodiversity into urban areas, absorbing CO_2, providing oxygen, and aesthetic benefits. There is a view that in the UK we have been '*building unhealthy conditions into many of our towns and cities*' (Barton, 2009) and have often neglected the fact that health and urban land use are *'inextricably linked'* (RCEP, 2007). There is a need to re-affirm and act upon the link between public health and land use planning (RTPI, 2009). Water is but one component of this link and needs to be seen within the context of urban masterplanning that includes the use of GI (English Partnerships & Housing Corporation, undated).

In the USA, GI is seen as intrinsically linked with the better management of stormwater. Nonetheless using GI for the better management of surface water is often problematic for engineers as it requires a more subtle and sophisticated approach than traditional 'hard' engineering (Wolff & Gleick, 2002). It means bringing together a broader spread of disciplines, co-operation, and co-funding across different organisations and boundaries.

This ROCK presents the elements of GI, its benefits, its limitations and the principles of implementing GI in relation to stormwater management. The synergies with surface water management in urban areas are illustrated with case study examples.

Section 2 considers the use of GI for the co-management of stormwater runoff and how and why it is useful in multi-value terms for improving urban areas. Examples are given of applications of GI and stormwater management including 'Sustainable Drainage Systems' (SuDS) in the UK and elsewhere. In Section 3 the way in which UK cities have developed and reasons for contemporary layout and form are briefly explored along with the challenges now faced in terms of the management of complex infrastructure systems and the place of GI and stormwater management. Section 4 outlines aspects of policy in relation to stormwater and GI and how delivery may be facilitated. Section 5 considers future opportunities and challenges in taking advantage of the multiple benefits of GI. Section 6 concludes that GI, and its flexibility when linked with stormwater management, provides a means to cope better with future change and uncertainty and that GI is therefore an essential element when considering how best to manage urban areas in the future.

2 Green Infrastructure

2.1 Introduction

Recent US studies have highlighted the importance of integrating urban planning with water catchment planning (USEPA, 2010). The City of Seattle has used citizens with professional design teams to develop GI and other urban plans for the future city in 2025 and 2050 (e.g. Open Space Seattle, 2010). As part of the master-planning for the housing development in Upton, Northampton, 'Enquiry by Design' exercises, provided for the participation of a much wider group of people and organisations in planning for the future of the area which included SuDS and GI. In Seattle, 'GSI' 'Green Stormwater Infrastructure' is the term used in design codes which specify the use of GSI to the 'maximum extent feasible' (MEF) – which means GI is to be fully implemented, constrained by the opportunities and physical limitations of the site, practical considerations of engineering design, and reasonable considerations of financial costs and environmental impacts (Seattle Public Utilities, 2009; Tackett, 2010). In Seattle the majority of 'Low Impact Development' (LID) or GSI BMPs are designed to more closely mimic pre-development hydrology, and address the reoccurring smaller storm events. As much of Seattle is not fit for infiltration, a performance target has been set that gives credit for developers in terms of the GSI performance standard expected as a percentage of the MEF, by estimating the benefits of the BMP based on the 3 primary needs of the receiving water systems: average annual volume reduction, peak flow reduction, and water quality treatment. The resulting 'credit' for impervious area (new or retrofit) directed to a properly designed GSI BMP is given in Table 1.

Table 1 Green Stormwater Infrastructure Categories and Credits for developments or stormwater disconnections in Seattle (Tackett, 2010)

GSI Evaluation Category, in order of preference		**GSI BMP measure**	**% of GSI performance standard attained by this measure**
Category	**Type**		
1	Runoff reduction methods	Retain Existing Trees	10-20%
		Dispersion (downspout or sheet flow)	86%
		Plant New Trees	1.9-4.6 m^2 impervious area is credited per tree planted
2	Infiltrating and reuse facilities	Bioretention Cells (without underdrain)	100%
		Rainwater Harvesting	100%
		Permeable Pavement Facilities (with storage reservoir and overflow)	100%
3	Impervious surface reduction methods	Green Roofs	59-70%
		Permeable Pavement Surfaces	60-100%
		Bioretention Cells (with detention)	85%
4	Non infiltrating facilities	Bioretention Planter	60-73%
		Detention Cisterns (tanks), above ground with harvesting capacity	30%-90%

Using the LID toolkit (SFPUC, 2010) Seattle's Viewlands Cascade project used vegetated cells to reduce storm runoff by 75-80% and peak flows by 60%, together with curved swales and vegetative planting to reduce overall runoff from the development to only 1% at an overall cost of \$3-\$5 per ft^2.

As well as planning GI on a catchment scale, as is being done in Seattle, opportunities exist at local level as illustrated in Figure 1, where local measures have been retrofitted in Michigan to ensure that stormwater runoff receives treatment through the GI systems shown.

Figure 1 Two examples of retrofit GI specifically to manage stormwater and which add aesthetic value – Raingardens and Bioretention area in Lansing, Michigan, USA (photo courtesy of Scott Struck, Tetratech)

In Philadelphia, the 'Triple Bottom Line' study (Philadelphia Water Department, 2009) has assessed the options for CSO control over the next 40 years and determined that the city-wide total present value benefits of using GI ranged from \$1.9bn - \$4.5bn depending upon the extent used in removing stormwater from the combined sewerage system; from 25% to 100% respectively. The make up of the relative multi-value benefits of GI in addition to CSO control and flood prevention are shown in Table 2.

Table 2 Present value breakdown of city wide net multi-functional benefits (additional to CSO control and flood prevention) from retrofitting GI in Philadelphia to control CSO spills for a 40 year period

Benefit of retrofit GI	% of present value
Reduction in heat stress mortality	37
Improved aesthetics/property value	20
Increased recreational opportunities	18
Water quality/aquatic habitat enhancement	12
Air quality improvements from trees	5
Social costs avoided by green collar jobs	4
Reduced damage from SO_2 and NO_x emissions	2
Energy savings	1
Reduced damage from CO_2 emissions	<1
Wetland services	<1

Table 3 shows some examples of the main benefits to surface water management and urban living from GI, based on typical SuDS as used in the USA as part of an LID approach. In the USA, regional SuDS, such as detention and retention ponds are considered only useful for larger scale application at catchment scale but are not included in the Table.

Table 3 Potential benefits from using GI (Wise et al., 2010)

	Measures and benefits from GI
Urban trees	Stormwater detention Reduced energy for heating or cooling in urban areas Reduced health impacts from extreme heat events Air quality improvements in urban area CO_2 reductions (both avoided and sequestered)
Permeable pavements (Seen as part of GI in the USA)	Increased stormwater retention Reduced energy use, air pollution and greenhouse gas emissions Reduced ground conductivity (urban heat island and use of salting in winter) Reduced air pollution Reduced noise pollution
Water harvesting	Reduced potable water use Increasing available water supply Improved biodiversity Public education
Green roofs	Storm water retention Reduced building energy use Carbon sequestration Greenhouse gas emission reduction Urban heat island mitigation Improved air quality Noise reduction Biodiversity and habitat Longer roof life
Other infiltration practices including rain gardens, bioswales, constructed wetlands	Stormwater retention and pollutant removal and many of the other benefits above
Other benefits from GI	Increased property values Recreation space value Avoided conventional infrastructure costs Reduced wastewater treatment costs Reduced flood risk damage Increased groundwater recharge Societal benefits such as crime reduction

The potential value of GI has been highlighted extensively in the plans for London (Mayor of London, 2009) as:

- protection and enhancement of biodiversity, including mitigation of new development
- making a positive contribution to climate change by adapting to and mitigating its impact
- improving water resources, flood mitigation and reduced flood risk through sustainable urban drainage systems

- increasing recreational opportunities, access to and enjoyment of open space to promote healthy living
- creating a sense of place and opportunities for greater appreciation of the landscape and cultural heritage
- promoting walking and cycling
- a place for local food production, in line with the Mayor's 'Capital Growth' strategy
- an outdoor classroom.

GI is now a ubiquitous term in urban planning and in design guides in the UK including (TCPA, 2004; Greater Norwich Development Partnership, 2007; Davies et al, 2008; Mayor of London, 2009; CABE, 2010a; Cambridgeshire Horizons, 2010; Community Forests North West et al, 2010; Climate East Midlands, 2010 and has a variety of meanings and definitions depending upon the cultural position of the particular individual, group or institution using the term. When used by diverse professionals, such as from the health, horticulture, engineering or social sectors, the term GI means something slightly different to each. For this ROCK, the emphasis is on the interaction between surface water (stormwater) systems and GI and the potential synergistic benefits that may accrue to those interested in GI for aesthetic, ecosystem health, societal or other reasons and for those who see GI as a better means of managing surface water in urban areas.

There are even differences in national perspective, with the UK for example, seeing GI as a means of promoting biodiversity in urban areas (e.g. TCPA, 2004), whereas in the USA, GI is strongly aligned with 'Low Impact Development' (LID) and surface water management (USEPA, 2010a; Sylwester, 2009). There is a distinction made in publications and practice between *what GI is* (noun) and *what the value of GI might be and what might be done with it* (verb and adjective).

Informal green 'space', such as that specified in planning permission for a new development is not the same as planned or unplanned interconnected networks (nodes and links) of green or open spaces; that may be termed 'infrastructure' and comprise the more functional GI. The seminal US work on GI (Benedict & McMahon, 2006) promotes GI both as a *concept* and a *process*. As a concept GI provides the means for better city planning by including GI at the core of the planning process, with frameworks conceptualising designs and layouts that include open/green space hubs and corridors as illustrated in Figure 2. Whereas as a process, GI provides the means for the diverse range of uses to which GI can be put to be accessed by a wide variety of stakeholders.

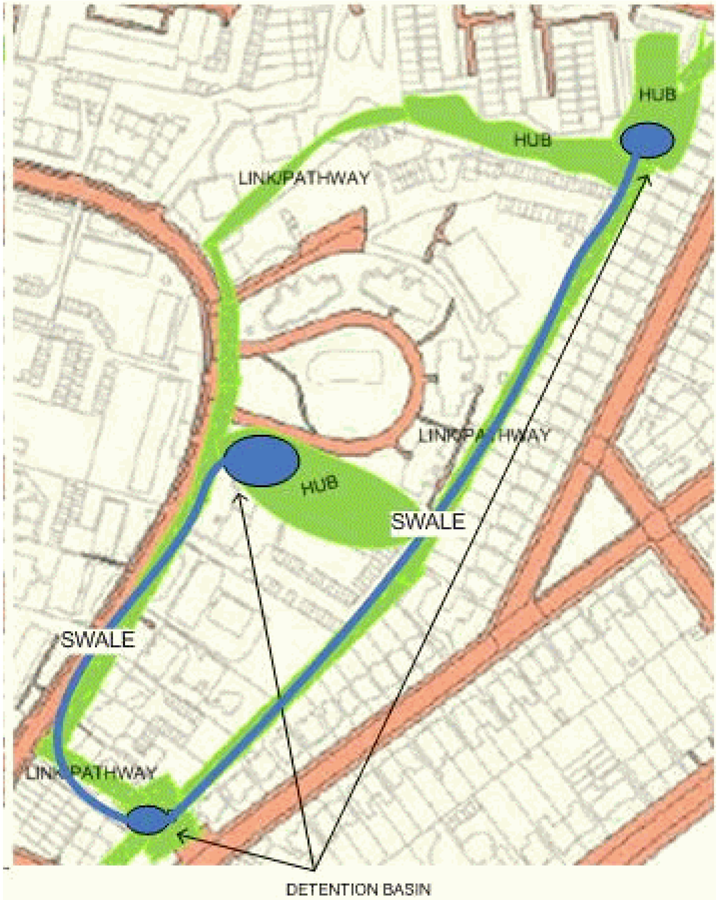


Figure 2 Illustration of interconnected GI hubs and corridors which may also be used as surface flow pathways (blue-green) and SuDS features, with for example, detention basins in the hubs and swales comprising the links (adapted from Thames Water, 2010)

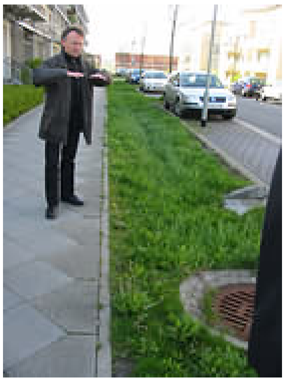
Urban areas typically have a range of traditional GI features which are protected from development. Predominantly smaller scale GI features specifically for water management can be employed from the outset in new development or retrofitted into existing development. Table 4 shows the UK defined SuDS and their relationship to GI (adapted from CIRIA, 2007). Figure 3 illustrates some SuDS as GI.

Table 4 SuDS and GI

Technique	Description	Opportunities for GI
Water butts, drainage layout and property housekeeping	Stormwater management at property level and immediate curtilage. Avoid adding waste chemicals etc.	To direct excess water on to garden areas, store for irrigation and other uses. Can maintain lawns, horticulture and be used for e.g. indoor plant watering Increasing proportion of permeable surfaces
Rainwater harvesting	Direct collection other than the above for toilet flushing or other purposes	May detract from GI if used for purposes other than irrigation
Green roofs	Variety of options – may promote growth of plants (e.g. Castleton et al, 2010)	Roof surface demonstrably green, or with vegetation and suitable substrate depth. Water retention on roof may influence other water uses as above. (Figure 3(d))

Filter drains	Linear drains/trenches filled with permeable material. Remove pollutants.	Infiltrates runoff but may be an opportunity to plant trees or shrubs on the surface.
Filter strips	Vegetated strips of sloping ground taking runoff away from paved areas and filtering solids.	Usually comprises grassed surfaces and as gently sloping can be considered to be useful GI, although solids capture may result in muddy areas.
Swales	Shallow vegetated channels that convey or retain runoff and may infiltrate also filters solids in vegetation.	As above and may include shrubs and bushes (Figure 3(c))
Ponds or retention areas	Usually contain standing water but have bankside and marginal vegetation. Remove pollutants by settlement.	A key GI component with attractive marginal and bankside green areas. Aquatic ecology is the most significant. (Figure 3(c))
Wetlands	As ponds, but with shallow standing water and different types of vegetation. Remove pollutants by a range of mechanisms.	Also a key GI component, but wetlands are less common in urban areas due to the land take requirements although recent designs mean these can be used at much smaller size than in the past. When established they are the most rich SuDS for biodiversity.
Detention basin	A combination of the two above, may have permanent but very shallow water as for wetlands, or may be dry until it rains. Usually retains some solids.	Also a key GI component that may be more readily installed than the above in recreational areas or other grassed areas not normally used during rainfall and supporting biodiversity. (Figure 3(f))
Soakaways	Sub-surface structures that store and infiltrate runoff. Remove pollutants.	Useful in GI terms only for maintaining soil moisture, although it may be possible to plant bushes and shrubs on the surface.
Infiltration trenches	As filter drains but wider and allows infiltration through the trench sides	Infiltrates runoff but may be an opportunity to plant trees or shrubs on the surface.
Infiltration basins	As for detention basins but stored runoff can also infiltrate.	A key GI component that may be more readily installed than some of the above, but not in recreational areas or other grassed areas not normally used during rainfall unless the permeability is high.
Permeable surfaces	As for infiltration systems but with porous paving. Remove pollutants retaining them in upper soil layers.	Some porous paving has openings (concrete lattice) that allow grass to grow creating a green area that is usually visually attractive (Figure 3(a))
Bioretention areas (including rain gardens)	Vegetated areas that collect and temporarily store runoff with the express purpose of treating it.	May be amenable to high quality planting (see Figure 3(e, g)). Typically very good at removing solids, nutrients and metals from runoff.
Sand filters	Treatment devices (usually proprietary) for removing pollutants from runoff	Not normally GI as located below ground.
Silt removal devices	As above, although may be in the inlets to ponds and basins…	Where located with ponds and basins may be amenable to planting, although frequent de-sludging may damage planting
Trench-troughs (also known as WADIs in NL)	A combination of infiltration trenches and underdrained conveyance swales used where infiltration capacity is low	Can be valuable means of adding GI into an area where infiltration capacity is low as surfaces are usually grassed (Figure 3(b))

(a) Grass growing through a lattice permeable pavement in a car park in Cardiff, UK



(b) A trench trough system in a dense housing area in Hanover, Germany

(c) Pond and swales in Kronsberg, Germany

(d) Green roof Rotherham, UK

(e) Street Edge Alternative, Seattle, USA

(f) detention basin in Elvetham Heath, UK

(g) Rain garden in Auckland, New Zealand

(h) Transfer of roof drainage to pervious areas in Seattle, USA

Figure 3 Illustrations of SuDS that are also GI. In each case the primary purpose is for stormwater management.

SuDS may comprise below ground installations, such as permeable car parks with storage beneath; they cannot provide amenity or visual benefits and are therefore not strictly GI, although surface planting may be feasible for some of these. Similarly some conventional drainage systems comprise green components, not specifically designed as SuDS conveyance systems, and are therefore both GI and urban drainage.

It is clear that not all SuDS are GI nor is all GI amenable to formal SuDS. However, all GI does have some value in the management of the water cycle via e.g. slowing down of overland flows and evapotranspiration.

2.2 The need for a change in water management

The relative sustainability of urban drainage and the water environment have been the topic of an earlier Foundation for Water Research review. Tyson (2004) considered the history of drainage systems and the evolution of urban drainage in the UK and emphasised the need to use and manage water and wastewater systems more efficiently in the UK, acknowledging that water is a finite resource, likely to be affected by climate change amongst other factors.

The use of alternative types of water streams for different purposes, coupled with SuDS that mimic natural drainage as far as practicable, was suggested as a promising way to help tackle future pressures on water systems in urban areas. These conclusions have since been reinforced and there is recognition that the effects of climate change on water resources and drainage systems may be even greater in some parts of the UK than had been anticipated (e.g. Evans et al., 2008; KTN, 2009).

Given the uncertainties inherent in understanding how climate may affect rainfall, temperature, wind, sea level and other water related phenomena in the future (UKCP, 2009), approaches that are more adaptable, flexible and resilient are required to ensure continued water and sanitation services (Milly et al., 2008; Defra, 2010). In the review of charging for water services in England and Wales, Walker (2009) states that "*SuDS offer an alternative to increasing the capacity of the sewerage system; it therefore reduces the need to make investment in the future and helps achieve lower future bills. This would also accord with the fairness principles of complying with the 'polluter pays' principle, reflecting in charges the costs that particular customers impose on the system*." This advocates the management of surface water at or nearer to source, rather than downstream at a treatment works (end of pipe), as currently occurs in most of the UK. GI and SuDS are now demonstrably understood to be more flexible for future adaptation than traditional piped drainage systems (Peters et al., 2011; CIRIA, 2011).

In the USA BMPs are seen to be a key component of LID approaches for new developments (e.g. France, 2002; Ashley et al., 2007). Elsewhere the approach is known variously as: Water Sensitive Urban Design (WSUD) in Australasia (Engineers Australia, 2006); and as Low Impact Urban Design and Development (LIUDD) in New Zealand (Roon & Roon, 2005). Each of these includes a strong emphasis on the use of GI for stormwater management and as part of urban master planning.

Stormwater runoff in urban areas has been recognised as one of the largest untapped potential sources of potable water; in Melbourne it is comparable with the annual volume of piped supplies provided (PMSEIC, 2007). This has triggered a major research programme in Melbourne investigating how best to utilise this resource via WSUD (CWCS, 2011).

In continental Europe a number of on-going studies are developing guidance and decision support tools for the application of WSUD ideas – e.g. the DayWater project (Thevenot, 2008) and the SWITCH project (Last & MacKay, 2010; Hoyer et al., 2011). Although the latter guidance is too focused on stormwater and largely ignores GI, the report provides some useful illustrations. In a parallel SWITCH study the inherent flexibility and adaptability of SuDS is shown to be superior in relation to the relative inflexibility of traditional drainage systems to cope with future climate change (Sieker et al., 2008; Peters et al., 2011).

It is important also to consider how existing GI assets can be actively utilised in water management either for existing or new development. The success of introducing additional roles for GI will depend on circumstances. Currently very few traditional GI assets in UK cities perform distinct water roles – even ponds may only serve a biodiversity and amenity role and have no planned runoff flow attenuation or water quality benefits.

The use of existing GI for stormwater management will require careful planning, e.g. in defining discharge routes for a site in order to reach the ideal situation with links and hubs as illustrated in Figure 2. Where GI manages surface water from two or more properties, under proposals in the Flood and Water Management Act (FWMA, 2010) in England and Wales a SuDS Approval Body (SAB) will then become responsible. GI may also require regular irrigation and maintenance to prevent negative impacts from the urban runoff it receives.

Infiltration and storage of onsite rainfall and surface water is variable depending on soil, geological and topographical circumstances and the quality of the land - which may be contaminated (Defra, 2009; Lerner & Harris, 2009). To ensure that GI receives adequate water, appropriate horticultural processes should be promoted through good practice in land management, for example reducing soil compaction, encouraging retention of water in low lying, flat or concave topographies and even providing opportunities for food production (e.g. Liebman et al., 2010; Garin et al, 2010). This will also reduce flows to onsite drains and subsequently sewers, culverts or watercourses and will control seepage or overland flows to surrounding areas. GI in this context can help to provide treatment for contaminant removal, for example the removal of nutrients from runoff from plant nurseries or ensuring there is healthy aquatic vegetation in ponds, wetlands and watercourses.

Where rainwater GI is retrofitted, it is necessary to determine where water is most usefully utilised or to where it is best directed. For example, street trees may require rooting space and sympathetically designed hard infrastructure to provide effective water and pollutant management (Volder et al., 2009). Trees are a major component in managing stormwater as they can intercept more than 35% of rainfall and reduce runoff by some 17% (Foster et al., 2011). Typically the soil around street trees in the UK has no or limited hydraulic connection with the hard surfaces around them and as such they provide significant opportunities for retrofitting rainwater GI as is happening in New York.

2.2.1 The practicalities of using GI

There are a number of aspects when using GI to manage stormwater that are more complex than when using traditional piped drainage systems. As many SuDS use and are part of GI, these aspects are dealt with in a number of SuDS guidance documents (e.g. CIRIA, 2007 for UK applications), but greater experience in the USA and Australia has also provided reliable and tested guidance for these countries that is of widespread value (e.g. USEPA, 2010; Melbourne Water, 2005; FAWB, 2009). The main difficulties in designing GI for stormwater, which are shared with most SuDS applications relate to:

- Hydraulic performance
- Water quality improvement performance
- Assessing aesthetic and other value
- Finding space to retrofit GI, including coping with the problem of services in urban areas
- The practicalities of adapting existing GI to a new role in managing stormwater
- The practicalities of balancing a catchment wide and site-specific approach to stormwater management using GI
- Managing the interaction between different functions (e.g. use of play area as occasional sacrificial storage)

The precise quantification of the hydrological performance of GI when managing rainwater-runoff is more problematic than for engineered SuDS systems, making the specification and control of flow rates and volumes something of an art for certain types of GI which is further complicated if a catchment–wide approach is taken. This is uncomfortable to many engineers and is one of the reasons for the slow uptake of rainwater GI in the UK. Coupled with the even greater uncertainty with regard to the improvements in water quality that rainwater GI can provide, there is significant reluctance to use ‘soft’ solutions rather than hard non-GI measures. Some progress has been made in Scotland where GI based SuDS are being used and strongly promoted despite this uncertainty, although in the Scottish ‘SUDS for Roads’ manual (SUDS working party SCOTS, SEPA et al., 2010), GI is not specifically mentioned; simply ‘green corridors’.

Increasingly, sewerage undertakers in the UK require peak flow restrictions on surface water entering combined sewers, particularly from road runoff. The FWMA removed the automatic right in England and Wales for a developer to connect site drainage to a sewer, irrespective of whether it is designed to convey stormwater or not and instead made the use of SuDS the first option. Sewer flooding and the audited requirement to prevent both property flooding and surrounding curtilage problems in the UK will also help promote a more vigorous interest in the use of GI as part of stormwater runoff management (e.g. Anglian Water, 2011). However, such moves away from below ground drainage systems require a better and more integrated management of overland flow routes for when flows exceed the above ground system capacity. 'SuDS for exceedance', as part of GI may be a useful concept for this within a catchment-wide perspective (Tourbier, 2002; CIRIA, 2006; Tourbier & White, 2007) although there is growing interest in using roads for safe exceedance flow pathways (Thorne et al., 2007, Carr & Walesh, 2008).

Stormwater removal from combined sewers is explored in studies for the Thames Tideway Sewer Tunnel in London (Thames Water, 2010; 2010a) where opportunities for sewer separation and GI based SuDS are considered for CSO control. It was concluded in these studies that the practicalities of retrofitting SuDS in the dense urban area of London are too great and too costly for this to be a practicable option and that this would take too long and be in contravention of the Urban Wastewater Treatment Directive. These studies, however, do not consider the wider multi-value benefits of GI based SuDS (Section 2.2.2). Since the recommended solution (a 7.2 m diameter tunnel) only intercepts the Combined Sewer Overflows (CSOs), it will not prevent flooding, unlike GI, which could have removed, and potentially utilised, rainwater at source. The preferred option is end-of-pipe rather than source control, unlike what is being done in many other countries worldwide, where multi-value benefits are included in evaluations (Thames Water, 2010b; MWH, 2011). It also misses the opportunity to collect rainwater as a resource, provides little benefit to flood risk abatement and therefore separate projects include a new desalination plant for London and several flood risk management schemes in addition to the sewer tunnel.

The use of GSI in the USA is seen as the major element in improving the quality of runoff during wet weather events and is heavily promoted by the USEPA for compliance with the 'Clean Water Act' of 1972 (e.g. Field et al., 2006; Foster et al., 2011). The equivalent legal instrument in the EU is the Water Framework Directive (Directive 2000/60/EC), delivered through River Basin Management Plans (RBMPs) in the UK, and for which daughter Directives on priority hazardous substances and groundwater respectively, seek to minimise the pollution caused by a wide range of substances originating from diffuse as well as point sources. These are therefore concerned with the better management of surface water runoff quality. This will promote activity which may well include the greater use of GI as part of redevelopment or retrofit (UKWIR, 2009; CIRIA, 2011). In the USA, diverting rainwater to grey infrastructure (and thence to CSOs) has been found to reduce groundwater levels. This is potentially very detrimental in Boston where it is imperative to keep water levels high to avoid drying out of the timber piled buildings (Shanahan & Jacobs, 2007). The alternative, using GSI, would maintain these levels.
Consideration of rainwater GI for the optional control of sewer system performance through separating surface water from wastewater in the UKWIR (2009) study shows that all SuDS measures are potentially useful for urban runoff water quality improvement. This also illustrated that there are other environmental and amenity benefits from separation of storm and wastewater inputs.

In the UK there are few performance data about the improvements in water quality that may accrue from the use of rainwater GI. There are, however, more extensive databases in the USA and Australia (e.g. Geosyntec consultants, 2008). Despite decades of water quality measurements from SuDS, BMPs and WSUD systems (Wong, 2006), pollutant removal efficiencies from GSI can still only be expressed in ranges. Rainwater GI performance with respect to water quality varies seasonally in temperate climes due to leaf fall, the loss of annual plants and changes in shading cover (DTI, 2006).

Nonetheless for some GSIs it is becoming possible to predict their pollutant removal effectiveness accurately enough to design for specified performance. For example, for bioretention areas, such as that shown in Figure 3(e) and 3(h), specific percentages of nutrient removal can now be predicted (Hatt et al., 2009), and when used in combination with media filters, also for bacteria removal. In Australia and in parts of the USA, there is sufficient confidence in the ability to predict the water quality performance of GI related SuDS to specify mandatory pollutant removal efficiencies from surface water runoff for suspended solids and nutrients (e.g. Wong et al., 2009).

Pollutant removal processes have been considered for each of 15 SuDS options in an EU funded project, ScorePP, looking at the control of priority hazardous substances (PHS) in surface water runoff such as arsenic, cyanides and herbicides, (Scholes et al., 2008). It was shown that comparatively, rainwater GI was consistently the best performing in terms of PHS removal.

A management train approach is recommended for SuDS used in surface water runoff quality control, with different levels and stages of treatment applied dependent upon the source and application. The sequence of stages recommended is: prevention; source; site; and regional controls (CIRIA 2007; 2010). GI has a place in each of these stages as illustrated in Table 5.

Table 5 The place of GI in the SUDS management train for water quality control

Stage of control	Examples of GI related measures
Prevention	Good housekeeping on the site and using only licensed pesticides, herbicides and fertilisers on plants and in gardens. Increasing the permeable area.
Source	Green roofs on buildings, directing roof runoff on to lawn areas Figure 3(d) and (h)
Site	Grassed swales, detention/infiltration basins Figure 3(b) (e) and (g)
Regional	Wetlands, retention ponds Figure 3(c) and (g)

The employment of water specific GI features will be dependent on:

- Local site, ground conditions and contexts
- The nature of any development
- Responsibilities for maintenance
- The interconnectedness and physical GI network (Figure 2)
- Character and aspirations of the area including professional and planning norms

Virtually all natural surfaces have some infiltration capacity, albeit this may be very limited during certain periods of the year (CIRIA, 2007). Impermeable soils are not a barrier to the use of GI as water can be managed on or near the surface before release offsite and GI can also lose water via evapotranspiration through vegetation. Even with soils suitable for infiltration, topography and deeper geology could lead to the release of water downslope where an aquifer comes to the surface (Bartens, 2009); i.e. an infiltrating grassed area may pass flood risk downstream. This illustrates the complexity of subsurface water movement and the need for site by site assessment to include a wider catchment perspective (Lerner & Harris, 2009) ensuring that appropriate consideration is given to soil science not only drift geology (Defra, 2009). The topography of the site will also determine choice of GI features and their placement, for example the creation of level areas for storage either above or below ground. Other aspects to be considered are whether or not the ground is contaminated and risk assessments need to be made of pollutants from surface waters if ground water protection zones are in the vicinity (*ibid*).

Building density is an important consideration in choice of GI but every surface from which rainfall can run off should be considered for retrofitting as there are always opportunities for removing water from piped drainage systems. It is notable that for suburban areas in the USA, the relatively wide streets and lower building density than typically found in the UK make retrofitting easier. However, city centres are invariably high density because land is so expensive. There still are many examples of GI in city centre areas. This is not always linked with stormwater management, but in many cases it is e.g. Portland, Oregon as illustrated in Figure 4. Note (a) the evidence of heavy rainfall in the rain gardens and (b) that even in litigious USA the city has not been sued for personal injury for pedestrians falling into or tripping on the rain garden.

Figure 4 Retrofit rain gardens in Portland Oregon (photo: Richard Ashley)

In many recent developments in England, higher levels of housing density in the past decade (typically 30-50 dwellings per hectare) have restricted drainage options (Kellagher & Lauchlan, 2006). However, a typical new development in the UK will comprise the land uses given in Table 6 which have a range of opportunities for the use of SuDS/GI. In densification considerations, as in the ‘compact city’ idea, urban water management is not made a priority and therefore it is unlikely to even be considered relevant, as is common for many planners and architects even where they avow to “*deliver more sustainable lifestyles*” (e.g. Rice, 2010). It is presumed that stormwater considerations can be dealt with once the transport, accessibility and other aspects have been planned.

Table 6 Typical division of land use for new housing developments and SuDS types most appropriate (adapted from Kellagher & Lauchlan, 2006)

Land use area	% of total	Opportunities for SuDS/GI
Roof	24	Water butts Green roof Gutter storage (blue roof)
Access roads and car parking	16	Pervious pavements
Local roads	10	Swales Filter trench Linear ponds
Main distribution roads	10	As above
Public open space	20	Ponds Basins Wetlands
Private gardens	20	Soakaways Infiltration trenches swales

The above applies to new developments, such as those illustrated in Figure 5.

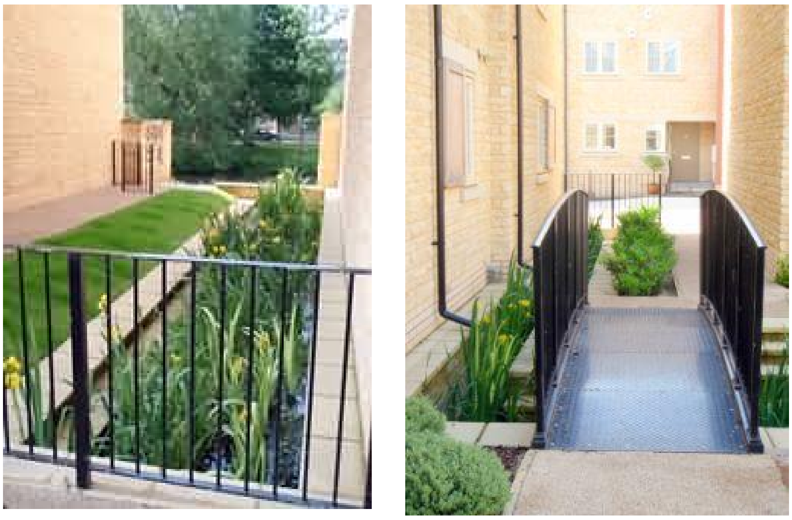


Figure 5 Canal and rill system used to manage surface water in a high density development at Riverside Court, Stamford.

GI related measures should be appropriate for the area (CIRIA, 2010). Even in the densely built area shown in Figure 6, it is possible to retrofit green roofs, rainwater barrels and biofilters at the sides of the road (rain gardens). The latter could also aid with traffic calming. Longer term, the road could be re-laid with a porous surface to aid groundwater replenishment.

Figure 6 Housing area in Putney, London and extract from the LID Center's website guide for Green Streets (Low Impact Development Center, 2011)

Uptake of these techniques is slow when people are uncertain about long-term functionality and costs, but actually, by now they are quite well proven worldwide. Bioretention areas are the sort of GI structure that can be more easily incorporated within dense development, although as a single GI, they provide only limited volume control. Perhaps if water-focussed GI is to be a prominent feature of future city centres then a vision has to be sold where blue spaces (water gardens) are part of a mixed portfolio of what is used as is demonstrated in Kronsberg, Germany (Figure 3c).

The use of new or existing street trees as GI for stormwater management is an option being pursued in many places (e.g. the million street trees initiative in New York) especially as this improves infiltration and evapotranspiration. However, mature trees (roots) and underground services in urban areas often restrict the options for the retrofit of GI based stormwater management systems designed to take runoff from paved areas. In the UK the root protection area for existing trees is usually estimated using the rule of 12x the approximate diameter of the trees, as given in BS5837:2005; although in many instances local considerations also extend this to the entire root zone (Kellagher, 2010). As an alternative, a shallow bioretention scheme often provides the flexibility to be designed to fit into the area without damaging the tree roots by including the trees in the bioretention space.

As well as this, adoption and maintenance responsibilities are among the greatest challenges to delivering GI for stormwater management, particularly for England and Wales where water services are delivered by a range of organisations including privatised water and sewerage utilities, and water services infrastructure planning is complex (EA et al., *undated*). Of the organisations involved, the water and sewerage utilities raise charges directly to customers and are regulated by Ofwat. Recent attempts to match connected contributing impervious surface areas in England to charges for draining these as is common in Germany, have been rebuffed due to [unjustified] public outcry about the high costs levied without warning on churches and other public buildings despite suggestions that the polluter should be made to pay (Walker, 2009). Therefore there is still insufficient incentive for property owners to reduce the stormwater runoff from their premises by retrofitting SuDS or rainwater GI. Nor is there incentive for those responsible for highway drainage to manage this source of stormwater better where it enters the public sewerage system as there are no direct charges for this service. This is in contrast with Toronto in Canada where since 2007 it became compulsory to disconnect all stormwater from buildings from the piped sewerage system.

The SuDS philosophy promotes the tripartite consideration of quantity, quality and amenity/biodiversity and suggests that wherever possible all three of these should be considered equally (CIRIA, 2007). Added to this is now the need to ensure systems are flexible and adaptable to future uncertainties. This requires a shift in thinking for those traditionally involved in surface water management. It is no longer reasonable to deal only with stormwater quantity management. Water should be managed on or near the surface where possible, it should be considered integrally with other functions of a city and should also provide visual amenity value. If the quality of urban life is to be enhanced, the role of aesthetics should be considered at all scales, from the small details to water management in an inner city open space.

In the UK considerations of the aesthetics and amenity value of GI in water management is at a very early stage compared with continental Europe, notably in Sweden (e.g. Stahre, 2006; Sandström, 2010) and most of the community see water as a threat not an opportunity especially after the recent floods. Water within developments can add aesthetic value when managed correctly (e.g.) http://www.artfulrainwaterdesign.net/projects/). This also requires controlling flow and cleanliness when water is integrated into the landscape. Figure 7 is an example of aesthetic use of GI and stormwater management.

Figure 7 Aesthetic enhancement of a former run-down dock area in Wellington, New Zealand using wetland GI that also collects and treats stormwater runoff from the surrounding area

2.2.2 Additional benefits of using GI for stormwater management

Managing surface water so that it can help to deliver multiple functions is a major opportunity for improving urban environments and for adding value that cannot be obtained from buried stormwater infrastructure. However, most UK guidance does not yet acknowledge this. In the USA, evidence indicates that using LID or GI for surface water management is considerably cheaper than using buried drainage systems even when comparing capital and operating costs (USEPA, 2007; Foster et al., 2011).

The SuDS manual (CIRIA, 2007) provides guidance on assessing the whole life costs of new build SuDS and more recent guidance (CIRIA, 2010a) considers the specific issues related to retrofitting. The latter provides information related to the synergistic use of GI with surface water management which is covered below. Specific guidance for benefit cost assessment (BCA) related to retrofitting surface water measures is also available in reports from UKWIR (2009) and the Environment Agency including carbon impacts of retrofitting surface water management measures (EA, 2009). The costs and benefits of the use of SuDS are also provided by WERF/UKWIR (2005) and a database for this is periodically updated by HR Wallingford. The sewerage undertakers' research body (UKWIR, 2009) looked at the benefits and costs of the use of SuDS as a means of separating combined sewers, whereas the Environment Agency (EA, 2007) developed an approach to the evaluation of the costs and benefits of using SuDS to retrofit surface water management systems. Neither of these methodologies includes the full range of potential added benefits of using surface water systems within the urban context.

Surface Water Management Plan (SWMP) guidance in England (Defra, 2010a) suggests the use of monetised costs and benefits for option assessment followed by an assessment of the unvalued costs and benefits. GI is mentioned in the guidance as a parallel consideration when fitting SWMP measures into existing planning frameworks. Acknowledging the potential synergies between GI and surface water management, the Leeds SWMP (Leeds City Council et al., 2009) is cited, which recommends that GI could be used to accommodate exceedance flows in urban areas.

A number of studies have reviewed current methods, tools and case studies for valuation of the socio-economic benefits of GI (e.g. MacMullan and Reich, 2007; Center for Neighborhood Technology, 2010; Wise et al., 2010; Green Infrastructure North West, 2010). The many potential benefits of using GI and the relationship with surface water management are given in Table 3 from studies in the USA. In the UK, the regional study by Green Infrastructure North West (2010) has produced a valuation toolbox for economic development related to GI uses with 11 benefit groups:

1 Climate change adaptation and mitigation
2 Water and flood management
3 Place and communities
4 Health and well-being
5 Land and property values
6 Investment
7 Labour productivity
8 Tourism
9 Recreation and leisure
10 Biodiversity
11 Land management

The benefits provided by each of these groups are defined by specific and in many cases, measurable indicators. Some of these are included in an assessment of the monetised benefits accruing from the use of GI, whereas other indicators may only be considered in a qualitative sense as a comparative evaluation. Examples are given of the application of the GI toolkit including an assessment for a new area of retrofit GI in Liverpool that includes green roofs in the University and hospital estates accompanied by some 3,300 newly planted street trees and limited additional green spaces. Increasing green cover from 37.7ha to 45.4ha (27% of the area). Table 7 shows the monetised benefits estimated. Overall the added value of the new GI amounts to some £29.3m - £45.6m (PV) of which some £1.6 - £2.0m is for stormwater and flood management. At an estimated cost of £29.7m, the investment would produce clear value for money.

Table 7 Value of retrofitting GI in Liverpool (using Green Infrastructure North West, 2010 toolkit)

Benefit category	Estimated benefits from the new GI (PV)
Climate change adaptation and mitigation	Savings in energy costs and in carbon emissions £3.4m - 4.7m Carbon storage in trees £6,000-£18,000
Water and flood management	Avoided surface water charges and reduced wastewater treatment savings £1.6m-£2.0m
Place and communities	Not monetised
Health and wellbeing	Pollution control benefits £14,000 - £112,000
Land and property values	Some 6,000 properties were deemed to benefit with a value of £1.7m-£6.7m
Investment	Assuming a 3.5%-4.6% annual GVA growth over the next decade, some 5,600-8,000 jobs will be created with 7% of this attributable to the GI at a value of £23m-£32m
Land management	Employment directly related to the new green space gives a value of £40,000

In US applications, the CNT's Green Values Calculator incorporates reduced runoff volume and maintenance savings, in conjunction with carbon sequestration, reduced energy use, and groundwater recharge. The methods of valuation of some of these benefits are summarised in Table 8.

Table 8 Value of GI component benefits (http://greenvalues.cnt.org/national/calculator.php)

GI's benefit	GI component	Value ($)
Reduced Air Pollutants	Trees	0.181 per tree
Carbon Sequestration	Trees	0.12 per tree per year
Compensatory Value of Trees	Trees	632 per tree
Groundwater Replenishment	Infiltration basins	86.42 per acre-foot infiltrated
Reduced energy use	Green roofs	0.18 per square-foot of green roof per year
	Trees	5-10 percent energy savings from shading and windblocking per 10% increase in tree cover
Reduced treatment costs		29.94 per acre-foot of reduced runoff

Whilst it is possible to criticise the details of the way in which the benefits such as local crime reduction, have been monetised in these tools, the relative value of using different options for surface water management can be still be compared. The benefits as related to surface water are listed in Table 3 for the USA tool and in Figure 8 for the City of Philadelphia’s vision of using GI for CSO spill reduction.

Figure 8 A vision of a GI retrofitted Philadelphia (now – left; future – right) (photographs courtesy of J Smullen CDM)

As well as providing significant reductions in the CSO spills in Philadelphia, the retrofit GI also provides significant social, environmental and financial benefits as illustrated in Tables 9 and 10 (Philadelphia Water Department, 2009). The 50% LID and 30 foot (9m) tunnel options were chosen as example alternatives to illustrate the differences between green and traditional infrastructure approaches. In the Tables, LID is synonymous with GI SuDS.

Table 9 Cumulative city-wide natural unit benefits of key CSO options for Philadelphia to 2049 (Negative numbers indicate a net sink of these gases)

Benefit category	50% LID option	30 foot sewer tunnel option
Additional waterside recreational user days	247,524,281	Nil
Additional non-waterside recreational user days	101,738,547	Nil
Reduction in number of heat-related fatalities	196	Nil
Willingness to pay for water quality and habitat ($/household.year)	9.70−15.54	5.63−8.59
Wetlands created or restored (acres)	193	Nil
Green collar jobs created (job years)	15,266	Nil
Change in particulate matter ($PM_{2.5}$) due to increased trees ($\mu g/m^3$)	0.01569	Nil
Change in seasonal ozone due to increased trees (ppb)	0.04248	Nil
Electricity savings due to cooling effect of trees (MWh)	369,740	Nil
Natural gas savings due to cooling effect of trees (MWh)	175,608	Nil
Vehicle fuel (for construction, operation, maintenance) (litres)	1,867,673	4,286,634
Sulfur dioxide (SO_2) emissions (tonnes)	-1,530	1,452
Nitrogen oxides (NO_x) emissions (tonnes)	-38	6,356,083
Carbon dioxide (CO_2) emissions (tonnes)	-1,091,433	347,970
Vehicle delays from construction and maintenance (hours)	346,883	796,597

Table 10 City-wide present value benefits of key CSO options for Philadelphia to 2049 in US$million

Benefit category	50% LID option $million	30 foot sewer tunnel option $million
Increased recreational opportunities	524.5	
Improved aesthetics/property value (50%)	574.7	
Reduction in heat stress mortality	1,057.6	
Water quality/aquatic habitat enhancement	336.4	189.0
Wetland services	1.6	
Social costs avoided by green collar jobs	124.9	
Air quality improvements from trees	131.0	
Energy savings/usage	33.7	(2.5)
Reduced (increased) damage from SO_2 and NO_x emissions	46.3	(45.2)
Reduced (increased) damage from CO_2 emissions	21.2	(5.9)
Disruption costs from construction and maintenance	(5.6)	(13.4)
Total	**2,846.4**	**122.0**

What is significant from Tables 9 and 10 is that in addition to dealing with stormwater from 50% of the city catchments, the LID (GI, SuDS) option has considerable added benefits in terms of direct social and environmental factors and at the same time delivers a financial present value benefit of almost $3bn compared with that from the equivalent traditional sewer tunnel of some $122M. Some of the key factors in making up added value from GI are considered further below.

The treatment of combined sewage when it includes surface water runoff adds considerably to society's energy and carbon use, potentially impacting on climate change drivers (Ross et al., 2004; KTN, 2009). Hence, removal of surface water from conventional treatment by retrofitting control nearer to source, such as rainwater GI, where the carbon use is limited in construction and may be reduced in operation by plant uptake, will potentially help mitigate climate change rather than add to it; although in a recent UK assessment, it was suggested that these benefits may not always accrue from SuDS, especially from retrofit measures (EA, 2009a).

Monetising and forecasting benefits and costs and discounting the result to present values is subject to the assumptions made, the criteria included or excluded, the lifetimes assumed for infrastructure, plant and equipment and the inflation indeces used for energy, labour, etc. For this reason there must be transparency in the process and it needs to be agreed by the stakeholders so that the BCA can be 'audited' (as should Life Cycle Assessment). The Environment Agency (EA, 2009a) assessed GI implemented in an existing development of 1 ha and estimated potential carbon savings at about 0.5 tonnes per year, with pumping (energy and carbon reduction commitment) cost savings in the order of £88 per annum. It was further shown that for half of the GI components there is carbon payback within a 25 year time period (Table 11). The valuation models cited above would have estimated much better payback and cumulative monetised benefits than this has produced.

Table 11 Summary of carbon impact of GI components (after EA, 2009a)

GI component	Construction tCO_2e	Annual maintenance tCO_2e	Annual pumping tCO_2e	Carbon payback years
Filter strips	3	0.13	-0.03	No
Infiltration basins	6	0.13	-0.54	14
Wetlands	7	0.13	-0.54	17
Detention basins	7	0.13	-0.54	17
Swales	2	0.13	-0.54	6
Trenches	63	0.13	-0.54	154
Pervious pavements	105	0.03	-0.54	208
Green roofs	109	0.14	-0.03	No

The EA study also indicated that infiltration basins, wetlands, detention basins and swales provide a net annual reduction in carbon emissions, offsetting the construction and maintenance emissions. For filter strips and green roofs a small net annual increase is projected, with the carbon emissions associated with construction and maintenance outweighing the benefits associated with a reduction in pumping. For new developments the default result is for no reduction in wastewater pumping as a consequence of GI since these developments are already required to have separate sewer systems discharging surface water to a local watercourse, and therefore there is no net reduction in emissions. The study did not include any of the wider GI benefits.
Climate change mitigation by GI is summarised by Community Forests Northwest (2010; 2011) as including but not limited to:

- Carbon storage and sequestration: GI is a highly effective carbon store and also sequesters (or removes) carbon from the atmosphere. However, carbon stored in GI does have the potential to act as a source in the future as does all biological storage.

- Lower embodied carbon: GI approaches use fewer carbon based materials than the traditional alternatives (which involve high fossil fuel consumption in their production), and hence there is a reduction in the embodied carbon.

- Reduced energy demand: by helping to reduce urban temperatures GI can also reduce energy demand for cooling in buildings, further helping to reduce greenhouse gas emissions.

GI plays a major role in helping to adapt new and existing urban development to climate change conditions in relation to water management. This is considered here separately in the context of flooding, drought, and heat waves (Gill et al., 2006; Community Forests Northwest, 2010 & 2011; UN Water, *undated*; Georgi & Dimitriou, 2010; Climate East Midlands, 2010) adapted in Table 12.

Table 12 The potential role of GI in helping adapt to climate change

Water related phenomenon	Adaptation needs	How and why GI can help
Flooding	Managing surface water runoff	Urban development results in faster runoff of surface water, and higher rates and volumes of runoff, because the capacity for local retention/infiltration is diminished. An increase in green areas (GI) to reduce the rate at which rainwater runs off and increasing infiltration can help to better manage intra-urban flood risk (Bartens, 2009).
	Managing overland pathways	An option to better manage intra-urban flood risk is to direct peak flood flows along green links (Figure 2) where the risk to infrastructure, buildings and people is minimal (CIRIA, 2006).
	Managing fluvial pathways	GI can provide water storage and retention areas, reducing and slowing down peak flows, and thereby helping to alleviate flooding from rivers and urban watercourses (Wheater & Evans, 2009).
Droughts	Maintaining water quantity	GI can provide a permeable surface which helps to sustain infiltration to aquifers, recharge groundwater and maintain base flow in rivers (Bartens, 2009).
	Maintaining water quality	GI catches sediment and can remove other pollutants from the surface water, thereby ensuring that water quality is maintained; this is especially important in the UK where the quality of water sources from uplands is deteriorating ostensibly due to a changing climate (EA, 2009).
	Maintaining the source	GI can assist with the provision and management of healthy and biodiverse catchments as a whole; reducing the stress on flora and fauna (Bartens, 2009)
Heat	Managing high temperatures	Urban areas are at increased risk of heat waves due to the urban heat island (UHI) effect. UHI arises because materials used in cities (asphalt, concrete, bricks) store heat and release it slowly during the night, keeping urban temperatures higher than rural temperatures (Rahola et al., 2009). GI can counteract the heat island effect of cities by providing shading and/or cooling through evapo-transpiration (Zoulia et al, 2009).
	Providing recreation	GI provides recreation services, so that people can enjoy positive consequences of climate change like warmer summers (Barbosa et al, 2007; Casperen & Olafsson, 2010).

Multi-functionality is fundamental to the GI concept and refers to the potential for GI to deliver a diverse range of functions and services. Only when individual sites (nodes, hubs) and links (Figure 2) are taken together can they form a fully multi-functional GI network (Natural England, 2009). Not all sites and links need to provide all types of function—rather the multi-functionality across them should be optimised (CIWEM, 2010). Table 13 gives an example of how an individual GI component (in this case a detention basin) can fulfil a variety of functions and services.

Table 13 Multi-functionality for an individual GI component (after Natural England, 2009)

GI component	Policy priorities	Functions
Detention basin	Environmental; Economic; Social	Flood risk management and water resource management; biodiversity enhancement; recreation; health; access; landscape setting; sense of place

The GI Strategy for Norwich, England describes multi-functional GI as an interconnected network of green corridors and a natural life support system providing benefits for wildlife and people and also serving as a surface water management system: "*At the heart of the concept is the provision of 'multi-functional green infrastructure' that can meet a wide range of social, economic and environmental needs. For example, a greenspace can function as a public open space, water retention/storage facility and as a wildlife corridor*" (Blandford, 2007).

In summary, because of its potential to deliver more than one function, GI produces a range of environmental, economic and social benefits in conjunction with water and flood risk management. Incorporating the value of those benefits into life cycle cost-benefit analysis is essential in comparing GI and conventional (grey) infrastructure (Wise et al., 2010). It is possible now to provide a better understanding of the net present value of GI approaches for investment decision making. Despite increasing recognition of the benefits of GI, these are often not addressed in UK Government planning policies, which may be due to the treatment of GI components in isolation from other factors and opportunities (CIWEM, 2010). However there does seem to be growing recognition of the role of environmental systems in providing ecosystem services (Defra, 2007). For example, an ecosystem services assessment for Mayesbrook Park as part of Mayes Brook regeneration found a benefit cost ratio of 7:1 provided the wider benefits, such as the cultural service value of ecosystems were included (Everard et al., 2011). The problem may be that one Government Department (DCLG) deals with planning, whereas another deals with environment and flood risk management (Defra) and therefore the value and cross-benefits of ecosystem, GI and better stormwater management are not sufficiently harmonised between these administrative functions (House of Lords, 2006).

Current planning policy defines green space by its primary function, such as a park, protected area, etc., making it difficult to provide integrated approaches to urban planning with a diverse range of benefits that include GI as a component of stormwater management. In future it will be necessary for planning policy to more fully acknowledge multi-functionality and to be better integrated to ensure that overall benefits are optimised (White, 2010).

Awareness is emerging of the need to supplant grey infrastructure with more ecologically aligned and fit for the future purpose approaches that provide adaptable and resilient systems. However, more evidence of the better resilience of GI systems compared with traditional drainage systems is required in order to convince decision makers to preferentially select GI.

The challenge is in updating and extending the number and type of benefits, including the quantification of benefits not easily monetised. More work is needed to account for the potential reductions in greenhouse gas emissions and the carbon adsorptive potential of GI. In addition there is a need to show how the future urban heat island problems can benefit from green corridors as well as providing overland pathways for exceedance flows, pleasant places to live and work and improvements to water quality. The apparent flexibility and adaptability of GI needs to be better quantified and shown against traditional hard engineering systems to be more aligned with the adapt and survive demands that will be required in the future (EU, 2009). The European Commission white paper on adapting to climate change (EU, 2009) states:

> *"Evidence suggests that working with nature's capacity to absorb or control impact in urban and rural areas can be a more efficient way of adapting than simply focusing on physical infrastructure. Green Infrastructure can play a crucial role in adaptation in providing essential resources for social and economic purposes under extreme climatic conditions."*

3. The Urban Landscape

GI and stormwater management are highly dependent on context. Most urban areas in the UK are long-established and the rate at which land use is altered is slow (0.7% over the period 1995-98 in England; White, 2008) therefore most GI for stormwater management needs to be retrofitted within existing urban areas.

3.1 The formation of cities

The location of most urban areas has been influenced by water, whether as a transport opportunity, a power source, or water supply. As urban growth expanded some benefits became obsolete and river channels and their natural flood plains became heavily modified and built over, often leaving large areas of cities potentially vulnerable to flooding.

Attempts to control building in flood vulnerable areas began in the 1940s, but the response has largely been to engineer solutions rather than to try to avoid the problem in the first place; leaving a legacy of heavily modified rivers and small watercourses within cities with little natural flood plain (Newman et al., 2011).

Most of the current built urban environment in the UK originates from the Georgian and Victorian periods (18^{th} and 19^{th} centuries) with subsequent additions and modifications that have not substantially changed the layout. Little remains of the earlier Roman/Medieval structure of cities and towns although many inner city and town layouts such as market places and squares are influenced by these periods.

Le Doux (1736 -1806) challenged the poor living conditions of the Industrial Revolution. He considered that the architect should be concerned with all aspects of community from work, morals and education to legislation, culture and government. From this grew the garden city and model town movement in the early 20^{th} century (Figure 9) via James Silk to Ebenezer Howard, Robert Howard, Cadbury brothers and Sir Titus Salt. There was the recognition of separating different incompatible land uses and providing recreational space and healthy conditions for workers (e.g. Howard, 1902).

Figure 9 Plan for Welwyn Garden City and as it is today (From Google images)

Modern town planning began as part of the reform movements concerned with health and sanitation measures to overcome the deleterious effects of the industrial revolution (1770 -1860). During this time engineers were very important in improving public health and a philosophy of getting all storm and foul drainage away from the town quickly was adopted in most urban areas by the early 1900s at the latest (Chocat et al., 2007). This was the start of the ‘out-of-sight-out-of-mind’ era for sewage and stormwater management (Tyson, 2004).

Only in the last two decades has the concept of flood risk management, including the need to allow greater freedom for surface water to pass around, through or under urban areas, been recognised or rediscovered (Newman et al, 2011). With increasing future uncertainties due to climate and other changes, the need to plan urban areas to accommodate surface water rather than try to exclude it has become apparent (Thorne et al., 2007; Milly et al., 2008; White, 2010).

GI was little evident in the early housing layouts, but parks were created with the intention of reducing discontent and providing a healthy environment for the workers in their ‘Sunday best’. Extensive areas of cities were also built less intensively for the wealthier, mainly in the suburbs where large gardens, street trees and verges still remain (Morris, 1997). The creation of allotments as we know them today, where urban dwellers could grow food, dates from the mid-19th century as a manifestation of social responsibility, and concern for civil harmony, health, leisure, etc. although allotments have been allocated since the 16th century.

In the inter-war years (1919-1938) emphasis on recreation for fitness though the provision of extensive sports pitches grew.

In the second half of the 20th century renewal processes began with the rebuilding of city centres and clearance and replacement of unfit 19th century housing with high rise apartments. From the 1930s onwards cities became connected by new road and motorway infrastructure and there was a level of decentralisation and creation of suburbs. Wider car ownership also meant the paving of front gardens to provide parking, thus creating more impermeable surface and more runoff.

Mixed tenure housing built as part of an ongoing process of regeneration towards the end of the 20th century has a dearth of GI. The GI in wealthier less intensively developed housing areas now often has the protection of a designated Conservation Area.

In the UK, state control and management of the planning of towns and cities was essential for post 1945 reconstruction. The principles that emerged (Davies, 1998) are still valid today though the emphasis has shifted from land-use to 'spatial-planning' designed to help maintain, create and re-create sustainable communities (Shaw & Lord, 2009).

From the late 1980s onwards more value was attributed to green space resources. Work included developing park regeneration strategies (e.g. Sheffield City Council, 1993) and proposing standards for natural green space access (English Nature, 1995). Competitive tendering for maintenance meant many local authority parks services lost human capacity and key skills; 68% of local authorities report that a lack of skills in horticulture affected the quality of service delivery (CABE, 2009a).

Methods of wastewater treatment advanced around the turn of the 19th/20th centuries and the widespread introduction of separate surface and foul sewer systems followed. All pipes came under the powers of the Local Authority following the 1936 Public Health Act. These publicly owned sewers were then transferred to the Water Authorities following the 1974 reorganisation of Local Government and then in 1989 to the private companies of today in England and Wales. In parallel, many of the smaller urban watercourses, often covered over in culverts, remained under local authority control. Many more of these were, and remain, the responsibility of riparian property and land owners.

3.2 Today's city and its challenges

Key challenges for the modern city include:

- Population changes and lifestyle expectations
- Continuing growth and urbanisation
- Climate change
- Economic challenges
- Resource challenges

Most of this list relates to land use. Many of the new challenges relate to future uncertainties (Milly et al, 2008). Dealing with uncertainty requires a diversity of approaches and building in potential redundancy to systems. There are various guidelines for planning an urban landscape that have been prevalent for some time and include the interconnected green/blue 'patches' shown in Figure 2 as part of the 'indispensable pattern' which includes greening infrastructure, planning for multiple use and delivery by 'learning by doing' (Ahern, 2007). Yet this is not routinely integrated with surface water management in the UK. The trend for small gardens in new developments in the UK, not encouraging the planting of significantly sized trees is also a problem as large species trees are keystone structures; that is, their contribution to ecosystem functioning is disproportionately large given the small area occupied (CIRIA, 2010b). This loss of opportunity needs to be balanced by greater use of trees within public open spaces and their retrofit as is happening in New York.

The population of the UK is likely to exceed 70 million people by 2031 (ONS, 2008), with some 4 million homes in London by 2031. The average building density for new developments has increased from 25 to 44 dwellings per hectare (2001-2007). This increase in density reduces the potential for green space and exacerbates water and flood risk problems in urban areas (DCLG, 2006; Kellagher & Lauchlan 2006).

Figure 10 Low- medium rise flats in south west London showing areas of grass and planting despite the high density housing

Even so, it would be possible to retrofit GI stormwater management measures to green urban areas such as that shown to the right in Figure 10. This was advocated as an option proposed in the investigation into disconnecting stormwater in London for CSO control (Thames Water, 2010).

More modern UK developments tend to be either terraced or surrounding a courtyard to meet density requirements (Kellagher & Lauchlan, 2006). Invariably there is some aesthetic green planting and this can also be designed to have some rainwater capture/GI functionality.

The UK Climate Impacts Programme (UKCIP www.ukcip.org.uk) and DEFRA have produced projections of future climate change (UKCP09) for the UK (with guidance on estimating uncertainty). Predicted changes relevant to GI and stormwater include increases in extremes of rainfall; increases in mean ambient temperatures, and more hot days and over prolonged periods. This will affect the amounts and rates of stormwater runoff and the nature and vulnerability of natural ecosystems in urban areas. The increased risk of water shortages due to lower volumes of rainfall will increase abstraction pressures on natural stored waters in aquifers and in open water bodies (EA, 2009).

Climate Change is identified as a particular challenge in urban areas, where the urban heat island effect is already recognised. The London Plan (Mayor of London, 2009a) states that: "*Green, vegetated roofs, roof terraces and gardens can enhance biodiversity, absorb rainfall, improve the performance of the building, reduce the heat island effect and improve appearance… Development should maximise opportunities to orientate buildings and streets to minimise summer and maximise winter solar gain; use trees and other shading; green the building roof, envelope and environs; maximise natural ventilation; expand green networks to create 'breathing spaces'; and wherever possible incorporate a range of public and/or private outdoor green spaces such as gardens and roof terraces*".

The impacts of flooding at the beginning of the 21st century combined with growing housing demand, has led to flood risk guidance that challenges building within flood plains. The term 'Flood defence' has been replaced with 'Flood risk management' within which 'living with rivers' and 'making space for water' have become the norm (DCLG, 2010; Newman et al., 2011). The challenge is to align this philosophy with the demand for regeneration processes in cities. Globally the idea of 'Green City – Smart Growth' has been adopted at senior level but has grass root origins promoting the incorporation of ecological principles into urban planning (Novotny, 2007). This has led to the restoration of a number of urban rivers, such as in San Antonio, USA and the linking of Smart Growth with GI (e.g. USEPA, 2005).

In the Netherlands, development in flood risk areas must be accepted; many developments are designed to accommodate occasional flooding and may even comprise amphibious buildings as at Maasbommel (Inhabitat, 2010). Integrating rainwater GI with development on flood plains means the systems will be overwhelmed occasionally, which can compromise their effectiveness (Doncaster et al., 2008) but this may be a necessary trade-off.

The Royal Horticultural Society (2006) suggests that some 75% of front gardens have been paved over in some parts of London, despite regulations designed to prevent this. The use of GI and associated SuDS measures that retain or enhance permeable areas is inherently more flexible and adaptive and Veerbeek et al., (2010) advocate that the inclusion of such measures should be mandatory in any redevelopment or regeneration project. CIRIA (2011) deals with the opportunities arising from the development of previously developed (brownfield) land. As there is strong encouragement to utilise brownfield preferentially to greenfield land for developments in the UK, the guidance provided for ensuring open spaces are included in such developments is helpful;

although it is rather too negative about the problems of using SuDS/GI where the land is contaminated.
Currently GI assets in the UK are largely maintained by non-statutory services and as a result are often subject to budget problems. Statutory services will always take precedence over non-statutory. The implementation of the EU Floods Directive, together with duties placed on Lead Local Flood Authorities in England under the Flood and Water Management Act 2010 (FWMA), is an opportunity to make GI a vital [statutory] part of managing the water cycle as part of the drive to use SuDS.

It was reported in London in 2007 that 40% of street trees were under threat (CABE, 2008) but the latest plan (Mayor of London, 2009) challenges this threat. Street trees are generally missed GSI opportunities that could be adapted easily to have hydraulic connection with the surrounding impermeable surfaces (CIRIA, 2010b). Many GI elements within cities have arisen through incidental rather than designed processes and are therefore vulnerable to removal, causing a reduction in connectivity and the wildlife migration routes important for ecological adaptation. There will be more protection in the future for GI associated with SuDS in England as the FWMA designates responsibility for maintenance to SuDS Approval Bodies (SABs) within County or Unitary Local Authorities.

Public investment in GI is still proportionately low compared with other service areas. A survey of four English local authorities showed that ‘green space’ expenditure represents 0.1% to 4.3 % of total annual expenditure; whereas revenue for roads was 24 times greater (CABE, 2009a).

Given the pace of climate and other changes and the need to manage carbon and energy more efficiently, it is necessary urgently to incorporate flexible and adaptable measures by the synergistic inclusion of GI and stormwater management within rehabilitation and renovation programmes. As compliance with the Water Framework Directive, the Floods Directive and the enabling regulations and instruments begins to unfold in the UK, the value of GI and non-piped stormwater management should become self-evident.

4 Green Infrastructure in the UK – Policy

The inclusion of GI in UK urban areas still predominantly occurs for traditional aesthetic, recreational and biodiversity reasons and is not usually linked specifically with surface water management. If the drivers for improved water management can be made more apparent then the arguments for linking it to GI with all its incidental benefits become stronger. The GI initiatives promoted in the UK by CABE, Natural England and regional agencies (e.g. Community Forests North West et al., 2010 & 2011; Climate East Midlands, 2010) all emphasise how existing and new GI networks can be effectively utilised to help to deliver multiple value by including surface water management.

Many policies in urban areas now recognise multi-functional land use as both an opportunity and a necessity for the provision of healthy, vibrant and functioning cities (Mayor of London, 2009a; White, 2010).

As an example, some of the functions, regulations and needs which GI can support in UK applications are shown in Figure 11.

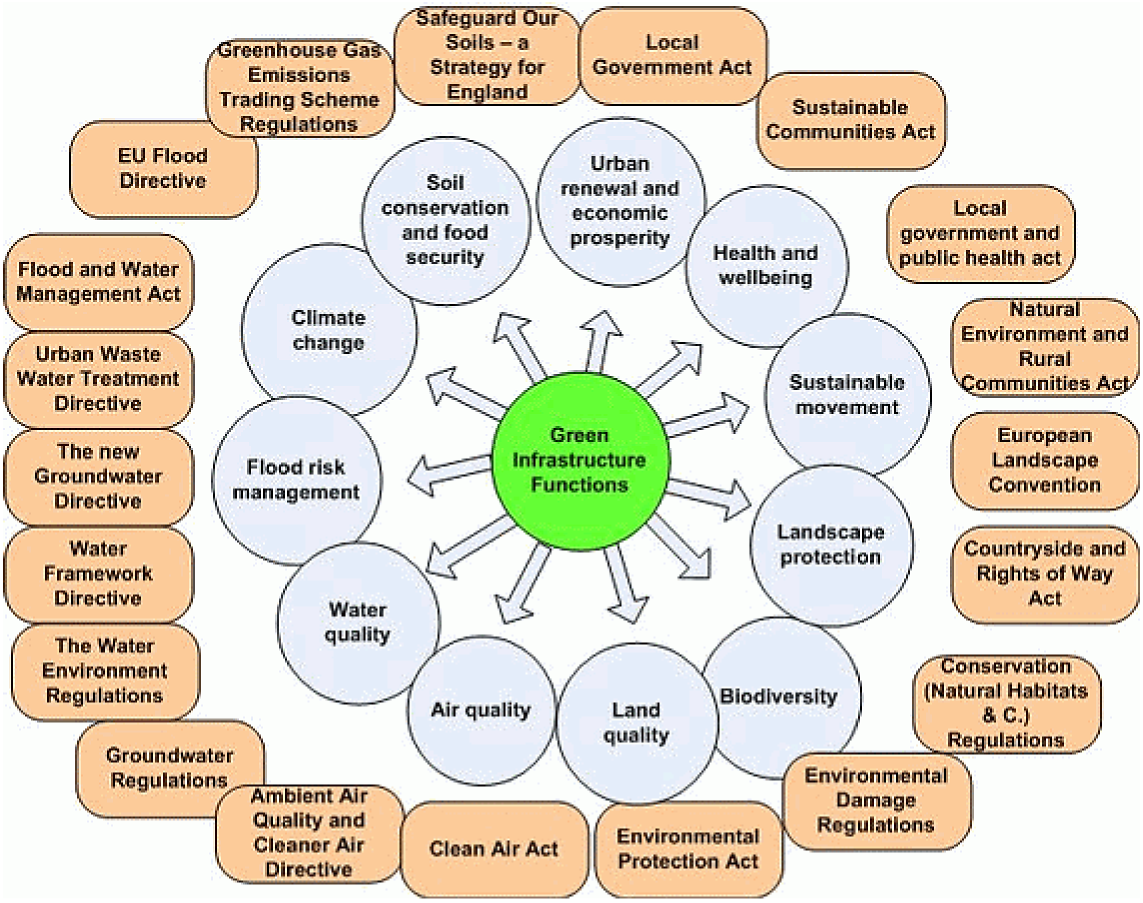


Figure 11 Potential GI functions (adapted from Hesketh et al., 2010)

With the FWMA 2010 in England, imperatives for using SuDS and hence taking advantage of GI synergies are now much stronger, although these will mainly apply only to new developments.

There are complex interacting factors that influence how rainwater GI may be implemented and used in relation to surface water management. These may be considered as grouped into:

- Core traditional GI policy – e.g. biodiversity, recreation
- Additional Ecosystem Services policy- e.g. air pollution, urban cooling
- Key influential policy where GI will be integral – e.g. housing, transport, climate change, sustainable communities
- Water policy – e.g. flood risk assessment, water resources, discharge rates

Delivery of GI planning and resourcing is dependent on policy. This could be for larger spatial land use planning scale or at the design scale of individual developments, for example how water is managed within a housing estate or used for place making within a commercial setting. Housing policy sets density targets which will influence street scale GI for water management, for example, in England PPS3 Housing (DCLG, 2010b) has constrained street frontage SuDS of the type shown in Figure 12, resulting in surface water systems that are largely situated on the edges of recent new developments. Future policy seems not to envisage any change to this perspective although a major revision of the Planning Policy Guidance system is underway in England.

Figure 12 Swales at Elvetham Heath, England

At the local level the 'home zone' initiative promoting shared space between people and vehicles, fails to connect any of the value of stormwater and GI, focusing on a perspective that recommends the abolition of front gardens in these areas (Home Zone, 2011) and stating that road surfaces should always be designed to prevent standing water (JMU et al., 2007). This Institute of Highway Engineers' guidance is typical of 'tunnel vision' and water is barely mentioned in any of the documents other than as a possible nuisance, although planting (in public areas) is recommended to restrict the view of vehicle drivers and slow them down.

A major challenge to delivering the multiple benefits and functionality GI can offer is in resolving potential conflicts between users e.g. between access routes, sensitive biodiverse areas, flow exceedance pathways, or managing a park for water management as well as for recreation.

GI can be viewed by type, function and benefits (Community Forests North West et al., 2010; 2011). In some situations GI will play a dominant role in planning, for example the location of a river or ancient woodland could determine the route of a motorway project, or a natural area may be appropriate as a new park by virtue of its ecological value. In other situations GI location will be completely subordinate, for example in the greening of a new inner city road. Until there is a change in mindset, it is nonetheless unlikely that planning for GI will be significantly influenced by surface water considerations in the UK, i.e. GI *not* GSI. Although some policies such as the Climate Change Act 2008 for England and Wales provide the opportunity for GI to be used to enhance the way surface water is managed in terms of energy reduction and carbon sequestration.

4.1 Policy, plans, guides and standards

There are no distinct policies in England and Wales for GI in relation to water management within national, regional or local government; but it is embedded within other policy areas and implicit in the FWMA 2010 with its stipulation that SuDS need to be used for surface water drainage unless these are found to be impracticable. The CIWEM (2010) Multifunctional Urban Green Infrastructure report pre-dates the FWMA, but provides an overview of the relevant policies for the UK and is adapted below:

- Pressures from development often threaten formally or informally functioning GI because the multi-value is not recognised or the way in which this is accounted for fails to value multi-benefits adequately (Green Infrastructure North West, 2010; Center for Neighborhood Technology, 2009). Existing GI could potentially provide opportunities to retrofit SuDS and relieve pressure on existing drainage systems (CIRIA, 2010a).

- Biodiversity is protected under the Wildlife and Countryside Act (1981) and the Countryside and Rights of Way Act 2000, which identifies protected species and Sites of Special Scientific Interest (SSSIs). The Natural Environment and Rural Communities (NERC) Act now places duties on Local Authorities to give due regard to biodiversity, considering ecological connectivity, high quality accessible landscapes and ecosystem services. Government guidance is currently provided through PPS9, Biodiversity and Geological conservation (DCLG, 2005). This requires local planning authorities to prepare policies for the protection of species and habitats through a network of sites identified through the UK Biodiversity Action Plan (BAP) targets. The Town and Country Planning Acts (1990 and 1999) give specific powers such as Tree Preservation Orders which protect both individual trees and woodland. Many of these statutory instruments could be linked with opportunities and needs for using GI for surface water management.

- Difficulties in establishing accurate figures about green space in urban areas include poor definition of green space types and categories. DTLR (2006) and many authorities in England have developed green space strategies to map their existing assets. The intention was that they supported the delivery of PPG17 Planning for Open Space, Sport and Recreation (2002) which aims to deliver national objectives for better public spaces and establishes the principle that open space should not be built upon unless surplus to requirements. The key planning document is the (living) Local Development Framework (LDF) which typically sets the amounts of green space for cities and its use and accessibility.

> As yet, LDFs usually do not explicitly link GI with SuDS, even where the latter are included in the Framework, although supplementary planning documents may refer to 'green links'; 'green spaces'; 'green networks', but typically never to '*green infrastructure*' (e.g. Ashford, 2010).

These policies/strategies encompass a wide range of issues and organisations but tend to be focussed primarily on the core benefits of recreation, amenity and biodiversity. Green space strategies are not just focussed in parks (DTLR, 2006), they also include areas of water such as rivers, canals, lakes and reservoirs which offer important opportunities for sport and recreation and can also act as a visual amenity. Recent guidance and initiatives are becoming more cognisant of the interactions and synergies between 'green' and 'blue' (Community Forests North West et al., 2010), although this is not yet evident in guidance such as CABE's Community Green report (CABE, 2010a) or even in development policies such as The London Plan (Mayor of London, 2009).

Very few existing green spaces play an active water management role even when they are ideally placed to do so, for example linear river parks. As this is not an area of typical expertise of the managers of these spaces and there is limited resource to explore wider aspects of green space potential. The future challenge will be to ensure joining-up of green space development and management with water management needs, such as flood risk management, water quality issues and long-term overall catchment management as required under RBMPs and e.g. FWMA in England. White, (2008) recommends the identification of areas of high infiltration in towns that could serve as future green space in areas of change.

As any co-management of surface water with GI in England must support planning policy, some of the more relevant documents related to this are outlined below.

PPS1 *Delivering sustainable communities* (DCLG, 2005a) – promotes sustainable patterns of development, avoiding flood risk and accommodating the impact of climate change, advocating an appropriate mix of uses including green space and place making. The Supplement on Planning and Climate Change (DCLG, 2007) suggests that GI can address climate change mitigation and adaptation whilst delivering other benefits. The Town and Country Planning Association (TCPA, 2007) also emphasises the need for consideration of climate change as well as to ensure existing infrastructure is resilient.

PPS3 *Housing* (DCLG, 2010a) guidance argues for a more sustainable approach to residential development, attaching particular importance to the 'greening' of residential environments. In the development design process pre-planning application discussions sometimes take place considering issues such as site layout, design details and drainage. These sorts of communications will become more important if GI is to play a stronger role in surface water management.

Section 106 of the Town and Country Planning Act 1990 (DCLG, 2005b) and Community Infrastructure Levy (DCLG, 2010b) allow a planning authority to enter negotiation with a developer in order to levy a charge on the development to pay for essential infrastructural support for the development. These arrangements may allow GI features such as parks to be installed and can be used to fund alternatives to site drainage requirements that cannot be provided locally in accordance with PPS25 (DCLG, 2010). Greater efforts need to be made to bring all of these together into a multi-functional provision of surface water management and GI. Perhaps the on-going rationalisation of the planning guidance system will be able to do this.

PPS12 *Local spatial planning* (DCLG, 2008a) provides guidance for the establishment of Core Strategies covering all land uses and infrastructure needs, including GI. Within the Local Development Framework (LDF) are a variety of scales of work with area development frameworks, neighbourhood development frameworks, master-plans and planning briefs recurrently renewed and updated. These plans are of increasing levels of detail and are drawn up depending on demand, for example in areas where there are predictions of considerable change. They provide the chance for local public and other inputs and an opportunity to examine GI potential in more detail. PPG 2 deals with Greenbelts (DCLG, 2001) and sets out appropriate and positive uses such as recreation for the urban fringe of cities. These areas can also play a role for surface water and flood risk management, as is planned in Hull (Hull City Council et al., 2009).

Making Space for Water (Defra (2005) is the Government strategy in England and Wales for flood and coastal erosion risk management; it establishes the principle of considering the full range of flooding problems and embeds flood risk management in all other relevant policy areas. Development and Flood Risk PPS25 (DCLG, 2010) requires development to avoid and manage flood risk and new development must adhere to a Sequential Test to steer all new development to areas at the lowest probability of flooding (Hull City Council et al., 2009).

Key roles for GI will be in providing compensation for areas of flood plain removed for development, inundation areas associated with planned overtopping of defences, and in improving channel cross section and bankside environments. Strategic interventions for main rivers, working in partnership across the main stakeholders, could also include storage wetlands or washlands as both of these can be valuable GI with a number of functions.

GI potentially has a more significant role to play in surface water management in solving local problems as well as improving overall catchment function. The way a site is drained is vitally important in avoiding the risk of surface water flooding. Annex F of PPS25 specifically deals with the management of surface water highlighting the impact of new development on drainage and providing best practice in the design, construction and management of more sustainable forms of drainage. The multi-beneficial nature is alluded to in "*Promoting the use of SuDS to achieve wider benefits such as sustainable development water quality, biodiversity and local amenity*" though GI is not used as a term as this is drainage centred guidance.

In England the FWMA 2010 is a response to the Pitt Review of the 2007 summer floods (Pitt, 2008). It aims to address the lack of clarity over responsibilities, in parallel with Future Water (Defra, 2008), the Government's water strategy. The key relevant issue is the requirement to use SuDS designed and approved in line with national standards and the establishment of SuDS Approval Bodies (SABs) within Unitary and Upper tier Lead

Local Flood Authorities (LLFA). The EA has an overview role with regard to flood risk through their continued use of their Catchment Flood management plans and strategies, whilst LLFAs have the local delivery role. Local Authorities will be responsible for fulfilling the Flood Regulations and implementing the EU Flood Directive. This requires flood risk assessment and hazard assessment followed by Flood risk management planning and is now leading to a new national and local flood risk management strategy (Defra, 2010b). The role of GI, which would have to be largely retrofit, to deliver the new SWMPs could be central to the strategy. For example recurrent culvert flooding could be a matter of improving maintenance or it could be managing overland flows; potentially utilising street scale green infrastructure, (e.g. Leeds City Council et al., 2009; CIWEM, 2009).

Changes in the roles and responsibilities for managing surface water and flooding in England are linked with Local Authorities' contribution to sustainable development in the FWMA 2010. In consultation, Defra (2010c) identified carbon accounting and setting carbon budgets, as part of the requirement to decrease greenhouse gas emissions and that local flood storage areas can also provide local amenity. GI is not mentioned as such, but LLFAs are recommended to base decisions on a sound scientific understanding of local surface water, fluvial and coastal processes and how these might change in the future.

Sustainable management of local watercourses should recognise the role they can play in mitigating diffuse pollution from surface water runoff (including highway runoff) and the slowing down of peak flows to downstream watercourses and communities.

There are a number of other instruments also being used within Local Authorities to encourage more sustainable management of water. These include The Code for Sustainable Homes (DCLG, 2009) which places standards on surface water runoff.

4.2 The emergence of a GI strategy

In 1999 the Urban Task Force stated: "*Green Belts have played a vital role over many decades in resisting urban decline … There is also a need for a more sophisticated approach in protecting and designating urban green space. There are important green buffer zones and strategic gaps both within and between our urban areas that could be given the same weight in development control terms as the Green Belt designation. This would help to protect urban biodiversity and ensure strong urban green space networks.*" In order to start the process of embedding GI within spatial planning and delivering early consideration many authorities have started to draft GI strategies at both regional and city scales. Increasingly the economic benefits of GI are also being promoted within policy, for example NENW (2009) highlights a list of eleven benefit groups.

There are many UK examples of GI strategy for example, the Northwest Climate Change Action Plan focuses on GI to help mitigate and adapt to climate change (Community Forest North West et al., 2010; 2011) and Cambridgeshire Horizons (2006; 2010) has a GI Strategy which is under revision. Examples of Green Space and GI strategies at different planning and spatial scales of: Regional; Sub-Regional and Local or Community are provided by CABE (2009; 2010) and Green Infrastructure North West (2010). The latter presents a vision and progress from a recent event developing GI in the Mersey River development 'belt' (Hesketh et al., 2010). They also define GI Assets, as "*particular areas of land and water, which by virtue of use, location or intrinsic value serve one or more functions of public benefit. Multifunctionality is generally desirable*." Thus there are strong links with water management in these visions and many guidance documents explicitly include SuDS (e.g. Climate East Midlands, 2010).

Guidance on the use of SuDS for planners in the UK (CIRIA, 2010) takes a 'masterplanning' approach from the Urban Design Compendium (English Partnerships & The Housing Corporation, undated & 2007) to their utilisation that includes GI: "*Open space, public realm, green infrastructure planning and opportunities for blue/green corridor links*…and… *Ecological connectivity and biodiversity strategies*." The masterplan approach whilst focused on the particular development site, also extends to the entire context of the development or change to an existing area. This is appropriate for GI planning because of the need for hubs and interconnected networks (Figure 2). The Urban Design Compendium sets out seven key aspects of urban design where each has potential for rainwater GI:

1 Places for people – safe, comfortable, distinctive and attractive places
2 Enrich the existing – the new should enrich the existing at all scales
3 Make connections – integrate places with their surroundings and make them easy to get around
4 Work with the landscape – balance between the natural and man made
5 Mix uses and forms – stimulating and enjoyable to meet a variety of uses and users
6 Manage the investment – understand an utilise the market mechanisms to maintain and preserve the development and surroundings
7 Design for change – design for changed expectations and uses in the future

As the new GI approach for stormwater management utilises non-traditional methods more akin to estate management, for example mowing, strimming, litter picking and vegetation management it is not an approach that the sewerage undertakers are familiar with and is more typical of municipal parks or landscape managers' functions; although they too might have outsourced this to specialist landscape contractors. Properly integrated rainwater GI would best be delivered by a range of different service providers including the water and sewerage utilities. Direct access to drain GI to watercourses or complete disposal of stormwater via infiltration will be limited in cities and thus there will be a need for some flow, albeit attenuated and controlled, ultimately to enter a sewer. GI would have first attenuated the flow and removed pollutants to some extent. In this situation, charges are still legitimate for the utilities and an alternative surface water charge to fund alternative management by for example, estate managers would be difficult to raise other than through municipal taxation. However, the multi-beneficial nature of GI would, if properly understood and acknowledged (or monetised), provide incentives for appropriate resourcing and expenditure for the aesthetic/amenity and community value. Although in many new developments in the more deprived parts of cities, management charges such as this are considered not to be a viable proposition.

Local Authorities in England usually refuse to adopt GI built for new developments unless there are additional sources of revenue. However, in other circumstances, for example the adoption of road infrastructure and its surroundings, very limited standards regarding the quality of the environment and GI are set because of tight budgets that constrain opportunities for GI. Street trees and grassed areas are often the only accepted features. Alternatives to this include the use of commuted sums where a developer passes a lump sum of money to a management body such as the Local Authority or a Trust to maintain the GI/SuDS. This works well for offsite or regional features but may be more complex for GI that is integrated within developments. There is also the concern over ring-fencing of such sums and lock-in by the local authority to the long-term; an often uncertain management need (WERF/UKWIR, 2005). Nevertheless such arrangements do exist, as illustrated in Figure 13 in Sheffield where new housing was constructed in a problem public area and GI based SuDS were constructed in 2006 and are functioning effectively.

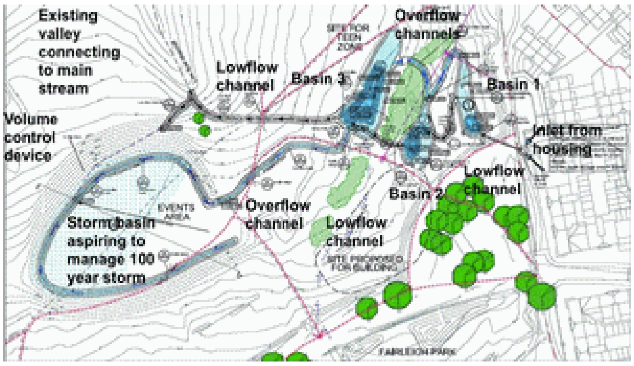


Figure 13 Manor Park wetlands in Sheffield constructed using a commuted sum arrangement (see also http://www.cabe.org.uk/case-studies/manor-and-castle-green-estate)

Private rainwater GI within the curtilage of an individual property would typically be the owner's responsibility, for example a rain garden or a swale. As a consequence, in England, there can be considerable complexity of responsibilities for different features within a rainwater GI management train – from source to regional control (Table 5). The new role of the SuDS Approval Bodies (SABs) within Lead Local Flood Authorities in England under the FWMA 2010 will in future provide detailed records of all the drainage assets within the various surface water management trains so that there will be better integration of the long-term understanding of system performance in the future.

SuDS have been legally required in Scotland for treating surface water for all new developments since 2006. New guidance is available for road drainage (SuDS working party, 2010) but sadly the latter does not mention GI, only 'green corridors'. Scottish Water is responsible for the adoption of SuDS which perform the drainage function that is their responsibility; i.e. from below ground systems (Water UK/WRc, 2007). This only includes the drainage of rainfall runoff from the curtilage of buildings generated by small storm events (up to 1 in 30 years). This leaves the responsibility for dealing with road drainage and flooding with the Local Authority. Despite leading the way in SuDS applications for several decades, the use of SuDS in Scotland is still fragmented between the various key players, with many developers using below ground systems in the expectation that Scottish Water will adopt them. Systems above ground should, if compliant, be adopted by the local authorities, but complex planning processes often lead to developers opting for below ground systems as their maintenance is guaranteed.

In order to achieve water quantity and quality management and to move the runoff to a point of discharge (e.g. a watercourse, infiltration or if all else fails, a sewer) GI can be employed in series as part of a process train (CIRIA, 2007). This can be at small scale, such as for a car park or at a larger scale for a catchment as a whole. At the individual development scale there are likely to be restrictions on discharge rate to avoid erosion of downstream watercourses and water quality requirements will become increasingly more important under the Water Framework Directive and the Daughter Directives for Groundwater and Priority Hazardous Substances (PHS). GI features deliver the management in sequence with a logical positioning dependent on typology; for example the use of large wetlands as a store of larger storm events and everyday polishing at the lower end of developments fed by flows from upstream features. CIRIA (2007) describes the suggested best sequencing of measures. Water quality demands of GI will be different for different land uses. The SuDS guidance recommends a number of treatment stages through different GI features based on approximate understanding of how they perform; for example an industrial site may require four stages of cleaning. Each stage may or may not, utilise GI with a relative effectiveness for PHS removal; a likely requirement from an industrial site.

GI linked to stormwater management can be employed on a wide (city or catchment) scale and this is where there is the greatest challenge in joining up the small scale of individual developments, GI hubs and links, with a planned infrastructure delivering joint benefits for larger areas. In SuDS these are termed regional features where for example new or daylighted/restored watercourses (CIWEM, 2009) or wetlands usually serve many developments. These large scale facilities present a particular challenge to planners and regeneration professionals to consider long-term establishment and sustainability of these features in unpredictable future change scenarios. This complexity can lead to a narrow focus of onsite management of water. GI needs to be planned and delivered in an integrated and coherent way within and across administrative boundaries. Matching this with drainage catchment boundaries as defined in the RBMPs is needed to ensure that co-planning of GI and surface water management is effective. Examples are now beginning to emerge showing how GI and water management can be planned jointly (e.g. EU, 2010).

5 Examples of Water Specific Green Infrastructure in Practice

The planned use of GI for water management takes many forms depending on the water management requirement and the opportunities available. GI can:

Address surface water management by being:

- Retrofitted into or adjacent to existing development
- Modified as part of a solution within or adjacent to existing development

- Created within new development
- Incorporated within new development

Address main river environment issues by:
- Creating new infrastructure
- Modifying existing GI

The following sections give some case studies that demonstrate the feasibility of GI approaches. The chosen case studies not only represent technical solutions for water and flood risk management, but focus on the options and strategies available to implement GI. There are different options for promoting or requiring the incorporation of GI. Many cases have financial incentives, such as subsidies, grants and tax incentives, in place to promote GI by offsetting some of the construction cost. Case examples also show how regulations may require green solutions on any new development.

In New York, public engagement plays a key role in the process of implementing GI and is intrinsic to the Blue Belt strategy. To date, the Blue Belt program has saved the City an estimated $80 million in (sewer) infrastructure costs, and saved homeowners money in prevented flood damage. In addition, property values in the immediate vicinity of the completed Blue Belt drainage corridors have consistently appreciated, also enhancing the city's tax base. They are expected to reduce the sewer management costs by a further $2.4bn over the next 20 years (City of New York, 2010). The NYC plan estimates that for every vegetated acre of GI, total economic benefits would accrue due to: reduced energy demand ($8,522/ac), reduced CO_2 emissions ($166/ac); improved air quality ($1,044/ac); increased property value ($4,725/ac) and all this in addition to reducing CSO emissions by 2 billion gallons at a cost of $1.5bn less than traditional methods (Foster et al., 2011).

Retrofitting GI is now seen as the norm in the USA (USEPA, 2008) with such examples as: 'million-tree' initiative in Los Angeles (Pincetl, 2010); a 'greener, greater New York' (City of New York, 2008; 2010; Gunther et al., 2010); 'Green Milwaukee' (Milwaukee Green Team, 2005). One of the greatest proponents, Chicago, installed more than 4.6 ha (500,000 ft^2) of green roof area in 2009 alone, with a total rising to some 65 ha (under construction, 2011) and has long had a clear agenda for using GSI and is a pioneer in green alley retrofitting (Lanyon, 2007; Foster et al., 2011). Portland (Oregon) has long been seen as a leader in GSI and invested $8M in retrofit GI to save some $250M that traditional approaches would have cost instead (Foster et al., 2011). In Portland the green streets now manage 8 billion gallons (30 million m^3), which is 40% of the total of the annual runoff. Disconnecting down pipes is alone responsible for reducing CSO peak spill volumes by some 20%. In the USA, a combined programme of retrofitting green alleys or streets, rain barrels and tree planting has been estimated to cost 3-6 times less than conventional methods in the management of surface water (Foster et al., 2011).

The approach taken in the USA encompasses a watershed to property perspective (USEPA, 2009). Many cities in North America provide direct advice to property owners (e.g. Toronto, 2010). The watershed approach is part of the National Pollutant Discharge Elimination System (NPDES) permitting process where the impacts of stormwater on water quality are controlled (DTI, 2006). At a single development or property scale, designs utilise GI approaches to comply either voluntarily (Milwaukee) or mandatorily with building codes and standards, such as LEED (US Green Building Council, 2010), the equivalent of the UK's BRE Environmental Assessment Method (BREEAM, 2010) (Prickett & Bicknell, 2010). Other approaches consider the neighbourhood or community scale and fit GI/LID into more widespread city planning (e.g. Struck et al., 2010; Gunther et al., 2010). This multi-level or varying scale approach is recognised in the USA (USEPA, 2010) where problems are addressed simultaneously at various scales using whichever is the most appropriate.

There are also examples in Europe, such as in the Emscher Region. In Berlin a Biotope/Green Area Factor (BAF) programme over the past few decades requires the use of GI with targets set based on land use type (Senate Department for Urban Development, 2011). The BAF is the ratio of areas of a site that have a positive effect on the ecosystem or an effect on the development of the biotope of a site in relation to the entire area. Commercial areas have a lower BAF (0.30) than housing (0.60) and GI can be provided by a variety of means, including green walls.

Examples are summarised below as illustrations. There are also examples throughout this ROCK that are not repeated here.

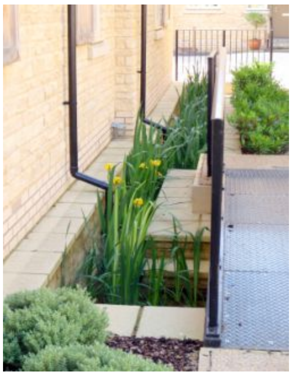
A. UK case studies

A1 Ashford, Kent

Retrofitted SuDS associated with roads and streets were included during the redevelopment of the 1970s ring road. Bioretention and other GI has been used in highway and car park areas for both new and retrofit developments. This is part of the UK 'shared space, living streets, traffic calming and home zones' ideas, providing the opportunity for GI to be introduced via the bioretention areas for water quality management of road run-off.

A2 Riverside Court, Stamford

This new development included permeable paving with subsurface flows to open linear wetland channels that provide further storage and a final polish before flows continue to an adjacent river. The use of permeable paving provides the first stage of water quantity and quality management before potential release into further storage and cleaning in GI areas. The majority of a 72 dwelling housing development's inner courtyards were constructed with permeable paving overlying voided stone, taking all runoff from roofs etc. and thence to small GI wetlands utilised as part of the GI (landscaping requirements) for the development. There is also a green exceedance flow pathway throughout the development.



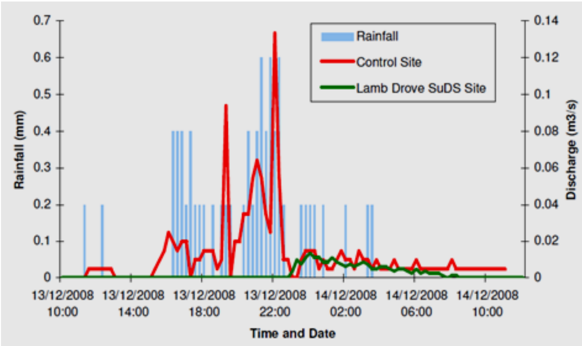
Rill and downspouts

Multifunction – learning and enjoying

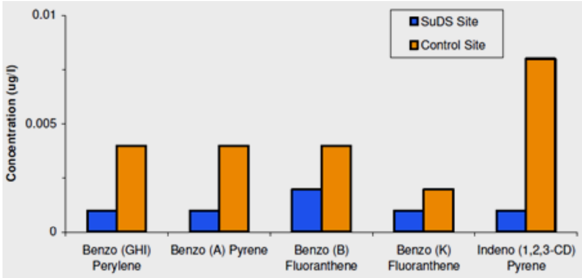
Final canal

A3 Camborne, Cambridgeshire

This comprises a complete SuDS train scheme for a new local development. It includes green roofs, water butts, swales, detention areas, permeable surfaces and a retention pond. The 35 dwelling development had already been designed using traditional concepts before a SuDS based approach to managing surface water was introduced. Planned GI was modified for water management with open spaces becoming detention areas receiving water from permeable paved areas and roofs. Linear green areas were utilised for conveyance for both low flow and exceedance flow conditions. This is one of the only SuDS monitoring programmes in the UK, it has shown that both flow quantity and quality are attenuated (Cambridgeshire County Council, 2010).



Monitoring results showing that SuDS have a beneficial effect on flow rates (control site is traditional drainage)



Monitoring results showing that SuDS have a beneficial effect on quality of runoff

A4 Springhill, Stroud

A newly built high density housing area (50 units /ha, i.e. denser than required under PPS3) with GI comprising rills, swales, green walls, pools and a pond. Ultimately the runoff, having passed through several GI stages (to regulate quality) via rills, enters a stream at the bottom of the development at greenfield runoff rates.

A5 Hopwood Services, Birmingham

This is a long standing use of GSI for car park runoff. Filter strips (typically road verges) are the first stage in a four stage cleaning process utilising the GI for the whole site for lorry park run-off. Further stages include a spillage basin, swales and wetlands (managing pollution) before entering a sensitive watercourse.

Constructed wetland

HGV filter strip and trench outfall

A6 Elvetham Heath, Hampshire

A new development covering 126 hectares: 50% residential; 15.5% Nature Reserve; 12.7% for passive open space. There is a retention pond, detention basins, swales and soakaways. The SuDS are considered as part of the public open space in the Project. The Sewerage Undertaker owns the SuDS components, maintaining the inlet and outlet structures but leasing the SuDS to the District Council for general maintenance. This allows the Council to coordinate the multi-functional use and maintenance of the GI.

A7 Greater Manchester Green Roof Programme

This is a strategic programme to retrofit green roofs to combat the effects of climate change, especially for the medium term attenuation of potential heat island problems (Climate East Midlands, 2010). Street trees and other natural micro-climate interventions were considered not to be suitable in the dense inner city. Four public buildings are pilot projects with retrofit green roofs. Bee habitats associated with the roofs were identified as a biodiversity priority.

A8 Ethelred Estate, London

Green sedum roofs at Ethelred Estate were retrofitted to apartments under renovation. The driver for this scheme was not specifically water related. Existing flat roofs were in need of replacement and the opportunity was taken to install green roofs to help promote sustainability in construction locally. Sedum roofs are expected to provide biodiversity benefits; though not as much as an intensive green roof. The entire refurbishment was occupant driven.

Before retrofit

After retrofit

A9 Re-Blackpool

A retrofit to upgrade the highway locally, remodelling existing car parking with landscaping and environmental improvements, traffic and pedestrian management improvements and a new external plaza and pedestrian crossing. Slotted kerb with a proprietary filter system is used to collect the storm flows from the highway. The treated surface runoff is then fed to rings of Permafoam modular crates with a hydrophilic material that absorbs water and releases it on demand. These are connected to wicking textile lined tree pits that irrigate the trees lining the road.

A10 Upton, Northampton

A major housing development that has used linked green corridors, primarily swales and local SuDS/GI features. It was planned in partnership with the residents and stakeholders took part in a week long 'enquiry by design' workshop leading to the final Upton Urban Framework. The parks and open spaces were designed to be amenities.

B. International case studies

B1 USA: Portland, Oregon

There are multiple green streets projects in Portland. The City of Portland's commitment to promote a more natural approach to urban stormwater management is well advanced with many examples. The one shown here is the winner of the 2006 American Society of Landscape Architects General Design Award of Honor and is located at SW 12th Avenue Green Street Project, Portland, Oregon. This was awarded because special attention was given to the multiple use of the street. A 1 m wide parking egress zone was dedicated for people to access their vehicles without competing with the stormwater planters. Perpendicular pathways were located between each stormwater planter so that a pedestrian would not have to walk very far to access their cars or the sidewalk. There is also a 10 cm kerb exposure at each planter to help indicate to the pedestrian that there is a drop in grade. Each kerb cut allowing the street runoff to enter the stormwater planters has an accessible grate to allow for unhindered pedestrian passage along the parking egress zone.

B2 Germany: Kronsberg, Hannover

Very little of the runoff from this high density social housing area on the outskirts of Hannover outflows into the regional ponds at the outlet. It is detained in trench-trough systems; evaporated in swales (even with clay soil) and detained in small ponds. There has been no vandalism in the more than 10 years that the system has been in operation.

B3 Australia: Little Stringybark Creek, Victoria

This is a community centred programme to gradually disconnect the entire community from the stormwater piped drainage system by retrofitting (there are financial incentives) GI and rainwater tanks (which also reduce mains water use). Home owners can sign up to disconnect via an interactive web-based online calculator. One picture shows a rain garden retrofitted to a property the other shows an online disconnection newsletter. The aim is to prevent excess flow to Little Stringybark Creek http://www.urbanstreams.unimelb.edu.au/.

B4 Australia: Melbourne

There is an ongoing greening redevelopment of areas and as part of this the retrofitting of 10,000 rain gardens by Melbourne Water in the city. A wide variety of rain gardens are being retrofitted with the multiple aim of providing treatment to the runoff into Port Philip Bay, greening the city and in some cases providing an alternative source of water with the city seen as a water supply catchment. The pictures show the prize winning Melbourne rain garden in 2010 and a more typical rain garden.

B5 Sweden: Malmö

The Augustenberg development and Tygelsjö Eco-corridor are some of the first ever retrofits with the whole range of SuDS being used in consultation with the local community to regenerate a lower income area of the city (Stahre, 2008). Malmö's sustainable drainage and regional eco-corridors use water, green and art in combination to create exciting interactive and liveable areas. It is one of the world’s pathfinder developments in use of GI at local and regional scale. The pictures show a green corridor (link) and a local area (node).

B6 USA: New York

New York has an ambitious combined green streets, green roofs, and urban trees programme, with stormwater source control GI. So far some 2460 green streets have been retrofitted. The million tree campaign, is planting a million trees to increase the City’s canopy cover from 24% to 30% by 2030. Bioswales are used to provide conveyance as well as storage to support a range of plant types in the longer green streets. Hardy plant species are used that tolerate drought, inundation, as well as high saline conditions. Volunteers are installing more than 90% of the trees planted in reforestation sites and a Stewardship Corps has been set up to focus on volunteer efforts. The Parks Department is attempting to start both a Natural Areas Conservancy and a Green Street Conservancy as a fundraising and advocacy mechanism for all the green work being done in the city. The Million Tree campaign has raised money to hire trainees to work on the programs while training each individual for a" green" career. The pictures show a greened derelict area and the 'High Line', a converted freight railroad that was derelict for more than 20 years.

B7 Canada: Toronto

Many green roofs and non-piped drainage systems have been retrofitted across the city. A green roof byelaw required green roofs on all new commercial, institutional and residential development with floor area of 2,000m^2 or more from January 2010. From January 2011, the Byelaw requires green roofs on new industrial development. It is also compulsory for all properties to disconnect from the main drainage system.

B8 USA: Seattle

As outlined in the report Seattle Public Utilities has a policy of GSI, with development incentives. Examples across the City include SEA streets and a wide variety of types of BMPs, but with the emphasis on using green surface based systems.

6 Conclusions and a Way Forward

Water in urban areas is often seen as more of a threat than as a potential benefit or opportunity. The summer of 2007 left a legacy of concern in England and Wales that flooding could happen anywhere at any time and this is fuelled by recent estimates that one property in five is at risk of flooding in England and Wales (Defra, 2010b). Floods in Cumbria in November 2009 reinforced these fears. Yet water is a vital and essential component of healthy, vibrant and functioning ecosystems, no less in urban areas than in rural areas. Surface water also contributes to the quality of our visual environment and to making places more attractive especially through vital ecosystems, many of which provide ‘green’ landscapes. Such place making should be an essential ingredient of urban areas enjoyed by those who live and work there (CABE, 2010).

In GI, blue and green infrastructure is combined in the use of natural processes for the management of surface water. Design of such infrastructure needs to go beyond conventional rating systems such as BREEAM (2010) which are not sufficiently comprehensive to deal with the multi-scale perspectives of environmental design issues (Yeang, 2010). New visions and ideas are emerging although no truly green neighbourhood or city yet exists in the UK, despite having been proved in many countries and GI and the co-management of stormwater being viewed synonymously as providing multi-functional value and benefits. Appropriate capacity building is required amongst all of the professions involved, including the better education of engineers, landscape architects, urban designers and planners that should begin at academic institutions, i.e. GI needs to be added into syllabi. Not only is this required for professionals, but also for those who will build, operate and maintain GSI. ‘Green collar workers’ need to be trained to appreciate the duality of functioning needs of green and stormwater GSI.

In England, the flooding in 2007 prompted policy makers to change practices via the FWMA 2010 and associated regulations. However, these initiatives have so far failed to recognise the potential multi-functional value of GSI. The forthcoming National SuDS Standards will emphasise only the water quantity and quality aspects of using SuDS for surface water drainage; not realising that it is actually much cheaper and more resilient to link GI with surface water management and that this has greater benefits to society as a whole as multi-value GSI. Doing this in policy and guidance is seen by policy makers as ‘just too difficult’. Perhaps allowing a missed opportunity to pass is the easy option, but at what overall cost? In April 2011 the UK parliamentary cross-party Environment, Food and Rural Affairs Committee urged Ministers to set out the justification for Defra's view that SuDS can have only a limited role in reducing wastewater in London and called for Defra to undertake further work on how increase the use of SuDS nationally.

At both the small and large scale, the known multiple benefits of using GI will become more apparent in future as economic constraints will eventually force decision makers to look for ways of getting more value from investments. This will inevitably change the way in which developments are laid out in future, with blue and green features being as, if not more, important than the road layout. There is really no alternative to using GI for stormwater management because traditional approaches (using hard engineered infrastructure such as piped drainage systems) are recognised to be inadequate to cope with the changing external stresses such as climate without incurring excessive costs (Ofwat, 2007). GI can provide many additional benefits in urban areas that have been discussed in this ROCK. GI based systems are inherently more flexible; hence adaptable, resilient and able to cope with uncertainties (Sieker et al., 2008; Peters et al., 2011). GI provides many opportunities including biodiversity, visual amenity, recreation and heat stress alleviation in urban areas.

This ROCK has shown that the use of GI as a main option for managing surface water in urban areas to provide multiple benefits is a real and practical opportunity. There is a need for greater rigour in the process of planning that takes better advantage of GI benefits. It is essential that in the future the benefits that rely on spatial planning at different scales are promoted as early as possible in discussions about development proposals. There is evidence, which is being recognised increasingly, concerning monetising the potential multi-value of GI, for example Green Infrastructure North West (2011), where the online calculator can provide estimates of the added financial value of using GI. In the USA, an earlier initiative has shown how using GI instead of a large sewer storage tunnel to control CSOs, can add almost $3bn in extra value to the management of the City’s stormwater. Realisation of such added value is hindered in England and Wales by the fragmented management of the urban water system, which restricts the ability of the various players to co-fund across their respective statutory duty areas (MWH, 2011).

The challenge will be how to implement rainwater GI within the constraints of existing urban areas (Ashley & Nowell, 2010). If we are to rely on the turnover in the normal building and development process it would take more than 50 years to adapt the urban environment. This is too slow for the challenges we now face like climate change (White, 2008). There is no time to delay in implementing GI for source control of rainwater. An incremental process of not too gradual adaptation is therefore likely to provide the best option allowing an evolution towards a more resilient system comprising multi-use and multi-value GI and SuDS. This will require a portfolio of approaches (Evans et al., 2004) including the use of engineered systems where these are the most resilient, together with an innovative, experimental and learning-by-doing approach led by visionaries (Schön, 1963; MWH, 2011).

A story that John F. Kennedy (35th US president 1961-1963) is reputed to have liked to cite is particularly apposite:

“The great French Marshall Lyautey once asked his gardener to plant a tree [to shade his troops]. The gardener objected that the tree was slow growing and would not reach maturity for 100 years. The Marshall replied, 'In that case, there is no time to lose; plant it this afternoon!'”

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