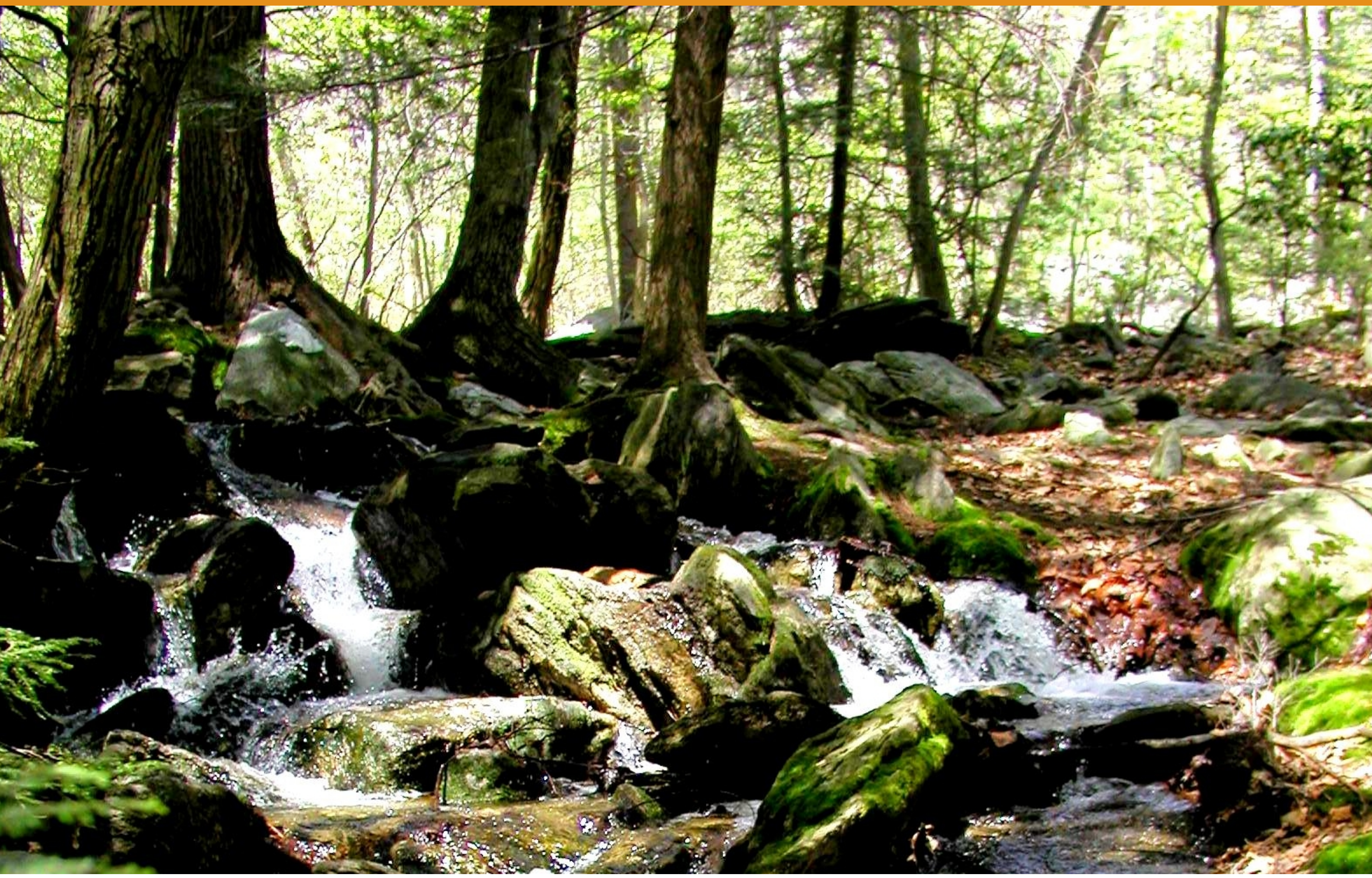
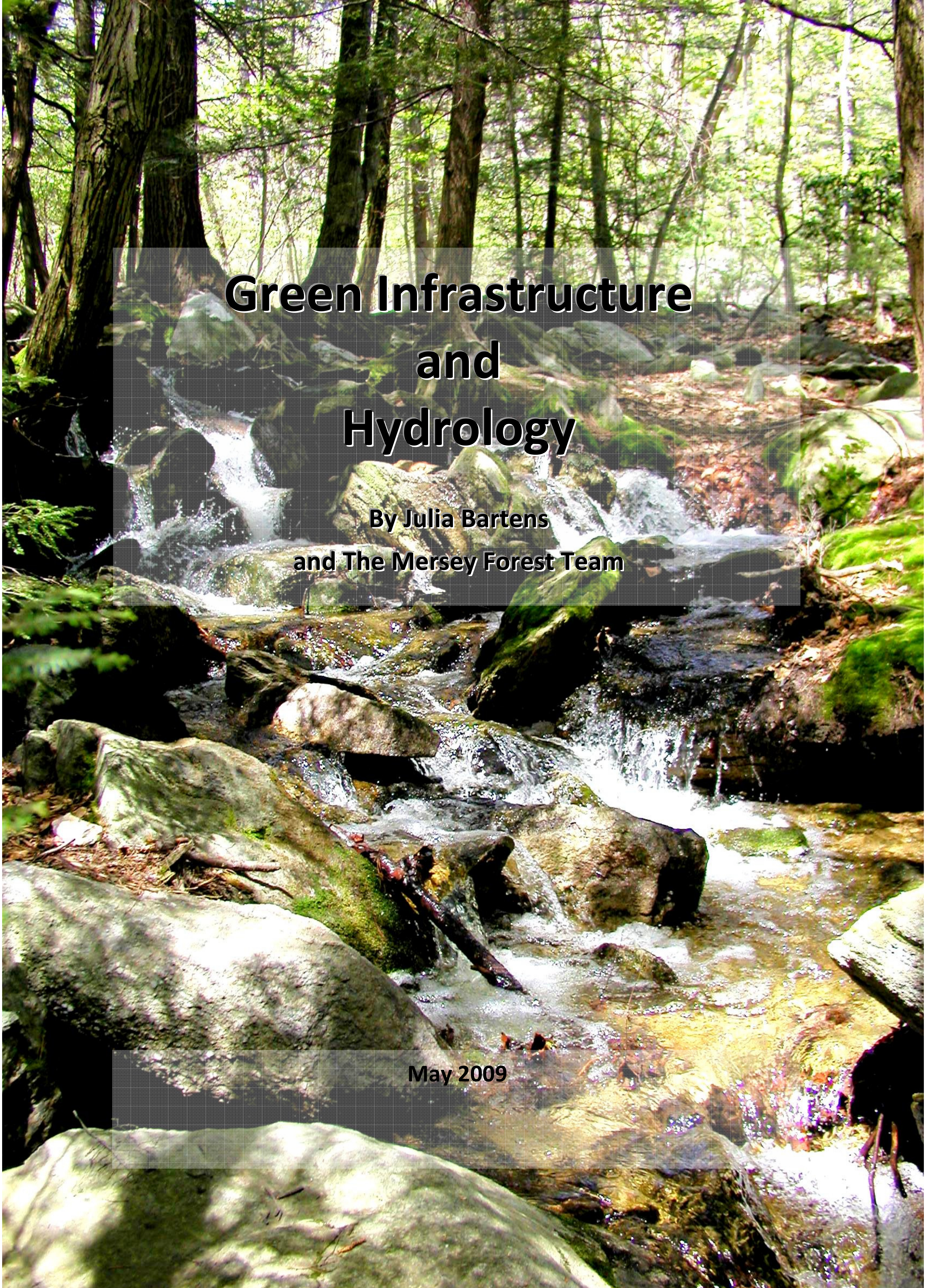
GREEN INFRASTRUCTURE AND HYDROLOGY





Green Infrastructure and Hydrology

By Julia Bartens

and The Mersey Forest Team

May 2009

With much appreciated help from:

Andrew Murcott
Clive Gaskell
Ian Douglas
John Handley
John Packman
John Thompson
Karen Potter
Malcolm Barton
Mark Robinson
Matt Ellis
Mike Savage
Paul Nolan
Peter Woods
Susannah Gill
Tom Butlin
The Mersey Forest Team
And others

Front Image: www.c4aqe.org/images/tumbling_run_5_2002.JPG

Table of Contents

Table of Contents 1

Figures 3

Tables 3

Abstract 4

Climate Change 4

Flood Facts 7

Hydrologic Benefits of Green Infrastructure (GI) 9

Policies Concerning Hydrology Issues 11

- Statutory 11
- Non-Statutory 14

Responsibilities 16

Practical Opportunities 19

- Sustainable Urban Drainage Systems (SUDS) 19
  - Planning Process and Design 20
  - SUDS incorporating vegetation 21
  - SUDS without vegetation 22
  - SUDS with or without vegetation 23
  - Other sustainable water management techniques 23
- Practical examples of implemented GI for water management purposes 23
  - SUDS train within an inner city suburb of Malmö, Sweden 23
  - West Garforth in West Yorkshire [33] 25
  - The Lower Irwell Valley in Salford [34] 26
  - Weaver Valley [35] 28
  - Watershed Forestry [36] 29
  - Flood risk through upland land management [18] 30

Flood and GI mapping 31

- Mapping of critical GI: 39

Examples of Current Modelling/Mapping Approaches 41

Problems and Opportunities 42

Conclusion 43

References 45

Appendix A Environment Agency Planning Framework 47
Appendix B SUDS Fact sheets 48
SUDS incorporating vegetation 48
SUDS without vegetation.. 56
SUDS with or without vegetation... 60
SUDS with or without vegetation... 60
Appendix C Species adapted to particularly wet sites 64
Appendix C Proposed future roles and responsibilities for flood and coastal erosion risk management in England (Flood and Water Management Bill Draft, 2008) 66

Figures

Figure 1) Percentage change in temperature from 1961-2006; winter, spring , summer, fall (left to right) [4] ... 4

Figure 2) Percentage change in total precipitation from 1961-2006; winter, spring , summer, fall (left to right) [4] ... 5

Figure 3) Percentage change in total annual precipitation amount between 1961-1990 and 1971-2000 [4] ... 6

Figure 4) Change in days of rain ≥ 1 mm from 1961-2006 based on a linear trend for, winter, spring, summer, fall (left to right) [4] ... 6

Figure 5) Change in sea-level pressure (hPa) from 1961 to 2006 based on a linear trend; winter, spring, summer, fall (left to right) [4] ... 7

Figure 6) Effects of natural and impervious surfaces on the hydrology cycle (Source: FISRWG, 1998, fig. 3.21) ... 8

Figure 7) peak stream flows before and after urbanization (Christopherson, 1997 in [7]) ... 9

Figure 8) Policies involved with flood water management ... 16

Figure 9) SUDS train installed in inner city suburb of Malmö, Sweden ... 24

Figure 10) IUD pilot project locations within the North West as part of Defra's Making Space for Water Urban Flood Risk & Integrated Drainage, IUD, (HA2) program. ... 25

Figure 11) West Garforth's drainage structure ... 25

Figure 12) River Irwell floodplain showing flood depth in meters (including allowance for climate change) ... 27

Figure 13) Sewer flood risk (left) and flood risk zones and UU sewer flood data (right). ... 28

Tables

Table 1) Number of development applications objected by the EA compared to those permitted by LPAs contrary to EA advice ... 14

Table 2) Possible solutions suggested by the project undertakers of the West Garforth IUD project ... 26

Table 3) Identified GI types ... 31

Table 4) Identified hydrological functions of GI regarding ... 31

Table 5) Definitions for GI functions ... 32

Table 8) GI functions, its means and the data required to map the function. ... 39

Abstract

This paper aims to give an overview of the organizations/entities and policies involved in green infrastructure and/or water management. This overview covers related policies on European, national, regional, sub-regional and local level, including statutory as well as non-statutory documents. This document aims to clarify the functions and importance of green infrastructure regarding water management to give more information on the potential GI has to help us adapt to water issues, mainly flooding. In addition, this work will identify data and information needed to adequately map flood risk areas including all sources of flooding such as fluvial, pluvial, and coastal flooding. This will help to identify the areas in which GI is most critical to be included. Understanding flood risk and the entities and policies involved in water issues is essential to be able to know where GI should be implemented and what is needed to realize it.

Climate Change

Global warming and therewith the frequency and magnitude of flood events is increasing. One of the main causes is human behaviour. Anthropogenic emission of greenhouse gases into the atmosphere has been identified as the main reason for climate changes at their current rate. Climate change results in a total increase of temperatures of 0.74^{o}C between 1906 and 2005. However, in the past 50 years temperatures increased by 0.13^{o}C per decade leading to the assumption that global warming is getting faster as time goes by. Temperatures have been estimated to rise by up to 3^{o}C by year 2050. Looking at the temperature changes by season (Figure 1) it can be seen that especially winter and summer temperatures are increasing but spring and fall temperatures as well. The greatest temperature changes occur in the southern part of the country with up to 2.8^{o}C average temperature increase but all parts of the country are experiencing temperature increases. Besides these temperature changes, effects of global warming are rising sea levels, hot spells and droughts during the summer, heavy rains, tropical cyclones in the North Atlantic, more precipitation during fall, winter and spring and less winter snowfall [1-3].

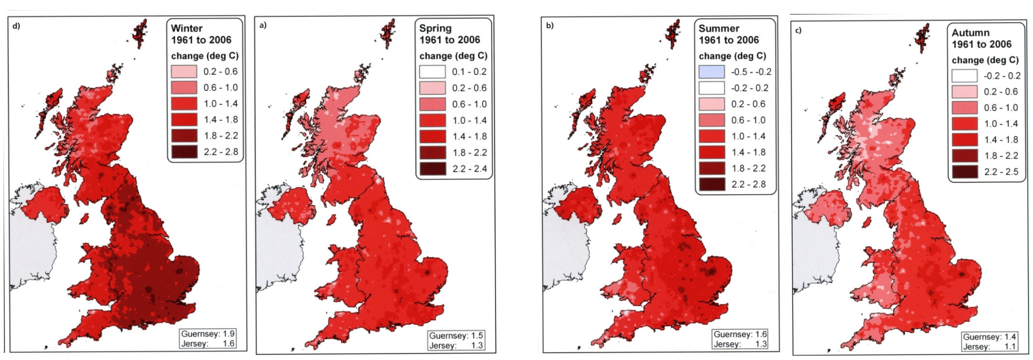


Figure 1) Percentage change in temperature from 1961-2006; winter, spring , summer, fall (left to right) [4]

In regards to precipitations the prognosis is that summers will be up to 40% drier and winters up to 25% wetter in the UK [2]. Looking at it in more detail (Figure 2), the North of the UK will experience an increase in winter precipitation of up to 215% whereas the south, depending on the particular region, may experience increases by only 50% or even decreases by up to 10%. Spring will become drier in the South (up to 25%) but wetter in the North (up to 50%) of the country. The summer generally gets drier by up to 25-50%, except some areas in the North West and South East of the country, whereas the fall season except for some small areas in the North of England, Ireland and northern Scotland will become a wetter season for the entire country by up to 50-100%.

However, it cannot necessarily be said that total annual precipitation will increase or decrease (Figure 3) but the distribution will change which may lead to more rainfall events with greater magnitude over shorter periods of time. Generally, it can be said that change in days of rain (Figure 4) increases during fall and winter. Winter rain days increase predominantly in the North of the UK with up to 18 more rainy days. During fall days of rain increase in the South by up to 8 and decrease in the far North by up to 8 days. During spring days of rain decrease in the South by up to 8 and slightly increase in the North by up to 8 days whereas in the summer change in days of rain decrease in most parts of the country by up to 8. This means that annually days of rain decrease in the South (where temperature increases are most severe) and increase in the North.

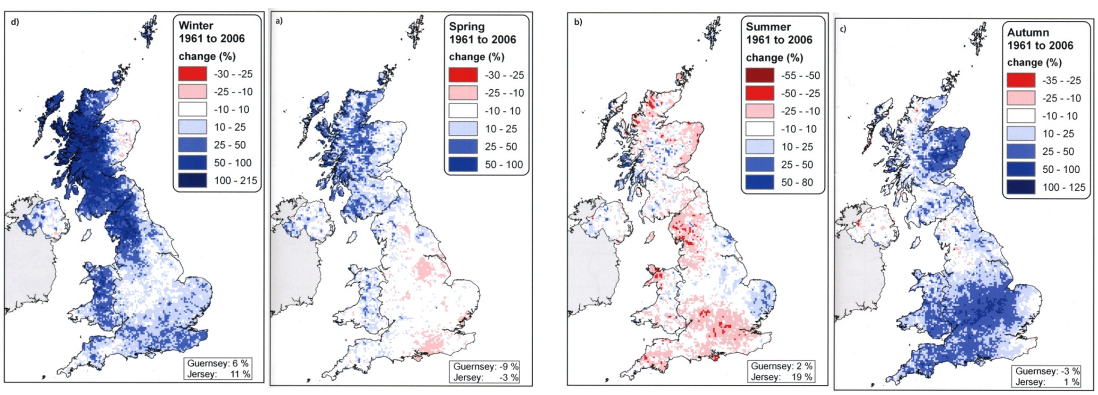


Figure 2) Percentage change in total precipitation from 1961-2006; winter, spring , summer, fall (left to right) [4]

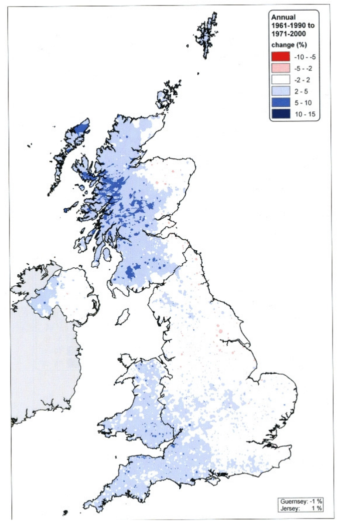


Figure 3) Percentage change in total annual precipitation amount between 1961-1990 and 1971-2000 [4]

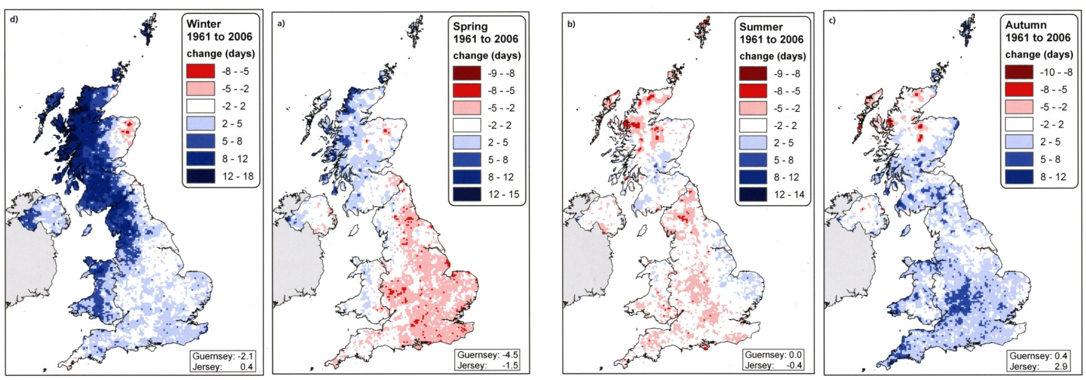


Figure 4) Change in days of rain ≥ 1 mm from 1961-2006 based on a linear trend for, winter, spring, summer, fall (left to right) [4]

Concerning sea levels a rise of up to 36 cm is estimated by 2050s. However, this is an average value. It has been calculated that in the UK vertical changes will occur due to moving of land in response to the melting of the ice-sheets following the end of the last ice age. This will result in the sinking of the South and rising of the North so regional sea level rises may vary greatly [2, 4]. This will result in no change or decreases (up to 2.8 hPa) in sea level pressure for winter and spring months in the North of the UK but increases in sea level pressure of up to 3.9 hPa in the South West during the winter and 1.1 hPa in the spring. There will be decreases in sea level pressure during the summer months (up to 0.9 hPa) and for the fall season (up to 2.0 hPa) for all the UK (Figure 5).

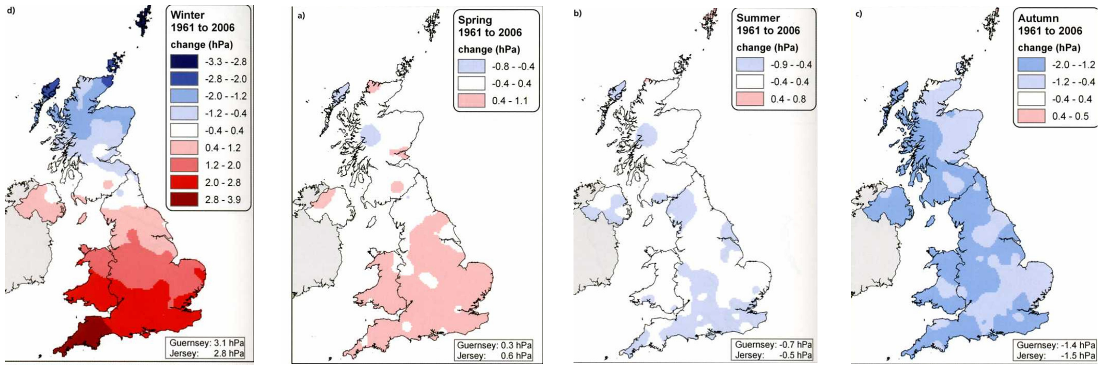


Figure 5) Change in sea-level pressure (hPa) from 1961 to 2006 based on a linear trend; winter, spring, summer, fall (left to right) [4]

In summary, temperatures will increase in winter and summer with more extreme/hazardous summer heat waves. Winters will become wetter with more days of rain and more volume of precipitation. This can lead to an increased flood risk by up to 200% [5]. Summers will become drier with less rain on fewer days. Sea level pressure will be higher during winter month which is the same period during which heavier rainfalls are expected. The North of the country is expected to rise while the South is expected to sink leading to the conclusion that flood events may occur in every part of the country, in some parts coastal flooding may present a bigger risk and it some areas it may be fluvial or pluvial floods. All these climate changes make foresighted stormwater management very important for generally all parts of the country.

Flood Facts

The increase in sea levels and the greater frequency and magnitude of heavy rainfalls result in higher probabilities of flood events. Other direct anthropogenic effects on flood events are ageing drainage infrastructure and the sealing of surfaces with pavements and buildings [5]. Impervious surfaces prevent water from infiltrating into the ground. In natural habitats surfaces are mostly pervious although to different degrees. For example, bare clayey soils are generally less pervious than vegetated soils with high organic matter contents. Even though pervious surfaces may produce some runoff during heavy down pours they generally are pervious and rainwater can infiltrate into the ground where it occurs. Paved surfaces are generally impervious and increase the amount of runoff that needs to be managed (Figure 6) by up to 10 times that of green fields [6]. The combination of increased heavy rain events and an increase of impervious surface increases the risk of flooding even more because rivers, sewer systems and flood defences have to cope with more water than they may have been designed for. This may be the result of short-sighted planning in the past. It was thought to be the most efficient and/or effective solution for stormwater management to bring stormwater out of urban areas. Water would reach stormwater sewers (separate or combined) and eventually reach streams and rivers. If a combined sewer system is in place then runoff is combined with household waste water and transported to a treatment plant before released to any waterway. This seems to be the environmentally friendlier system as all waters are treated before being released. However, in case of significantly heavy rain water volume may exceed the capacity of the combined sewer system and excess water is being released to waterways. This excess water is an untreated mixture of storm water and sanitary waste and therefore causes water pollution. Compared to the combined sewer the separate sewer is designed to only collect and transport household wastewater to the treatment plant; runoff is directly led to waterways [7]. This results in increased peak flows (Figure 7) and flushy rivers and streams which again lead to stream bank erosion, sediment deposition and habitat destruction. In addition, the stormwater is not gone. The flooding event may just not happen where it occurs in the urban area but somewhere else down stream. This may be another urban area that now has to deal with the stormwater. About 10% of houses in England are built on a floodplain and since the year 2000 11% of new homes have been built in flood hazard areas [2]. The increase in heavy rain events and increase in impervious surface and therefore runoff makes the location of a particular house or (new) development ever more important. In regards to the 2007 flood events it has been determined that approximately 25% of the flooded houses where build within the past 25 years. Even if no more houses are being build in flood risk areas the effects of climate change on flood events are likely to increase costs resulting from flood damage to properties. A report by Foresight estimates an increase in average costs of damages of flooding and coastal erosion to be as low as £1.4 billion and up to £27 billion a per by 2080. These costs however could be decreased by 40-70% through adequate risk management [8].

The facts that many houses are and are likely to be build in flood risk areas and that resulting costs are high but likely to increase through flood damage let one conclude that more rigorous measures have to be taken to avoid an increase in flooded properties in the future that could be avoided. One way would be to avoid developments in high flood risk areas/floodplains all together to avoid flooding of these new build houses and the effects that sealing these surfaces has on other properties “downstream”. For the same reason, one mitigative way that many home owners could implement is the avoidance of impermeable surfaces in yards and gardens. These are just two examples of recommendation that came out of the Pitt Review [2] from 2007.

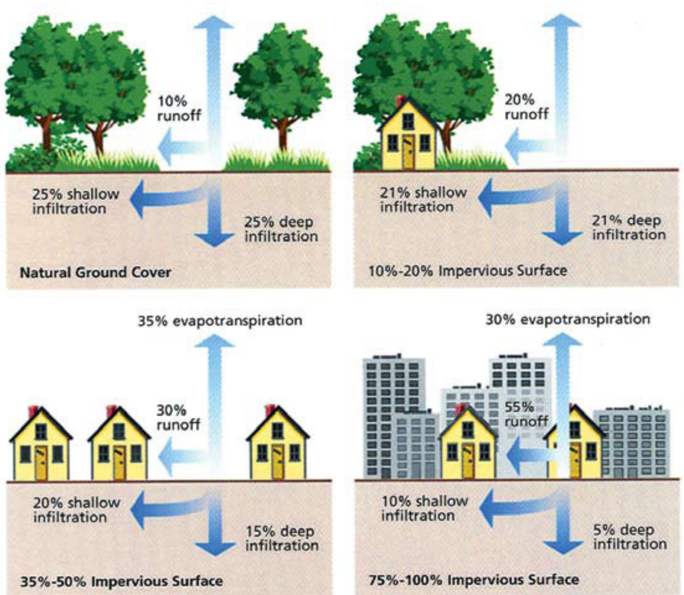


Figure 6) Effects of natural and impervious surfaces on the hydrology cycle (Source: FISRWG, 1998, fig. 3.21)

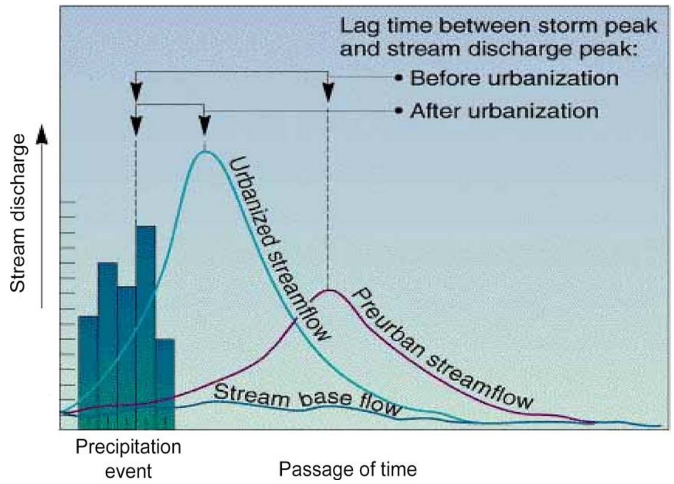


Figure 7) peak stream flows before and after urbanization (Christopherson, 1997 in [7])

Hydrologic Benefits of Green Infrastructure (GI)

Planning policies, such as PPS 1 and PPS 25 (see section below) are meant to ensure sustainable developments, taking flooding into account and incorporating climate change. These statutory planning policies suggest green infrastructure (GI) as a means to adapt to effects of climate change in regards to flooding, biodiversity, urban cooling, renewable energy and noise and light pollution. Generally, GI are all green and blue surfaces and 'non-surfaces' such as single trees which cannot be describes as surfaces. Green and blue surfaces are grass surfaces/meadows, woodlands, wetlands, parks, yards, agricultural fields, rivers, ponds and others. As mentioned one aspect of GI is flood adaptation.

The main **benefits of GI** regarding hydrology are rainfall interception, increased soil infiltration, water uptake, water storage and delaying & decreasing peak flows all of which decrease the volume of water that requires management. In more detail, depending on size and species, big trees have the potential to intercept 80% of precipitation where smaller trees may only have 16% rainfall interception [9]. Generally conifers intercept more water than broadleaved trees with extreme differences during the dormant season when broadleaved trees are leafless. In this time period they intercept only between 10 and 30% of their potential when in leaf [10]. Vegetation also increases the infiltration rate of soils through roots and the turnover of roots. Research has found that root growth by for example trees can increase the infiltration rate of soils by a factor of 2-17 [11]. Bartens et al. found an increase in subsoil infiltration rate through tree roots by up to 153% [12] and Calder at al [10] found that infiltration rates increase by 90% within two years after converting a grazed pasture into woodlands. Besides increasing the infiltration rate of the soil and therefore removing water from the surface and possible runoff from other surfaces vegetation also removes water through water up take. Generally, shorter vegetation, such as grasses, take up less water than trees and woodlands because trees have deeper roots which help trees to cope with droughts. Annual water uptake by woodlands, depending on the type, have been described to be between 300 and 410 mm [10]. Research shows transpiration rates of about 40,000 L per summer for a large deciduous tree or about 300 L per day [13]. Hinkley at al. [14] determined the water use of hybrid poplar stands, with trees ranging in size between 11 to 15 m in height (8 to 15 cm in diameter). They found water use of 20 to 26 kg/day for the smallest and 39 to 51 kg/day for the largest tree. Cermák et al. state 65-140 L per summer day for mature apple trees [15], which agrees with the findings of Meinzer et al. [16] for various tropical angiosperm species and Simpson [17] for Douglas-fir. Meinzer at al. determined water uptake to be 200 kg/day for trees with 60 cm stem diameter, whereas Simpson found water use of Douglas-fir with 70 cm diameter stem to be 166 kg/day. Therefore, factors, such as species, size, leaf area, and location influence the water use of trees. In regards to water storage it is obvious that ponds, rivers and wetlands can store water depending on their width and depth. However, areas such as football fields within a floodplain have the potential to temporarily store stormwater until it fully infiltrates into the ground and therefore prevent flooding of homes and other valuable estate.

Research on upland pastures has shown that shelter trees and complete afforestation can decrease peak flow by 20 and 60%, respectively [18]. Thomas and Nisbet simulated the effect of woodlands on flood events of a 2.2 km reach of a river and found that woodlands increased water storage of the catchment by up to 71% while delaying peak flows by up to 140 minutes. Woody debris and live vegetation generally increase the effect as it increases the roughness of the catchment surface therefore decrease the flow rate of the water resulting in lower and later, peak discharge [19]. However, it needs to be taken into account that with increasing vegetation water levels will be increased as the volume capacity of the catchment will be party taken up by this vegetation. This increased water level and the delayed peak flows need to be considered as they may lead to backing up of water upstream and thus damages to properties if not taken into account.

Sustainable urban drainage systems (SUDS) have been developed to improve urban drainage and therefore reduce the volume of urban runoff. There are various systems some of which provide infiltration and some don't. Swales, infiltration trenches and basins and detention ponds were developed to capture water when needed and encourage its infiltration into the ground. These systems however can be implemented with a liner to avoid infiltration for example at polluted sites. In this case water will be treated and directed to another facility and may infiltrate into the ground after filtering treatment. Some systems are developed for water storage which then can be reused such as water butts and water storage facilities below ground. These systems do not require a large as ponds may do. Rainwater harvesting systems have been developed to capture and store rainwater and to reuse this water instead of mains water to flush the toilet or even run the washing machine. There are various systems available that suit virtually every site. More detailed information is in the following section and in Appendix B.

Summarizing can be said that green infrastructure has great potential to decrease the volume of stormwater needing management at all levels. Rainfall interception, mainly by trees, reduces the amount of water reaching the ground. Increased infiltration of soils through root growth and root turnover increases the rate at which water is relocated from the surface to the subsoil/groundwater. Vegetation removes water from the ground through transpiration and therefore increases the capacity of the soil to store water. Finally the remaining stormwater can be stored in ponds, wetlands and other open spaces within the floodplain and prevent damages to homes and other properties. Tree species adapted to wet/moist soil conditions can be found in Appendix C.

However, one of the difficulties regarding stormwater management appears to be that the function of green infrastructure is seen to be unclear and therefore developers may lean towards engineered stormwater management solutions whose capacity and efficiency can be calculated with confidence. In addition, the general issue of developments and stormwater management it is not overseen by one single organization or entity but rather split between the EA, local authorities (LAs) and water companies which makes smart and sustainable planning and implementation of stormwater management solutions difficult/virtually impossible.

Policies Concerning Hydrology Issues (Fig. 5)

Statutory

The highest level of statutory policies covered here is the European level. The EU Water Framework Directive (WFD) and the European Directive on the Assessment and Management of Flood Risk (aka Floods Directive) are the main ones to be mentioned. The Water Framework Directive has the goal to achieve good ecological and chemical status for all waters within the EU through management plans at a catchment level by 2015. To reach this goal the following five priorities have been established: 1) Water knows no frontiers. Especially large catchments can extent over multiple countries. Therefore, the WFD stipulates that the concerned member states develop a common management plan involving local, regional and national authorities. 2) Water concerns us all. Since we all use it we all need to use our knowledge on how we impact water quality and quantity to change our behaviour to a more responsible and sustainable way. 3) Water is a fragile resource. Urbanization, agriculture, and other human activities impair water bodies by inducing pollutants or even just changing water quantities. This makes the conservation of ground water resources even more important. 4) Water at a price. Although the WFD supports basic supply accessible for everyone it also supports that charging policies should be established by every member state which should be based on the 'polluter pays' principle. This gives an incentive for a more rational and sustainable usage of water resources. Currently the daily consumption for Europeans is 200 litres, whereas North Americans use 600 litres per person per day. The identified minimum quantity of water that should be provided for human consumption is 20 litres. This shows that there is great room for a more conservative water usage. 5) Integrated and supplementary. The WFD needs to be linked to all other related legislations because WFD's goals can only be reached if participates [20].

The second mentioned policy at European level is the Floods Directive. It aims to reduce and manage flood-related risks to human health, the environment, and economic assets. It states that flood risk management plans should take areas into account that have the potential to retain water such as natural floodplains. It notes that elements of flood risk management plans should be periodically reviewed and if necessary updated, taking into account the likely impacts of climate change on the occurrence of floods [21].

On national level Building Regulations and Planning Policy Statements by 'Communities and Local Governments' are the main documents. Building Regulations set procedural regulations and technical requirements. Parts of the regulation concern site preparation & resistance to moisture (part C), drainage and waste disposal (part H) and conservation of fuel and power (part L). In more detail, part C3 focuses on the providence of subsoil drainage to avoid passage of ground water to the interior of the building and damage to the fabric of the building. Part H3 is in regards to rainwater drainage and states that “systems that carry water from the roof of a building to a sewer, soakaway, or some other suitable rainwater outfall shall be adequate" [22]. Here, it is recommended to give preference to SUDS rather then traditional piped drainage systems [6] but GI, which oftentimes is incorporated in SUDS, and climate change are not mentioned.

The Planning Policy Statements (PPS) concerning water issues are mainly PPS25: Development and Flood Risk and PPS1: Delivering Sustainable Developments with its supplemental planning policy ‘Planning and climate change’. PPS25 gives guidance to ensure that flood risk is taken into account at all stages of a planning process. It is the document that makes the Environment Agency statutory consultee for all new developments in areas at risk. PPS25 expects that local authorities apply risk-based approaches to the preparation of development plans with key planning objectives being risk appraisal, risk management and risk reduction. This should be done in partnership with the EA. PPS25 requires that all new developments are assessed for flood risk from all sources, including flooding form sewers and groundwater. It supports the restriction and reduction of runoff and encourages the use of sustainable urban drainage systems (SUDS). Besides benefits for stormwater management purposes the policy recognizes the potential that SUDS have when it comes to amenity and wildlife [23].

PPS 1: Development and Flood risk and its supplemental document ‘Planning and Climate Change’ sets out overarching planning policies on the delivery of sustainable development. Included in this policy are mitigation/adaptation to climate change, protection of biodiversity, soil, air and groundwater with support of the ‘polluter pays’ principle. Key principles of this document are that regional and local planning bodies should ensure sustainable developments build for a lifetime, not short term, by addressing causes and impacts of climate change, protecting and enhancing the natural and historic environment and by protecting landscapes, wildlife habitat and natural resources [24]. The PPS1 supplemental document ‘Planning and Climate Change’ sets out how planning should contribute to reducing emissions and stabilizing climate change and states that the unavoidable consequences of climate change need to be taken into account. It acknowledges that climate change is happening and that man-made emissions are its main cause. It states that the effects of climate change are far reaching and that it is important to shape sustainable, resilient, and appropriate communities. In addition it says that policies should promote not restrict renewable and low-carbon energy and supporting infrastructure and that planning policies should support innovation and investments in sustainable buildings [25].

Government statements such as ‘Making Space for Water’ [26] are not statutory but are likely to be included in statutory documents. This document by Defra has a holistic approach to managing floods and coastal erosion acknowledging the importance of information transparency and availability including effects of climate change, sources and consequences of flooding and incorporating more natural solutions for flood adaptation such as wetlands, river restoration and coastal realignments. This document seems to be widely used e.g. for Catchment Flood Risk Management Plans from the Environment Agency which are taken into account by Regional Spatial Planning and other statutory policies and vice versa.

Regional Spatial Planning develops Regional Spatial Strategies (RSS) and Regional Flood Risk Appraisals (RFRA) and follows the PPS25. RSS is prepared by the (English) Regional Assembly which includes members of country and district councils, unitary authorities and appointees from other regional interest groups [6]. In the North West RSS used to be prepared by the NWRA until it ceased to exist in 2008 and the new North West Leaders Forum 4NW was introduced. Generally, the RSS represents the vision on how the area should look like long-term and gives the framework for the development that will occur within the region over the next two decades. It includes issues regarding housing, infrastructure, economic development, agriculture, waste management and deals with environmental issues. To address these issues the RSS includes policies, local authority surveys and flood risk rankings which will then be incorporated into Regional Flood Risk Assessments and Catchment Flood Management, Shoreline Management, River Basin and Catchment Abstraction Management Plans which however are non statutory.
The North West of England's RSS to 2021 includes policies regarding the environment, minerals, waste and energy in section 9. Policy EM 1 focuses on the enhancement and protection of the environmental assets of the North West region. It includes landscapes, natural environments and trees, woodlands and forests and has the general goal to identify, protect, enhance and manage the region's environmental assets with special consideration to impacts of climate change and adaptation measures. EM 3 is the green infrastructure policy. It states that "plans, strategies, proposals and schemes should aim to deliver wider spatial outcomes that incorporate environmental and socio-economic benefits by conserving and managing existing GI, creating new GI and enhancing its functionality, quality, connectivity and accessibility." Amongst other recommendations, the policy recommends LAs to work with partners to "maximize the role of green infrastructure in mitigation and adaptation to climate change." The document acknowledges GI's various social, economic and environmental benefits to enhance quality of life for present and future generations. LAs are encouraged to use an interdisciplinary approach involving bodies responsible for leisure, countryside and environmental benefits to be able to deliver greater profit. LDF policies should identify and protect green infrastructure and seek to improve GI where possible. EM 5 focuses on integrated water management. It is encouraged to include SUDS and water conservation and efficiency measures into new developments and existing developments. Adverse impacts of developments on sites of importance for nature conservation should be avoided. Factors such as climate change and urban and rural diffuse pollution need to be considered and it should be understood that it is a long-lasting process (5-25 years) to plan and develop new water resources and waste water disposal schemes.

Local Development Frameworks include Local Development Documents such as Core Strategies and a proposals map. The Core Strategy is the LDF's principal development plan document and sets out the general spatial vision and objectives. The proposals map includes all site-specific policies in all the adopted development plan documents in map format including identification of areas of protection such as conservation areas. For the Local Development Framework a Strategic Flood Risk Assessment (SFRA) is required as evidence base, according to Planning Policy Statement 25 (PPS25). The SFRA takes sources of flooding and impacts of climate change into account when giving refined information about an area at flood risk. The SFRA is used to inform the Sustainability Appraisal of the Local Development Documents. It also functions as the basis from which to apply the Sequential and Exception test during the development process. The LDF together with the RSS sets out

how the particular region should change in the future.
River Basin Management Plans are the only statutory Management Plans on the sub-regional/local level. RBMP aim to improve water and wetlands and is an important document to reach the goals of the Water Framework Directive.

Non-Statutory

The environment agency (EA) is statutory consultee for developers regarding new developments concerning flood risk (for EA planning framework chart see Appendix A). Through this consultation development in flood risk areas or developments that would increase flood risk somewhere should be prevented. However, even though the EA is statutory consultee following their advice is not statutory.

Between 2001 and 2007 almost 10% of all applications have been approved by Local Planning Authorities (LPAs) contrary to the advice by the EA but the trend is declining from 11.3% in 2001/2002 to 2.3% in 2006/07 (Table 1). However, this still means that developments are put into place each year in flood risk areas and/or increasing flood risk for areas somewhere else that could have been avoided.

Table 1) Number of development applications objected by the EA compared to those permitted by LPAs contrary to EA advice
(adapted from Will McBain's presentation at Ecobuild 2009)

	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07
Total # of applications where objections made on flood risk grounds	2,500	4,523	5,077	4,634	4,201	4,750
Applications permitted by LPAs contrary to EA advice	283	221	323	248	136	110

On regional level, as mentioned above, RSS includes documents such as Catchment Flood Management Plans (CFMPs) published by the EA and Shoreline Management Plans (SMP) by LAs and the EA. These documents enable strategic, proactive and risk-based approaches to flood risk management by categorizing areas into policy regions according to their needs regarding floods from 1) no active intervention, 2) reduce flood risk management actions, 3) manage flood risk at current level, 4) take further action to sustain current flood risk, 5) take further action to reduce flood risk, to 6) increase frequency of flooding of some areas to deliver flood risks reduction for more vulnerable areas. For example, category 3 applies to areas where current flood defence is adequately done but does allow changes if appropriate. This may involve sewer and river maintenance, flood warning, emergency planning, development control, flood resilience, sustainable drainage systems (SUDS) and possibly land management change such as tree planting or blocking of drains on high moorland areas. Category 4 applies to areas which require further actions to offset the increasing risk of flooding due to e.g. climate change. The same actions as for category 3 are appropriate but additional measures may need to be taken to adjust to the increasing flood risk, such as build/raise/improve flood defences, provide flood storage, contain natural floodplains, create wetlands, over-design SUDS, increase sewer capacity, do more of modified river maintenance, and include safeguards such as overland flood flow routes [27]. Using these six categories it will be possible to more appropriately identify areas of need for flood management (changes) and thus decrease flooding of properties and other vulnerable areas.

As an example of a *CFMP* within the North West, the Mersey Estuary Catchment Management Plan [28] can be mentioned. The aim of the document is to include policies to best manage flood risks from rivers within the catchment sustainably and therefore acknowledges climate change as a major effect that will increase risks of flooding. The main activities mentioned within this document are flood mapping and the management of data, management of flood defence assets and delivery of operations, flood warnings and flood incident management. As opportunities the document points out that it is important to improve and create new possibilities for recreation as well as improving biodiversity. In regards to flooding the promotion of SUDS is of importance which will help to achieve the goal of more natural rivers and drainage networks. However, the document does not fail to acknowledge limitations within the catchment that may prevent the realization of above mentioned opportunities. These constrictions occur where there is risk to human life or major infrastructure. Areas of environmental value, protection or habitat may pose constraints on achieving goals as well as areas of archaeological interest. Within this document the Mersey Estuary catchment is separated into 14 policy units depending on their needs regarding flooding. It is important to mention that none of these 14 areas are categorized as P1 (no active intervention). This means that some form of action is needed for all areas within the catchment in regards to flood management.

SMPs generally focus on environmental, social and economical benefits. It includes reducing the thread of flooding and erosion. This needs to be done by setting out flood risks, identifying opportunities to maintain and improve the environment, identifying the preferred policies for managing risks, identifying the consequences, setting out procedures for monitoring, informing others so that future planning incorporates preferred policies and takes all risks into account, discouraging inappropriate development, and by meeting international and national conservation legislations [27]. CFMP, SMP and River Basin Management and Catchment Abstraction Management Plans can be sub regional or local, depending on their location and size.

Most sub regional/local and regional documents feed into Local Spatial Planning including Local Development Frameworks (mentioned above) and vice versa. These documents are developed by Local Authorities and focus on future developments within the locality and set out e.g. how the LAs will involve the community and identifies areas designated for development or conservation. Here, section 106 of the Town and Country Planning Act is of great importance. It is the legally-binding agreement between the LA and the land developer [29]. Within this document LAs can oblige the land developer to e.g. plant a certain number of trees, provide a recreational area of a certain size, incorporate SUDS as a mean to adapt to floods. It can also include other requirements regarding land use or community benefits.

In regards to flood management it can be summarized that policies are from the European level down to the local level. On the European level the Floods Directive and the Water Framework Directive have been put into place. On national level Building Regulations and Planning Policy Statements are important plus documents such as "Making Space for

Water". The latter is well accepted but not statutory. However, it is being incorporated into statutory policies. Regional Spatial Planning policies are fed into by national PPSs and used for Regional Flood Risk Appraisals. On the local level Local Development Documents and Local Spatial Planning Documents and River Basin Management Plans are statutory but there are other non-statutory policies on sub regional and local level such as CAMs that could play an important role when it comes to the adaptation of flooding.

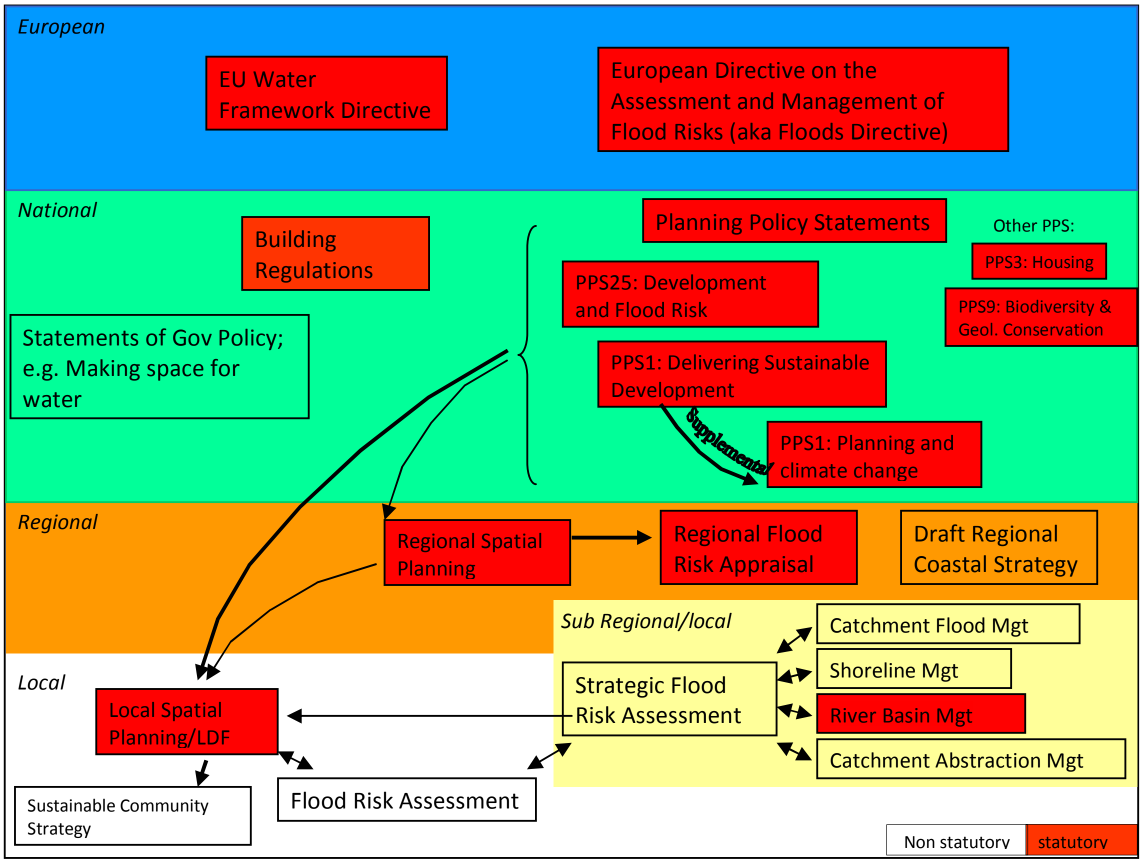


Figure 8) Policies involved with flood water management

Responsibilities

In *Making Space for Water* [30] the main entities involved with stormwater management have been summarized to be water companies/sewer undertakers, LAs (including highway authorities), the Environment Agency and the Internal Drainage Board. Here, the water companies and sewer undertakers have to manage waste water and stormwater from their customers. This generally includes water from highway drainages. Water companies and sewerage undertakers are also a consultee for development planning but unlike the EA non-statutory. The EA is statutory consultee for planning decisions, however, as already mentioned, following their advice is not. Generally, the EA has a supervisory duty regarding flood defences and flood risk management from river and the sea. In addition, they are the lead authority to prepare documents such as river basin and catchment flood management plans. The Internal Drainage Board has the authority to undertake work to secure drainage, water level and flood risk management within their district. They are funded by Special Levy from LAs and by a drainage charge to property owners whose land is drained. However, there are no IDB in the North West of England. Local authorities are responsible for surface water draining from roads and public spaces and for highway drains. They also prepare strategic flood risk assessments which feed into local development frameworks. Besides many entities being involved they all seem to have different standards. Water companies/sewerage undertakers plan for 1-in-20 to 1-in-30 rainfalls whereas the EA and the Internal use an annual probability of 1-in-75 to 1-in-100. The lowest volume of water is planned for by LAs for highway drainages. They plan for an annual probability of 1-in-5. All this indicated that the involved organizations and entities may have different goals and standards regarding stormwater issues which may hinder appropriate decisions and sustainable stormwater management designs.

Within the Pitt Review [2] several recommendations are given concerning different policy levels to help us adapt to flooding some of which are mentioned here. Pitt recommends that Building Regulations need to assure that all new and refurbished building in high-flood risk areas are designed to be flood-resistant or resilient. Local Authorities are advised for example to:

- extent eligibility for home improvement grants and loans for flood resistance and resilience products for properties in high flood risk areas.
- address local issues of flooding by collaborating with all relevant parties
- identify and map flood risk areas and drainage assets
- assess and enhance their technical capabilities related to flood risk management
- enhance flood warnings
- coordinate a systematic program of community engagement

Many recommendations by Pitt involve the Environment Agency. The EA should cooperate with local responders to raise awareness regarding flood warning in flood risk areas. Generally, the EA should maintain its risk-based approach regarding maintenance which should be supported by LAs through published schedules of works. The EA, Defra and Natural England should cooperate with partners to develop a program through CFMPs and SMPs to further incorporate *natural processes*.

Regarding the Government, he recommends to commit to a strategic long-term approach regarding flood risk management. The Government needs to address the question of which organization or entity is responsible for sustainable drainage systems, including their maintenance. In addition, he recommends that the government sets out a single guidance document for LAs and the public to use.

As for new developments, the automatic right to connect to public sewer systems should be removed according to Pitt. Householders should also not be able to implement impervious pavement anymore. Both of these recommendations would lead to more sustainable property design regarding surface water thus potentially a decrease in urban runoff and its already mentioned negative effects.

All these recommendations by Pitt's Review, again, make clear that many entities are involved and that there is great room for improvement when it comes to adequate and sustainable stormwater management. It has been recommended by multiple entities to have one responsible/over-seeing organization rather than many different ones with different incentives and standards. This would improve adequate and sustainable stormwater management in the long run but is not realizable quickly. In the short run, I think, it is most effective to educate all involved entities to improve adaptation and mitigation of climate change while the Government realizes the goal of one responsible entity. Some measures can be implemented without long-lasting political planning processes yet improve urban drainage and thus reduce the amount of urban runoff and its negative effects are sustainable urban drainage systems (SUDS). There are various SUDS designs available to fit visually every urban site (see section on SUDS).

Summary of policies regarding GI and possible points of intervention

STATUTORY POLICIES

European level **(may be a useful educational tool)**

- WFD, priority 3) Water is a fragile resource. Water quality is deteriorating through human activity, thus conservation of groundwater is very important!
- Floods Directive: areas that potentially retain water, such as natural floodplains, should be taken into account. CC is taken into account

National level **(for educational purposes)**

- Building Regulations state in Part H3 to give preference to SUDS then to conventional designs (GI and CC are not mentioned)
- PPS25 supports the restriction and reduction of runoff and encourages the use of SUDS, recognizes their amenity and wildlife benefits
- PPS1 is the overarching planning policy reg. sustainable development and includes mitigation and adaptation to CC , protection of biodiversity, soil, air and groundwater. It supports the 'polluter pays' principle
    - Regional and local planning bodies should ensure sustainable developments build for a lifetime by addressing impacts of CC etc
- Making Space for Water (not statutory) supports natural solutions for flood adaptation such as wetlands, river restoration and coastal realignments. This doc is widely used in Catchment Flood Mgt Plans and Regional Spatial Planning and other statutory docs.

Regional level **(1st point to intervene?)**

- Regional Spatial Strategies set out how an area is going to look like long-term and gives the framework of the development within the following two decades. They include issues reg. housing, infrastructure, economic development, agriculture, waste mgt and *environmental issues.*

- **Catchment Flood and Shoreline MP (done by EA) are considered by RSS and vice versa. If GI is included in RSS than potentially incorporated in CFMP and SMP and implemented**
- **Here, I think is the first point to incorporate GI and, I think, it has been done/started for the North West. Documents above should be used as a tool to deliver the message on benefits of GI.**

NON-STATUTORY POLICIES

- EA advice to reduce development in flood risk areas and to prevent flood risk somewhere else through development→ **following advice is not statutory but mostly followed, therefore the EA would be a effective advocate for GI**
- Shoreline MP and Catchment Flood MP for a proactive and risk-based approach to flood risk mgt. Flood risk categorization with recommendations for further actions if needed, *SUDS, natural floodplains* and land mgt such as *tree plantings* are included **→ GI is included and (hopefully) implemented; SMP and CFMP not statutory though**

Thoughts:

→ Generally the EA needs to be GI's advocate to encourage developers and LAs to incorporate GI

→ More detailed/applied information on GI's benefits needs to be incorporated in national and regional policies

→ LAs need to be further educated so they include GI in section 106 for new developments as well as in Catchment, Shoreline, River Basin and Catchment Abstraction Mgt Plans.

→ need to make sure that GI does not get crossed out of 106 agreements

→ For single properties, homeowners should be educated on water use, water conservation, runoff, flood risk, and flood risk prevention

→ Pitt's recommendations may be a useful supporting tool, probably not from our position

→ wording needs to be improved; "having regards to" a document does not mean that its suggestions need to be accounted for or implemented

Practical Opportunities

Sustainable Urban Drainage Systems (SUDS)

(Taken from the SUDS Manual [6] if not cited differently)

Much work has been done to develop SUDS. There is a variety of different designs available some of which include vegetation and some don't but they all have the same basic idea, sustainable drainage by mitigating many of the environment-impairing effects that urban stormwater runoff has. The duties of SUDS are to:

- reduce runoff rates and therefore reducing the amount of pinch points created,
- reduce the amount of runoff and frequency of runoff occurrence to counteract effects of urbanization on runoff,
- promote natural groundwater recharge to support natural river baseflows and aquifer recharge,
- reduce pollutant discharge to water bodies,
- serve as a buffer for accidental spills through preventing (contaminated) water from being directly discharged into streams and rivers,
- reduce the amount of runoff being discharged into combined sewer systems. This way the discharge of pollutants to water bodies is reduced/avoided through Combined Sewers Overflow (CSO) spills during heavy rains,
- improve amenity and aesthetic values of developments,
- improve biodiversity in urban areas by providing wildlife habitats.

To provide different designs so that e.g. land use, future management and needs of the community can be incorporated. The following section gives an overview of available SUDS designs.

Planning Process and Design

In regards to the planning process many entities are concerned and different perceptions and issues need to be considered. Organization/entities that may have great interest in the planning and/or implementation of SUDS are Conservation Authorities, the Royal Society for the Prevention of Accidents (RoSPA), the insurance industry and developers, landowners and homeowners. Conservation Authorities have the responsibility to enhance biodiversity, landscape and wildlife in urban and rural as well as marine areas. SUDS have great potential to function as drainage system yet still provide the opportunity as wild habitat. RoSPA gives advice on safety issues including near or on water. They offer factsheets on safety issues to be considered when it comes to ponds (which can be a SUDS) and other landscape features. In regards to the insurance industry it is important to point out that SUDS that are planned, designed and maintained well only provide only a low risk for civil liability. The considerations that need to be addressed are different from those for conventional drainages to assure safety but they are not more hazardous than the traditional alternatives. When it comes to ownership of SUDS homeowners are generally responsible for drainage within the cartilage of their property. However, relevant stakeholders need to be in agreements and need to make decisions regarding long-term ownership early in the planning process to prevent and future issues especially since the land ownership may change from landowner, to developer and eventually to homeowner.
When it comes to planning and designing SUDS a multidisciplinary approach is needed. Simple smaller scale systems are within the capability practical drainage engineers. However, for larger scale or complex systems specialist advice and early consultation from technical experts may be needed.

Since SUDS are different from conventional designs the inclusion of contractors during design discussions can be useful to get advice on practical solutions and point out any drainage issues there may be.

The general idea of SUDS is to store and then safely pass runoff from heavy rain events without putting the public or any property at any risk, on-site or downstream. The amount of pollutants contained in runoff should be reduced before being released to prevent any water body pollution. SUDS also prevent bank erosion downstream through prevention of direct discharge of runoff which leads to flash flows of rivers. Generally, flood risk after development should be at least equal but possible reduced through SUDS compared to flood risk before development. However, it is impossible or at least impractical to design for all flood events since the costs or the size of the system would not be feasible. Therefore, consequences of an event larger than the system can manage need to be determined. Generally, consequences are less for SUDS than if conventional systems are overflowing. For the design of SUDS hydraulics, water quality, amenity and ecology need to be considered by taking the level of service required for the system, the sustainability and the costs of the drainage solution into account.
The size of the system should be designed for a 30 year critical event without causing any significant damage. Here, allowance for the effect of climate change need to be made.

In regards to runoff, the idea is to avoid floods on-site and downstream so the runoff rate after development should be equal to pre-development (also called Greenfield runoff rate). Due to the drainage differences caused by the development the actual rate of runoff will not be exactly the same as that of Greenfield runoff. However, the frequency of the runoff rates should be as close as possible.

50% of small rainfalls produce no measurable runoff on Greenfields whereas almost any rain events, no matter how small, produces runoff from impervious surfaces. This leads to flashy rivers and decreased groundwater recharge and river baseflow.

Therefore, the general goals of SUDS are to keep natural drainage patterns to reduce runoff and maintain groundwater recharge after development. Here a series of SUDS may be suitable to provide optimal drainage for a specific site.

SUDS incorporating vegetation

Several SUD systems have been identified that incorporate vegetation, such as grasses, shrubs or trees. These systems provide benefits regarding stormwater treatment, aesthetic value and ecological benefits such as improve biodiversity, cooling/shading and further more. The most common vegetated SUDS are green roofs, swales, bioretention/rain gardens, wetlands, and ponds/basins. Green roofs are vegetated areas on the top of buildings. These areas collect rainwater that then either evaporates or is lost through transpiration by plans. Water from heavier rains is redirected through overflow pipes to storm sewers or other water collection devices. There are several advantages of green roofs. They support biodiversity, reduce runoff, and improve the urban climate. Bioretention or rain gardens may appear to be ordinary landscape beds. However, the basin is filled with a special, highly absorbent soil mix and plants resulting in a system that can collect, store and treat runoff. Bioretention takes up water and allows for it to infiltrate into the ground. They *function* similar to infiltration basins, which are vegetated depressions in

the landscape, oftentimes just planted with turf and wild flowers. Infiltration basins *appear* similar to detention basins, which also are vegetated depressions that collect stormwater. Both systems are generally dry and may provide recreational value until it fills up with stormwater. The difference between detention basins and infiltration basins is often not obvious yet generally different in function. Infiltration basins collect water and allow for it to infiltrate into the ground whereas detentions basins collect water but do not allow for infiltration. They are lined and store water for some time to delay peak flow before they redirected the stormwater via outlets to storm sewers or other systems.
Ponds and stormwater wetlands contain water for most/all parts of the year. Ponds collect runoff from surrounding areas and store it until it evaporates or drains somewhere else. They may or may not have outlets. Wetlands are areas made up of ponds and marshes that are covered almost entirely in aquatic vegetation. The have a high ecological value and are a useful tool for stormwater management.

The main SUDS located besides roads are filter strips and swales. Filter strips are generally located between paved surfaces and streams. They collect runoff and treat it via vegetative filtering, infiltration and settlement of particulate pollutant. Swales are linear vegetated drains that can be located along roads and other paved surfaces. They slow down flow rates while allowing sediments to settle out. The following fact sheets give a useful overview of vegetated SUDS.

Structural soil (stone-soil mix) reservoirs as stormwater management systems [31] were investigated at Virginia Tech (Blacksburg, VA, USA) and are relatively new and therefore not yet well known. Structural soil is a gravel-soil mix (80 to 20% by weight) which was developed at Cornell University (Ithaca, NY, USA) to increase the root-penetrable soil volume for street trees to improve their growing conditions. Many street trees suffer from inadequate soil conditions because they are surrounded by impenetrable soil leading to little available nutrients, water and oxygen. Structural soil has high load-bearing capacity yet still provides large voids for water, oxygen or roots. The idea regarding stormwater management was to use this load-bearing stone-soil substrate below pavement (no land-take) to allow stormwater management on site because, depending on its design, it can take up large amounts of water due to its high porosity (~30%). Once stormwater reaches the reservoir it can slowly infiltrate into the ground. To allow stormwater to reach the reservoir either pervious pavement can be installed or water will be directed into the reservoir through drains or pipes if impervious pavement is preferred. This leads to the opportunity to manage stormwater on site therefore decreasing runoff and the effects of runoff without any additional land-take as the system is below pavement.

SUDS without vegetation

SUDS that do not incorporate vegetation are oftentimes technical/engineered solutions below ground. The most common ones are soakaways, water butts, pervious pavement and geocellular/modular systems. Soakaways are the most commonly used infiltration device in the UK. They are below-ground systems that store runoff from a single house or from a development and allows for infiltration of the stormwater into the soil. Geocellular/modular systems are below ground storage devices made up of modular plastic geocellular systems with a high void ration. They can be used to store water or as infiltration device (soakaways). Water butts are a common storage device for rainwater which allows the use of this rainwater for e.g. watering of the garden or other purposes.

Pervious pavements can be used as a substitute pavement for any area, such as driveways, roads or parking lots. Pervious pavement allow for water to infiltrate into the soil below the pavement therefore reducing the amount of runoff normally resulting from these paved surfaces.

SUDS with or without vegetation

There are three main systems that may or may not incorporate vegetation. These are sand filters, trenches and structural soil reservoirs. Sand filters are structures made up of single or multiple chambers filled with sand to treat runoff via filtration. These filter strips can allow water to infiltrate into the ground or, if this is not desired, can be installed with an impervious liner. Temporary water storage is achieved by ponding above the filter layer. Infiltration and filtration trenches accept water from adjacent impervious surfaces. Infiltration trenches allow exfiltration of water into the surrounding soil whereas filtration trenches can be used to filter and then pass on of water to downstream SUDS.

Structural soil can be used as a sustainable stormwater management system with or without vegetation. A structural soil reservoir is incorporated below the pavement which allows for water storage because of its high porosity. Depending on the volume of stormwater expected/needed to be manages the depth of the structural soil reservoir is designed. The infiltration rate of the subsoil is highly influential to the capacity of the system as higher infiltration rate allows for more runoff volume to be managed. Impervious or pervious pavements can be used as long as a path for the stormwater to reach the structural soil below the pavement is provided. Trees can be incorporated in the system as islands or strips adjacent to the reservoir. They would grow in regular soils yet root growth into the structural soil reservoir is encouraged.

Other sustainable water management techniques

Rainwater harvesting allows the collection and usage of rainwater for different purposes. It can be used to water the garden or it can be used as grey water substitute for flushing toilets and even showering and running the dishwasher. There are different water quality standards that have to be met depending on the proposed usage of the water. Therefore different systems/treatments may be needed.

Practical examples of implemented GI for water management purposes

Various sustainable drainage systems (SUDS) have been identified that are suitable to ‘manage’ urban stormwater by using the above mentioned benefits of GI to different degrees. These systems are designed to help decrease the volume of runoff reaching storm sewers by draining surfaces in a rather natural and sustainable way. Examples for such systems are swales, filter strips, trenches, bioretention/rain gardens, pervious pavement, infiltration basins, detention ponds and stormwater wetlands (See section below).

SUDS train within an inner city suburb of Malmö, Sweden

As one example for an implementation of a SUDS train can be mentioned a project [32] within an inner city suburb of Malmö, Sweden. It consists of council offices and apartment blocks with courtyards, roads and parking space. Here, they installed a number of SUDS including green-roofs and open channels leading to detention ponds to treat the stormwater on site (Fig 9). They found that green-roofs are an effective tool for lowering total runoff and that ponds should successfully decrease peak flows for a 10yr rainfall.

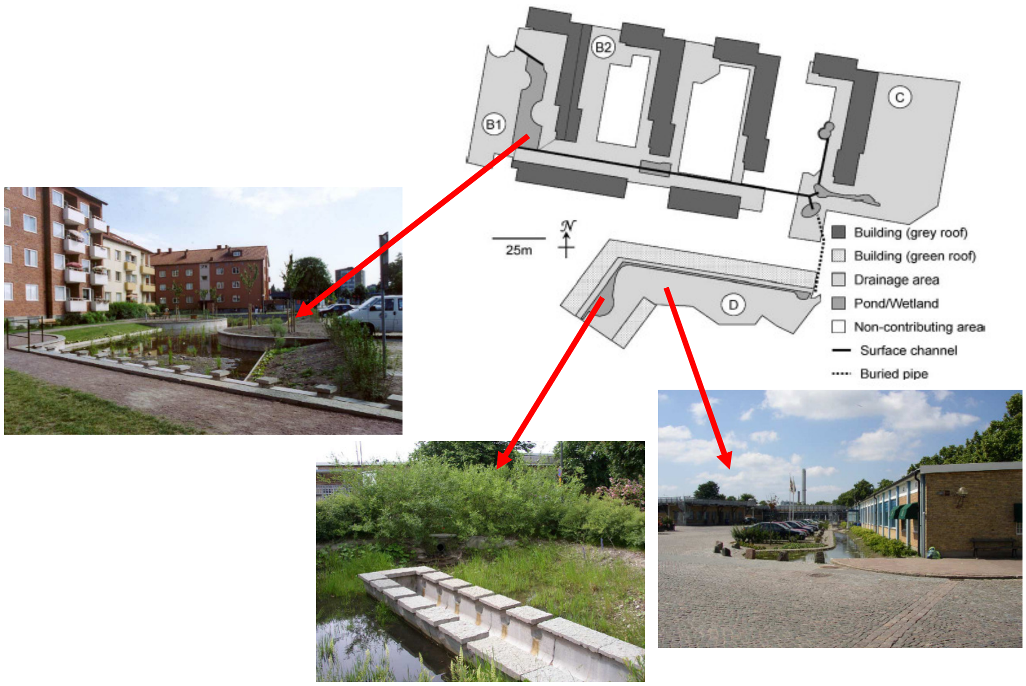


Figure 9) SUDS train installed in inner city suburb of Malmö, Sweden

SUDS have also been installed within the North West of the UK. As part of Defra's Making Space for Water Urban Flood Risk & Integrated Drainage (IUD) program fifteen IUDs have been implemented (Fig. 9). The projects have been funded to help understand the causes of urban flooding and the best ways to manage urban drainage to reduce flooding. In addition, the effectiveness of partnerships is examined and new approaches are tested. The projects have the goal to improve mapping and modelling of surface water flow risks, working in partnerships, solutions to reduce surface water flood risk and drainage strategies for new developments. The project undertakers were faced with challenges such as poor data and models to work with, many different techniques available which require new guidance to be able to use an approach resulting in appropriate cost, detail and accuracy. They were also faced with difficulties resulting from the numerous institutional arrangements and responsibilities involved which made it difficult to coordinate and fund integrated-approach projects. Generally, many urban water flood risks are located in urban areas. To resolve the problem redevelopment and town centers may be needed which may not be practicable as it would be an expensive and longsome process.

Two of these fifteen projects are explained in the following section; West Garforth in West Yorkshire and the Lower Irwell Valley in Salford.

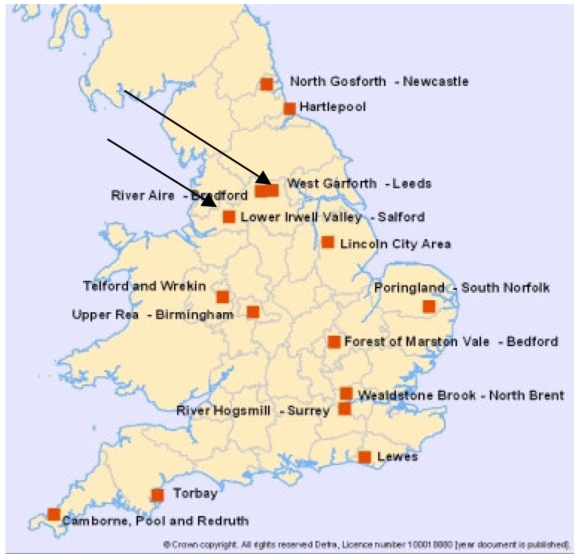


Figure 10) IUD pilot project locations within the North West as part of Defra's Making Space for Water Urban Flood Risk & Integrated Drainage, IUD, (HA2) program.

West Garforth in West Yorkshire [33]

The main part of West Garforth's drainage system (Fig. 11) consists of a series of culverted watercourses that were determined to be inadequate. These culverts receive water from surface water sewers, from highway drains and overland runoff and pass through hundreds of properties. The owners of the adjacent properties have no responsibility to resolve any capacity issues or the ability to address maintenance issues. In addition, no entity has the statutory responsibility to inspect or keep record of these culverts.

Since 1950s West Garforth has grown substantially which resulted in covering and culverting of open water courses in a 'piecemeal fashion'. New drainage infrastructure has been connected but capacity limitations seemed to be disregarded.

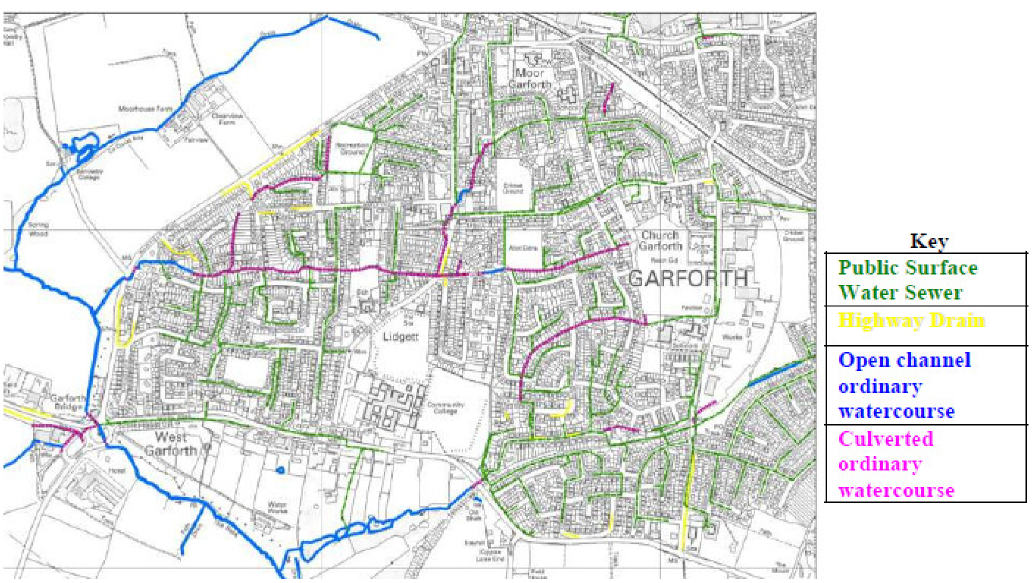


Figure 11) West Garforth's drainage structure

The study started on November 15th 2006 and ended on April 14th 2008 and had the objectives to develop a hydrological model of the drainage infrastructure so that existing system performance could be estimated and to identify a range improvement measures to be able to determine a preferred mix of solutions (table 2).

The project undertakers estimated the performance and determined the possible solutions for a 1 in 30 year design storm and came up with the following solutions:

Table 2) Possible solutions suggested by the project undertakers of the West Garforth IUD project

Flooding locus	EAD £k		Responses	Costs £k	Performance of responses		Residual EAD £k		EAD benefit ratio**		EAD current cost benefit
	Current	2085			Current (years)	2085 (years)	Current (£K)	2085 (£K)	Current	2085	EAD reduction/£ spent on response
Lowther Road (A)	373	460	1. Replace local pipes to remove adverse gradients 2. Construct new pipe to take flows south 3. Disconnect some upstream inputs (roofs, rainwater barrels)	 390 250	10	5 years	108	200	0.29	0.43	0.41
Oak Drive (B)	228	353	1. Storage at school (pond) 2. Swale along Oak Drive 3. Disconnection (roofs rainwater barrels)	70 150 250*	50	15 years	29	127	0.13	0.36	0.42
Barleyhill/Rec. Ground (C)	107	183	Storage pond at recreation ground	120	30	10 years	23	97	0.21	0.53	0.7
Ninelands Lane (D)	477	695	Disconnect factory hard standing (pond)	110	100	5 years	7	288	0.15	0.41	4.27
Richmond Rd/Glebelands (E)	186	246	Only solution is upsized pipes (disconnection removes little inflow)	220	30	10 years	9	65	0.05	0.26	0.80
Various other areas than above	441	279	Local solutions will be required – these are relatively modest problems currently but will increase by 2085	-	-	-	441	279	-	-	-
Totals	1812	2216	-	1560	-	-	617	1056	0.34	0.48	0.77

The results of the project showed some quick solutions for West Garforth to be the obstructions and removal of a culverted watercourse, drainage ditches with good maintenance to improve their effectiveness in Poringland and upstream storage to benefit properties at risk downstream in Hartlepool. It was estimated that the latter system could save 20% of the costs needed to install a combination of traditional stand alone solutions usually needed to resolve fluvial, surface water and sewer flooding.

The Lower Irwell Valley in Salford [34]

Even though the last flood occurred in 1946 it can be said that Salford has been experiencing periodic flooding in the last 150 years. During the 1946 flood, 243 hectares of land were flooded including 5,000 residential properties. The reason is that Salford is low lying within the lower reached of the catchment. Today, many properties are protected from flooding through flood embankments along the river, however, 7,000 are still at risk of fluvial flooding. In addition to fluvial flooding sewer flooding can be a big issue. The sewer network services in Lower Broughton depends on combined sewer overflows into the river. However, during high river flows the combined sewer can physically not discharge into the river which leads to sewer back ups.
Strategic Flood Risk Assessments (SFRA) of the City of Salford in December completed in

December 2005 provides an assessment of the fluvial flood zones across Salford with the majority of the area being in flood zones 2 or 3. The SFRA distinguished between main river flooding and sewer and surface water drainage but not enough attention was given to surface and sewer floods which is a big issue (Fig. 13).

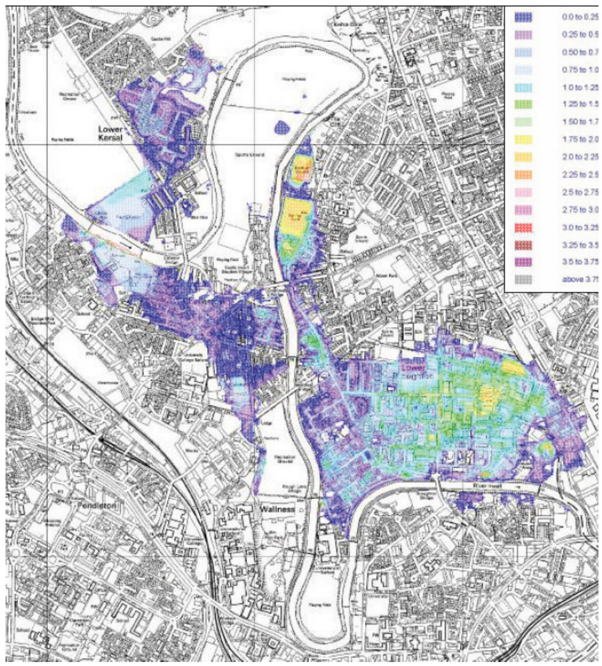


Figure 12) River Irwell floodplain showing flood depth in meters (including allowance for climate change)

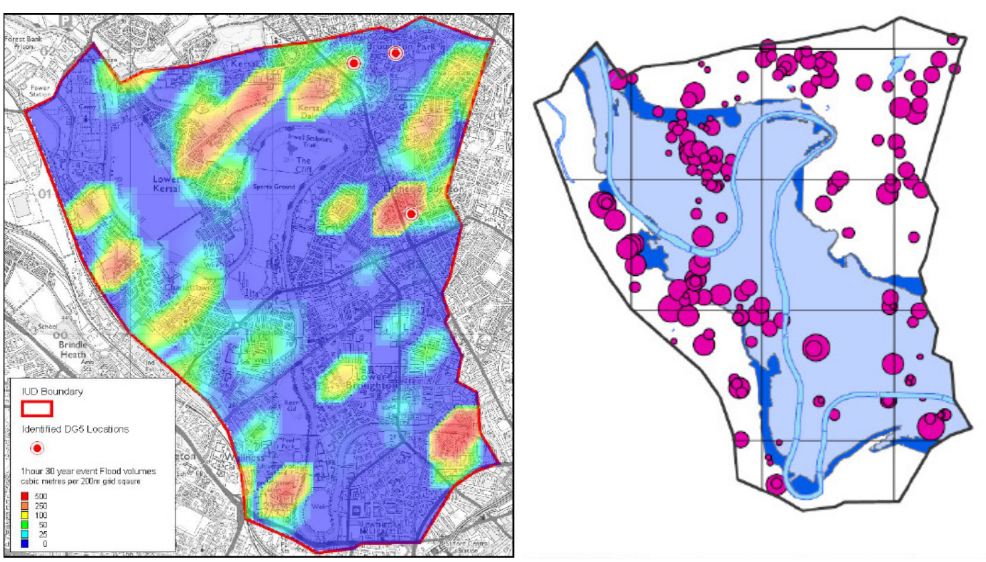


Figure 13) Sewer flood risk (left) and flood risk zones and UU sewer flood data (right).

Through this project SUDS maps have been developed and a range of recommendations such as SUDS maps, the greater use of pre-planning meeting should be attended by stakeholders to be able to develop integrated urban drainage to be embedded within formal planning policies. Non-statutory consultees (e.g. UU) can play an important role and should be taken into account in planning and development processes. Local drainage knowledge held by LAs drainage engineers should be recognized, recorded and capitalized within the development and planning process and applied to aid implementation of IUD. SUDS should be included in new development in accordance with the SUDS maps where possible, including systems such as green roofs, rainwater harvesting systems, soakaways and retention ponds.

Weaver Valley [35]

For the Weaver Valley project an 'action plan' including suggestions for the area has been developed based on the five steps given by the North West Green Infrastructure Guide. These steps were identified as 1. Partnership and Priorities, 2. Data Audit and Resource Management, 3. Functional Assessment, 4. Needs Assessment, and 5. Intervention Plan. The partners identified include entities such as British Waterways, the EA, Natural England, the Mersey Forest and others. To produce GIS maps, typology maps, of all existing green infrastructure within the area Ordinance Survey MasterMap Topography data have been used as parcel system. To define the green infrastructure types that provide a certain functions a typology system based on that from Planning Policy Guidance Note 17 was developed. The GI types are as followed:

- Agricultural land
- Allotments, community gardens & urban farms
- Cemeteries, churchyards & burial grounds
- Coastal habitat
- General amenity space
- Grassland, heathland, moorland & scrubland
- Institutional grounds
- Orchards
- Outdoor sports facilities
- Parks & formal gardens
- Private domestic gardens
- Street trees
- Water bodies
- Water courses
- Wetlands
- Woodland

Other datasets that were used are: Aerial photographs, Ordnance Survey raster mapping, The Mersey Forest's woodland planning data, LAs Open Space Studies, and Public Rights of Way data.

Each GI type on each parcel was analyzed regarding its function so that all functions of each parcel could be determined. The list of functions used for this project included environmental/ecologic functions such as habitat for wildlife and soil stabilization, community functions such as recreation and shading from the sun, and economic functions such as biofuel production and food production. Water management has been separated into four functions: water storage, water interception, water infiltration/natural drainage, and coastal storm protection. Once all the functions have been mapped, the benefits resulting from these functions can be mapped as well. To do this a list of benefits was used based on the eleven economic benefits identified by Natural Economy North West. After GI was mapped a needs assessment was conducted to determine where which GI should be created and where and what improvements are needed to existing GI to improve its functionality. These data will be used to develop an intervention plan which will include information on where GI exists, what function it provides, and where it is needed to provide additional functions that may be desired.

Watershed Forestry [36]

The USDA Forest Service published a series of manual on Urban Watershed Forestry. The goal of this series is to give information on increasing forest cover in a watershed, conserving and planting trees at development sites, and giving guidance on urban tree plantings. The series give a good overview and explanation on the benefits of trees within urban watersheds. Watersheds are defined as “land areas that drain surface water and ground water to a downstream water body or outlet, such as river, late, or estuary.” In addition, it defines the terms “forest”, “forest cover”, “urban forest cover”, and “urban tree cover” and it seems this would be useful to be able to speak the same language especially since different entities and professions are involved.

The manual define the terms as follows:

Urban forest: the “trees growing individually, in small groups or under forest conditions, on public and private lands, in cities and towns and their suburbs.

Urban tree canopy: the layer of tree leaves, branches, and stems that cover the ground when viewed from above.

Forest cover: the total land area that is classified as forest by the land cover data used.

Forest: generally it seems that areas with more than 40% canopy cover can be classified as forests.

The goal of Watershed Forestry to 1) protect, 2) enhance, and 3) reforest. Two ways to protect Watershed Forestry from human encroachment and land development are conservation easements and ordinances that require developers to physically protect selected forests during construction. Land use planning that directs developments away from forested areas are desirable.

The enhancement of health, condition, and function of urban forest fragments are the second goal. Reforestation of open land through natural regeneration or plantings is the final goal and aims to regain some of the functions and benefits that urban forests provide and to increase the overall watershed forest cover.

It becomes clear, again, how important vegetation, especially trees, is in urban areas and urban watersheds for the various benefits they provide. For example, Regional Ecosystem Studies conducted by American Forests used satellite imagery and CITYgreen software to give lost forest an economic value. For the Baltimore-Washington area it was estimated that tree cover declined from 51% to 37% between 1973 and 1997. This decrease in forest cover was estimated to have resulted in an increase in stormwater runoff by 19%. The costs needed to implement stormwater treatment systems to intercept this runoff were estimated to be $1.08 billion. The lost tree cover would have removed approximately 9.3 million pounds of pollutants from the atmosphere annually which would equal a value of $24 million per year. Thus spending a fraction of this money to maintain urban tree cover may have been much more lucrative.

Flood risk through upland land management [18]

One example of research that focuses on upland surface water runoff is a project by Wheater et al 2008. They saw the need to determine the impacts of upland areas as a source area of runoff. Upland soils especially when the land is used as a pasture can be highly compacted. This great degree of compaction can lead to high volumes of runoff because the water has no chance to infiltrate into the ground. This infiltration depends also on the soil type and antecedent conditions, so whether the soil was dry or moist when it rained.

The researchers developed a multi-scale modelling methodology to be able to extrapolate from small scale observations to predict catchment-scale responses. Data from statistically-replicated experiments where used including land management treatments, from instrumented field and hillslope sites, including tree shelter belts, and from first and second order catchments. Rainfall and climate variables were measured, soil moisture, soil water pressure and soil hydraulic properties at multiple depths and locations.

The results revealed that at this site, which was dominated by clay-rich soils, the removal of sheep and/or planting of trees resulted in a significant increase in hydraulic conductivity and saturated moisture content showing an increased ability of the soils to store and conduct incoming rain water or potentially overland flow from the hillslope above. Even just tree shelterbeds protected from grazing may reduce surface runoff since overland flows are reduced under the tree areas compared to open grassland.

Summarizing can be said that there are many ways to improve stormwater management conditions with green infrastructure, either in the uplands, in the urban area within a catchment, or by incorporating SUDS. However, it is essential for the determination of the potential of GI to know where the pinch points are thus where the areas are in which GI is most critical. To do this, flood and GI mapping is necessary which 1) includes all the factors influencing flood risk to give information on the areas most at risk and 2) gives information about the areas in which the incorporation of GI would be most appropriate and efficient.

Flood and GI mapping

Floods are a major threat to human health and wellbeing. Human behaviour has a major influence on flooding events as industry and development influence the severity and likelihood of flood events. The question would be what we can do to work against this increase in frequency and magnitude of flood events.

Green infrastructure can play an important role in climate change mitigation and adaptation. When it comes to flood events it is important to identify the areas and regions where green infrastructure is most critical to be implemented. To do this it is necessary to identify its functions.

Green infrastructure has been broken down in to multiple types. These types are:

Table 3) Identified GI types

- parks & formal gardens
- general amenity space
- outdoor sports facilities
- woodland
- water courses
- water bodies
- green roofs
- constructed ponds and wetlands
- grassland, heathland & moorland
- coastal habitat
- agricultural land
- allotments, community gardens & urban farms
- cemeteries, churchyards & burial grounds
- derelict land
- private domestic gardens
- institutional grounds
- natural wetlands
- other?? (e.g. verges)
- orchard
- street trees

Then the functions of GI regarding hydrological issues have been identified and broken down into:

Table 4) Identified hydrological functions of GI regarding

- Conveyance
- infiltration / natural drainage
- interception
- Pollutant removal from soil/water
- storm protection - coastal
- Surface flow reduction through surface roughness
- water capture (no reuse potential)
- water storage (with reuse potential)

Table 5) Definitions for GI functions

Function	Definition / description
Conveyance	Controlled movement of stormwater somewhere else
Infiltration	Passage of surface water though the surface into the ground
Interception	Preventing rain from reaching the ground to become runoff
Pollution removal from soil or water	Removal and storage of pollutants from soil or water
Storm protection -coastal	Buffer against coastal storms
surface flow reduction through surface roughness	Above ground flow of water can be slowed down by barriers of vegetation which will result in delayed and reduced peak flows
Water Capture (no reuse)	Capacity to capture and hold significant volumes of water
Water Storage (reuse)	Stored water to be reused

These functions have been broken down in this manner to provide an adequate mapping tool for the potential of GI. GI functions can be difficult to define because green infrastructure integrates the existing conditions. Rather than being a specialist vegetation and water bodies are able to “pick and chose”. Taking trees as an example; trees require certain conditions above and below ground. But it is difficult to put threshold values on each influencing factor as these thresholds are different for each tree depending on the particular tree and a particular site. For our purpose, GI types have been broken down and GI functions have been broken down to break down the functions for each GI type. Since GI integrates conditions, we needed to decide whether a particular GI type always fulfils a certain functions or only under certain conditions. However, to be able to map these types and functions in a useful manner it is necessary to identify/clarify the functions. For this reason the function ‘Water capture’ was separated in to ‘no reuse potential’ and ‘with reuse potential’. It needed to be avoided that, since GI types fulfil multiple functions, the functions themselves are only vaguely defined. For example, soils, rain gardens, and ponds can capture water and thus reduce the volume of water that requires management. But only the water from ponds can be directly reused. These are two different functions and will be important during times of water shortage.

When assigning functions to a particular GI type it is important to think about the various forms and sizes this type may exist in. For example, trees intercept rainfall. You may think they always do, which is correct, but it would only be significant and worth mentioning if the tree has a certain size and its interception potential would actually make a difference.

The table below shows the types of GI on the left (rows) and the hydrological functions GI can provide (columns). If the particular GI type fulfilled a certain hydrological function, ether an ‘A’ for ‘always’ was assigned or an ‘S’ for ‘sometimes’ in which case the conditions below apply.

Table 6) GI types and their Hydrological functions including the conditions under which they may fulfil this function (2nd page)

	A= this type ALWAYS has this function S= this type SOMETIMES has this function, see notes below as to when	water capture (no reuse potential)	water storage (with reuse potential)	water interception	water infiltration / natural drainage	storm protection - coastal	Conveyance	Pollutant removal from soil/water	flow reduction through surface roughness
TYPE	parks & formal gardens	S[46]	-	-	S[49]	S[12]	S[44]	S[42]	S[52]
	general amenity space	S[46]	-	-	S[49]	S[12]	S[44]	S[42]	-
	outdoor sports facilities	S[47]	-	-	S[50]	S[12]	S[44]	S[42]	-
	woodland	S[9]	-	S[38]	S[49]	A	-	A	S[52]
	water courses	-	A	-	-	-	-	S[42]	-
	water bodies	-	A	-	-	-	-	S[42]	-
	green roofs	A	-	A	-	-	-	S[42]	-
	constructed ponds and wetlands	-	A	-	-	-	S[44]	A	S[53]
	grassland, heathland & moorland	S[46]	-	-	S[51]	S[12]	S[44]	S[42]	S[52]
	coastal habitat	S[48]	-	-	S[51]	A	-		-
	agricultural land	S[47]	-	-	S[49]	S[12]	S[44]	S[42]	S[52]
	allotments, community gardens & urban farms	S[46]	-	-	S[49]	S[12]	S[44]	S[42]	S[52]
	cemeteries, churchyards & burial grounds	S[46]	-	-	S[51]	S[12]	S[44]	S[42]	S[54]
	derelict land	S[46]	-	-	S[51]	S[12]	-	S[42]	S[52]
	private domestic gardens	S[46]	-	-	S[49]	S[12]	S[44]	S[42]	S[52]
	institutional grounds	S[46]	-	-	S[49]	S[12]	S[44]	S[42]	S[52]
	natural wetlands	A	-	-	-	A	S[44]	A	A
	other?? (e.g. verges)	S[46]	-	-	S[49]	S[12]	S[44]	S[42]	S[52]
	orchard	S[46]	-	A	S[11]	S[12]	-	A	S[52]
	street trees	S[46]	-	S[43]	S[51]	-	-	S[43]	-

→ **all types of GI provide** evaporation from surfaces and transpiration by plants which decrease the amount of management requiring water by transporting it back into the atmosphere

WHEN

9 if in floodplain or areas with heavy rains/pluvial floods

11 if on soils with high infiltration rates, e.g. little compacted soils or those with high fraction of coarse materials

12 if on coast and either on large area or elevated

37 if system designed WITHOUT a liner

38 if trees (of **significant size**) are present, roots increase infiltration of soils, canopy offers interception

39 if one of the following SUDS is present: swale, detention basin, infiltration trench or basin, bioretention/rain garden or sand filter

40 if one of the following SUDS is present: detention basin or bioretention/rain garden

41 if one of the following SUDS is present: infiltration basin or trench, or these SUDS without a liner, filterdrains or strips, swales, detention basin, bioretention/rain garden, sand filter

42

type	**heavy metals**	**nutrients**	**total suspended solids**
bioretention	high	low	high
sand filter	high	low	high
infiltration and filter trench	high	low/med	high
infiltration basin	high	med	high
ponds	high	med	high
wetlands	high	med	high
swales	med	low	high
green roofs	med	low	high

43 depending on tree species, size and condition

44 if one of the following SUDS is present filter drain, filter strips, swales, wetlands, infiltration trench

45 if soils have high porosity

46 if 9, 39 or 45

47 if 9 and 45

48 if 39 and 45

49 if 11, 38 or 41

50 if 11 or 41

51 if 11 and 38

52 if vegetation is dense enough

53 if wetland

54 if vegetation is dense enough or if structures provide sufficient roughness

Table 7) GI functions, location of GI to fulfil this function and problem/opportunities for each source of flooding, fluvial (page 1), pluvial (page 2), and coastal (page 3), and GI functions regarding water quality and water resource (page 4).

Water issue	GI function	GI type	Location	Problems/ Opportunities
Fluvial Flooding	**↑ drainage area** to ↓ water in sewers and streams	• Pervious surfaces and coarse grained soils provide (higher) soil infiltration	Floodplains and land adjacent to water courses; land in low elevation that may collect water; SUDS in high and low densely developed as well as open land; incl. parks, yards etc	Potential for recreation; high potential for pollution in 'hotspots'
	↓ peak flow rate to prevent flooding and stream bank erosion	• Trees and coarse woody debris as barriers • Wider detention reservoirs to collect water • Trees intercept rainfall and roots increase soil infiltration rates	floodplains, wetlands, detention basins/ponds; upstream from vulnerable land to prevent flooding downstream	Water back up potentially leading to flooding upstream
	↑ water storage to protect critical flood risk areas	• Detention/retention ponds, wetlands, raingardens/bioretention	Floodplains, areas of high precipitation, areas with high percentages of impervious surface, within and upstream of vulnerable land	Maintenance and potential health hazard e.g. insect ; poor aesthetics if not well maintained
	↑ 'water loss' to decrease the volume of water that require management	• water collected on leaf surfaces evaporates • water is lost through uptake by plants, most significantly trees	within and upstream of vulnerable land, floodplains and areas of high precipitation,	Evaporative cooling
	↑ rainfall interception to ↓ runoff and flood water	• All trees intercept rainfall but most significantly when of substantial size; conifers intercept all year round, broadleaved trees only during the growing season • Green roofs	within and upstream of vulnerable land, floodplains and areas of high precipitation,	Trees require maintenance but high ecology, aesthetics, community and economy value
	↑ soil infiltration to ↓ runoff and flood water	Roots of all plants, most significantly tree roots as the root system is wider and deeper, increase soil infiltration rate	within and upstream of vulnerable land, floodplains and areas of high precipitation,	Recreational, ecological, economical and aesthetic value. Plants require maintenance/ management

Water issue	GI function	GI type	Location	Problems
Pluvial Flooding	↑ **pervious (drainage) area** to ↓ runoff and flood water	• Pervious surfaces and coarse grained soils improve soil infiltration, e.g. implementation of SUDS	Close to frequently overflowing sewers, flood plains, areas of heavy rainfall, land in low elevation that may collect water	Potential for recreation; high potential for pollution in 'hotspots'
	↓ **flow rate and volume** of water to the sewer to prevent flooding and stream bank erosion	• Water can be stored in designed depressions, e.g. detention basins, and other features thus reducing the volume and rate of water reaching a sewer • Trees and coarse woody debris as barriers • Trees intercept rainfall and roots increase soil infiltration rates	Close to impervious surface to collect its runoff, within depressions and measures of conveyance; SUDS can be implemented in areas of high and low densely developed as well as open land; incl. parks, yards etc	Water back up potentially leading to flooding upstream
	↑ **rainfall interception** to ↓ runoff	• All trees but most significantly when of substantial size; conifers intercept all year round, broadleaved trees only during the growing season • Green roofs by preventing rain from hitting the ground and turning into runoff	within and upstream of vulnerable land, floodplains and areas of high precipitation; in all urban areas to decrease sewer pressure;	Trees require maintenance and adequate (soil) conditions; *the right tree for the right place* is essential, otherwise they may provide no benefit but nuisance and poor aesthetics. otherwise high ecology, aesthetics, community and economy value
	↑ **water loss** to decrease the volume of water that require management	• water collected on leaf surfaces evaporates water is lost through uptake by plants, most significantly trees	within and upstream of vulnerable land, floodplains and areas of high precipitation; in all urban areas to decrease sewer pressure; areas at low elevation that may collect water	

Water issue	GI function	GI type	Location	Problems
Coastal Flooding	↑ **buffer** to protect vulnerable land	• All types are effective, most significant influencing factor is area/distance between coast and vulnerable land	Between the coast and vulnerable land	Large space required
	↑ **drainage area** to ↓ flood water	• Wider pervious area offers drainage to flood water, • Vegetation, most significantly trees, improves soil infiltration	Within the buffer and vulnerable land. SUDS can be implemented in areas of high and low densely developed as well as open land	Potential for recreation; high potential for pollution in 'hotspots'
	↑ **water loss** to decrease the volume of water that require management	• water collected on leaf surfaces evaporates • water is lost through uptake by plants, most significantly trees	Within the buffer and vulnerable land; areas of high precipitation or flood risk	
	↓ **flow rate/progression** of water inland to prevent flooding and stream bank erosion	• Trees and coarse woody debris as barriers • bigger detention reservoirs to collect water • Trees intercept rainfall and roots increase soil infiltration rates	Within floodplains or areas of storm-water collection and conveyance at distance from water ways	Water back up potentially leading to flooding up-stream

Water issue	GI function	GI type	Location	Problems
Water Resources Mgt	↑ **water storage**	• Ponds store water that can be re-used	Areas of high precipitation for ponds; streams store water	Maintenance and potential health hazard or nuisance e.g. insect reproducing in standing water; poor aesthetics if not well maintained
	↓ **evaporative water loss** due to shading	• Shading of water bodies by vegetation reduces water temperature rise and may reduce evaporative water loss	All water bodies, especially smaller ones that may be more heavily affected by solar radiation	Large vegetation, e.g. trees, provides shade and thus enhances the living conditions for aquatic wildlife, and possibly reduces evaporation from the water body surface, however, vegetation takes up water
Water Quality	↓ **peak flow rates** to ↓ stream bank erosion and sedimentation	• Water can be stored in designed depressions, e.g. detention basins, and other features thus reducing the volume and rate of water reaching a sewer • Trees and coarse woody debris as barriers • Trees intercept rainfall and roots increase soil infiltration rates	Areas of high precipitation; trees and coarse woody debris within floodplains, wetlands and other water collection and conveyance measures;	Water back up potentially leading to flooding upstream
	↓ **pollutant load** due to uptake and adsorption	• Vegetation takes up pollutants • Soils including structural soils (gravel-based) can adsorb pollutants and thus remove them from the water	Urban and rural areas, pollutant sources are cars, agriculture, industry etc	

Mapping of critical GI:

To be able to map where GI will be most useful to help us adapt to water issues it is necessary to determine how each function is fulfilled. Then the factors influencing these means equal the data needed to map the particular function.

The following table summarized the GI functions, the means through which the function is provided and the data required to map this function. The table is followed by a list of possible sources for the required data.

Table 8) GI functions, its means and the data required to map the function.

GI Function	Means	Data required
↑ drainage area	Pervious surface, e.g. pervious pavement, green and brown (open) surfaces	• land cover & land use data • rainfall
↓ flow rates	Water flow barriers of trees, coarse woody debris, low vegetation within floodplains and catchments; detention areas; soil infiltration, interception	• land cover/vegetation and open space (incl. trees and low vegetation) • topography • soil types • rainfall
↑ water storage	Detention and retention ponds, wetlands, rain gardens/bioretention, trees	• topography • land cover/water bodies • land cover/vegetation • SUDS/wetlands, ponds, bioretention
↑ rainfall interception	canopy and stems of vegetation, mainly trees	• Land cover/vegetation • rainfall
↑ soil infiltration	Coarse grained soils, roots increase soil infiltration, SUDS provide infiltration function	• Soil type • Land cover/land use (incl. vegetation, pervious/impervious etc) • SUDS • rainfall
↑ protection coastal floods by buffering	Vegetated or non-vegetated open space; wider area for detention; higher elevation for blocking water	• Land use/land cover • Topography • Sea level • storm
↑ runoff reduction	Evaporation from surfaces, transpiration by plants, interception, infiltration, water storage	• land use/land cover (incl. pervious vs. impervious cover, vegetation, water bodies) • temperatures • soil types • rainfall
↓ pollutant load of soil and water	Uptake by plants, soil filtration	• Difficult as surrounding industry, type, size, and condition of vegetations, climatic, soil conditions, and antecedent conditions may play a role

Sources for data required

Flood zone maps by the EA for fluvial and coastal flooding (do not include pluvial flood risk)

Climatic conditions

- **rainfall**
- **temperature** influencing evaporation and transpiration
  → *may not be useful to include in maps!*

→ rainfall and temp data from Met Office

→ UKCIP for the Weaver Valley

→ emailed Met Office to extend license for the NW

topography (in regards to depressions for storage and elevation resulting in water flow)
→ *DTM*
→ *resolution??*

→ data from the CEH, I have contacted John Packman and Mark Robinson

→ we have DTM for TMF

soil types and flood zones:
P:\Projects\Climate Change\Julia - Internship\data\soilsdata

→ soilscape more detailed data for £4-4,500

land use/land cover

- vegetation
- water bodies
- pervious and impervious surface
- land use change?????
- Catchments
- Floodplains

→ we have OS MasterMap for TMF

→ LCM2000 or LCM2007 when it comes out

Sea level (change) incl. during/after storms

Sewer data, incl. size, to determine sewer overflow potential

SUDS maps (land cover may be sufficient (and all we can get) for now)

Examples of Current Modelling/Mapping Approaches

- Flood Alleviation and Water Management model, NE NW

The flood alleviation model developed by Natural Economy NW covers well which benefits are provided by GI and were these benefits are reflected economically. It explains that improvements of quality of the environment, reduction in flood risk for highly polluted areas, and the encouragement of inward investments are the benefits of GI. These benefits would be reflected in economic values, which are increased land and house prices, reduction in insurance costs, lower clean up costs for local and central governments, increased economic activity, and lower costs for SUDS compared to engineered solutions. There are two factors that should be included within this model. The first benefits "Improvement in the quality of environment within urban and semi-urban locations" does not seem to include rural areas which I think should be included since they are 1) affected and 2) influencing water management. Upland land management has an impact on surface water/runoff, whereas downstream rural areas would be affected by pollution, stream bank erosion, and sedimentation. In addition, reduced sewer works resulting from a decrease in sewer pressure could be included.

- Weaver Valley

The Weaver Valley (see section on page 29) is a great example for a GI analysis on local level. The project consisted of 5 steps: 1. Partnership and Priorities, 2. Data Audit and Resource Management, 3. Functional Assessment, 4. Needs Assessment, and 5. Intervention Plan. GI types were defined and mapped to be able to assess the needs to develop an intervention plan which would include recommendations for GI implementations for the area to optimize GI benefits. GI functions regarding water issues were identified to be water storage, water interception, water infiltration/natural drainage, and coastal storm protection. I believe that this list needs to be extended to be:

- Conveyance
- infiltration / natural drainage
- interception
- Pollutant removal from soil/water
- storm protection - coastal
- Surface flow reduction through surface roughness
- water capture (no reuse potential)
- water storage (with reuse potential)

I feel that these functions better cover all the hydrological functions that GI offers.

Problems and Opportunities

One of the general problems seems to be that there is currently no real incentive. There is the automatic right to connect for new development which gives developers the right to connect to the nest sewer network. This may lead to several issues. One being that t may be difficult for sewer undertakers to plan for the future as it may not be clear how many developments and of which size will connect to the sewer network. This again may then lead to sewer overflows and thus flooding and pollution issues. This policy also results in no reason to even look for more sustainable solutions for water management because any solution may be more expensive for the developer then just to connect to the sewer network. This right however may be resented by the new Floods and Water Management Bill whose draft is currently out for review. Another way to increase or give an incentive to implement more sustainable solutions would be the "polluter pays" principle which would lead to more cost reflective charges by water companies. To manage road runoff LAs can connect to public sewers. However, they only pay a connection fee and no maintenance fee. However, maintenance is an important issue to assure the function of the system to avoid flooding.
Ofwat does recommend that water companies charge customers on an area of drained surface base but this is currently uncommon. Some have amended their tariff structure to include area-based charges for private non-household properties only. This, however, is not clear to me as I would assume that larger developed properties have a bigger influence on the volume and quality of runoff, thus the environment and human wellbeing, so these would be the properties where sustainable drainage and green infrastructure is most critical.
Some water companies give rebates to households whose surface water is disconnected. This seems to be a good approach to give an incentive to householders to implement for example pervious pavements or swales to drain the surface water from their property. However, these rebates seem to be rather small and barely known which then is not very effective. Bringing householders to implement pervious vs. impervious surface may be reached by extending planning permits so that impervious pavement require a permit but pervious ones don't. This reduction in time and effort may bring people to implement pervious surfaces thus decrease the amount of runoff on their property. Another improvement that may be included in the Floods and Water Bill is the inclusion of two new statutory nuisances, one of which is regarding surface runoff risk. Noise for example is a statutory nuisance as it can have a major effect on neighbouring home owners. The new statutory nuisance will come into play when properties receive runoff from neighbouring properties due to their large area of impervious surfaces. This again, may bring people to implement pervious surfaces if not more green spaces, vegetation, or SUDS.

Looking at related policies and organizations/entities is becomes clear that many statutory and non-statutory policies are involved. Many of which recommend the implementation of SUDS or the preservation of natural landscapes especially within floodplains. The problem though is that policies "have to be taken into account" or "have to have taken regards to". This practically means that planners can read them and thus "have taken regards" to the particular document yet decided not to follow the document's advice. Legally, the planner did not do anything wrong yet the policy's advice has not been followed.
Regarding involved organizations/entities is obvious that many different ones are involved. There are water companies and sewer undertakers, LAs, the EA, IDB (not within the NW)

and finally the property owner and all entities are having different goals and standards. When it comes to planning for rainfall events for example, the EA plans for 1-in-75 to 1-in-100 year rainfall events whereas LAs only plan for 1-in-5 year rains. With these many organizations/entities involved the ownership and maintenance of GI or SUDS is very difficult as nobody may feel the responsibility. The new Floods and Water Management Bill recognizes that no entity has any responsibility for flooding from surface runoff or groundwater and proposes responsibilities for each organization regarding flood and coastal erosion risk management, including the EA, LAs, and IDBs (Appendix D). For example, the EA will continue to have a strategic overview role, including being a statutory consultee, with also executive roles regarding flood risk management on main rivers and the sea and coastal erosion risk management work which is currently with LAs. LAs have a local leadership role and need to set local strategies for local flood risk management. They will also have the responsibility of coordinating the production of a surface water management plan. LAs will have the executive role for works for surface runoff and groundwater flood risk, amongst other duties. IDBs, district authorities, highway bodies, and water companies have the duty to undertake flood and coastal erosion risk management functions in accordance with the local and national strategies.

One major issue that prevents the implementation of GI and SUDS is that there are many unknowns. People do not have sufficient information regarding maintenance requirements and the longevity of systems thus they do not know what the long-term costs will be and not even the ownership may be clear. In addition, the efficiency of the “soft” solutions as it may not be as confidently calculated as engineered solutions.

However, I believe that if flood mapping and the identification of GI has been done adequately and if there are sufficient show cases available so planners can see that and how a system works and how many different and functioning designs are out there, people may be more inclined to implement a soft solution when they realize that they are efficient, sustainable, and provide all the many functions that GI provides for the environment, community, and economy.

Conclusion

Flooding from all sources, fluvial, coastal, and pluvial is a major threat to society. Falls, winters, and spring will get wetter whereas summer will get hotter and drier which more frequent heavy rainfalls. This, and the development on floodplains, has major influences on flooding events within the floodplain its capacity and natural drainage is impaired and downstream since rivers collect high volumes of water leading to flash floods within the river and downstream floodplains. These high rivers in combination with high volumes urban runoff and insufficient sewer networks also lead to pluvial floods through runoff and sewer overflows. Statutory and non-statutory policies encourage the preservation of natural landscapes and the implementation of natural/open spaces and SUDS. However, there is no real incentive to do so since new developments are “automatically” allowed to connect to the sewer network leaving no reason to implement a more sustainable solution. This is decision is strengthened by the fact that there are no standards for “soft” solutions out there that will give clear information of the efficiency, longevity, and economy of alternative solutions. Maintenance costs are unclear, ownership is unclear, and potential nuisances or risks are unclear. We need data to map flood risks from all sources plus hard data on soft solutions so we can have a convincing argument for why green infrastructure is not just optimal but essentially necessary in certain areas. In addition, arguments need to be aimed for the particular target group. More reasons are not necessarily better, fewer well chosen and well aimed reasons would be more convincing. More case studies or show cases will be useful so doubtful minds can see the potential and functionality of green infrastructure.

In regards to policies, the new Floods and Water Management Bill may be essential as it clearly identifies the responsibilities of the involved organizations, plus it may resent the "automatic right to connect" for new developments and will require SUDS to be implemented at new developments where practicable. However, the wording may always be an issues; SUDS are required for new developments "where practicable" lets us believe already that this will not be followed. However, I think that if we include all data and information of flood risk, capability of GI, and costs for flood prevention/defence and from damages plus climatic projections, I hope that people will see that need and potential of GI for water management.

Personal Conclusion

I very much enjoyed working on this project within this team. I think it is very important but it is also very interesting and applied. However, I feel that 4 months were clearly not enough to understand the policies and organizations involved and the projects and models currently or recently done. There is more to take in than possible and now that I have to leave I am at the stage where I feel that I understand the situation well and could therefore really focus on the issues. I hope that this project will continue well and I hope to have contributed a little bit even though it was not nearly as successful or detailed as I had hoped.

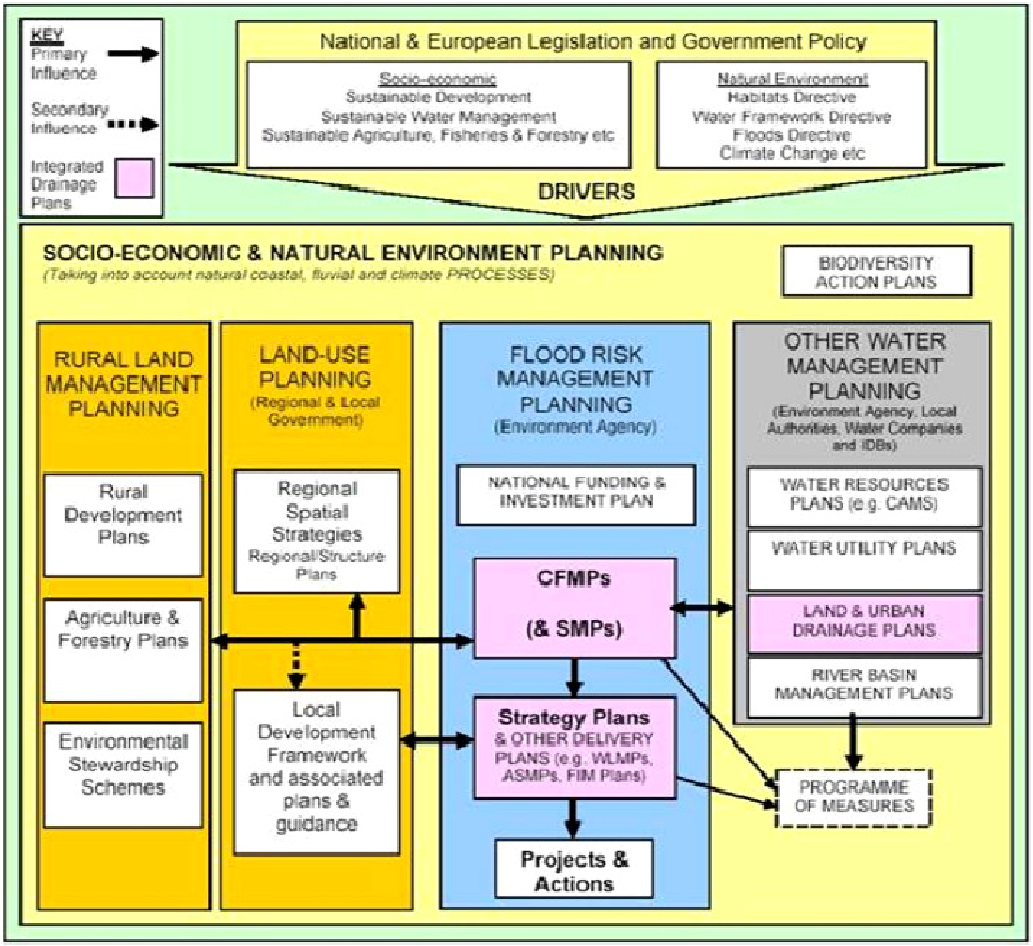
I very much appreciate that you let me work on this project. I have learned a lot about work outside of academia and about myself. It would be great if I somehow could stay involved, hopefully we will stay in touch.

References

1. The World Conservation Union. 2006. Climate Change and Nature. Adapting for the Future.
2. Pitt, M. 2008. The Pitt Review. Learning lessons from the 2007 floods - Full Report
3. Munich Re Group. Natural catastrophes 2007. Analysis, assessment, position *in* Knowledge Series. Topics Geo.
4. Jenkins, G., M. Perry, and M. Prior. 2007. UKCIP08. The Climate of the United Kingdom and recent trends. Met Office Hadley Center, Exeter.
5. Parliament Office of Science and Technology. 2007. urban flooding. postnote. (289).
6. Woods-Ballard, B., et al. 2007. The SUDS Manual. CIRIA, London.
7. White, L. and J. Howe. 2004. The mismanagement of surface water. Applied Geography. 24(4): p. 261-280.
8. 2004. Foresight Future Flooding *in* Scientific Summary Vol. 1. Office of Science and Technology, London.
9. Xiao, Q. and E. McPherson. 2002. Rainfall interception by Santa Monica's municipal urban forest. Urban Ecosystems. 6: p. 291-302.
10. Calder, I., et al. 2008. Woodland actions for biodiversity and their role in water management. Woodland Trust.
11. Bramley, H., J. Hutson, and S.D. Tyerman. 2003. Floodwater infiltration through root channels on a sodic clay floodplain and the influence on a local tree species Eucalyptus largiflorens. Plant and Soil. 253(1): p. 275-286.
12. Bartens, J., et al. 2008. Can urban tree roots improve infiltration through compacted subsoils for stormwater management? Journal of Environmental Quality. 37: p. 2048-2057.
13. Thomas, P. 2000. Trees: Their Natural History. Cambridge, United Kingdom: Cambridge University Press.
14. Hinckley, T.M., et al. 1994. Water flux in a hybrid poplar stand. Tree Physiology. 14(7/9): p. 1005-1018.
15. Cermák, J., et al. 2000. Urban tree root systems and their survival near houses analyzed using ground penetrating radar and sap flow techniques. Plant and Soil. 219(1/2): p. 103-116.
16. Meinzer, F.C., et al. 2005. Does water transport scale universally with tree size? Functional Ecology. 19(4): p. 558-565.
17. Simpson, D.G. 2000. Water use of interior Douglas-fir. Canadian Journal of Forest Research. 30(4): p. 534-547.
18. Wheater, H., et al. 2008. A multi-scale modelling procedure to quantify effects of upland land management on flood risk. *in* FLOODrisk Keble College, Oxford.
19. Thomas, H. and T. Nisbet. 2007. An Assessment of the impact of floodplain woodlands on flood flows. Water and Environment Journal. 21(2): p. 114-126.
20. European Union. 2008. Water Our Wealth. *in* International Exposition Zaragoza.
21. European Commission. 2007. European Directive on the Assessment and Management of Flood Risks (the Floods Directive).
22. 2000. The Building Regulation. No. 2531.
23. 2006. Planning Policy Statement 25: Development and Flood Risk.
24. 2005. Planning Policy Statement1: Delivering Sustainable Development. Office of the Deputy Prime Minister.

25. 2007. Planning Policy Statement1: Planning and climate change (supplement to PPS1) Communities and Local Government.
26. Bassuk, N., J. Grabosky, and P. Trowbridge. 2005. Using Structural Soil™ in the Urban Environment.
27. 2008. Regional Spatial Strategy -Regional Flood Risk Appraisal (North West). North West Regional Planning.
28. 2008. Managing Flood Risk. Mersey Estuary Catchment Flood Management Plan Environment Agency.
29. Section 106 (S106) *in* Town and Country Planning Act 1990.
30. Defra. 2007. Annex B - Impact assessment on the institutional arrangements required to promote integrated urban drainage management - early options for stakeholder comment *in* Making Space for Water Environment Agency Strategic Overview: Inland Flood Risk Management. Department for Environment Flood and Rural Affairs.
31. Day, S.D., and S.B. Dickinson (Eds.). 2008. Managing Stormwater for Urban Sustainability using Trees and Structural Soils. Virginia Polytechnic Institute and State University, Blacksburg, VA.
32. Villarreal, E., A. Semadeni-Davies, and L. Bengtsson. 2004. Inner City stormwater control using a combination of best management practices. Ecological Engineering 22 p. 279-298.
33. Leeds City Council. 2008. West Garforth Integrated Urban Drainage Pilot Study.
34. Doncaster, S., V. Stovin, and B. Morrow. 2008. Lower Irwell Valley, Salford, Integrated Urban Drainage Pilot Project, TRE344.
35. Weaver Valley. 2008. A Green Infrastructure Plan for the Weaver Valley. *prepared by* The Mersey Forest.
36. Cappiella, K., T. Schueler, and T. Wright. 2005. Urban Watershed Forestry Manual Part 1: Methods for increasing forest cover in a watershed. *prepared for and published by* USDA Forest Service.
37. Hodge, S. 1995. Creating and managing woodlands around towns. Handbook 11. Forestry Commission. HMSO. London, UK.

Appendix A Environment Agency Planning Framework



Appendix B SUDS Fact sheets

SUDS incorporating vegetation

Green Roofs	
  images: earthfirst.com/10-photos-of-stunning-green-roofs-from-around-the-world/	
Space requirements	Require no additional space
Drainage area	
Costs	No land-take costs, low to high capital costs, medium maintenance cost
Maintenance	Irrigation during establishment of vegetation, inspection for bare soil and plant replacement, litter removal
Site suitability	Residential, commercial/industrial, high density, retrofit, contaminated sites and sites above vulnerable groundwater
Performance	Medium peak flow & volume reduction, good water quality treatment and amenity & ecology potential
Pollutant removal	Medium heavy metal removal, low for nutrients and high for total suspended solids
Advantages	- sound absorption - air quality improvement by e.g. removing atmospheric pollutants - reduces the expansion and contraction of roof membranes - building insulation - no land-take - ecological, aesthetic and amenity value (improves biodiversity; Dusty Gedge "The case for Living Roofs" at WaterWise 2009) - potential to retrofit - suitable for high density areas - mimics building footprint from before development - optimal below photo voltaic systems (PVs) as green roofs keep temperature cooler and more suitable for PVs (Dusty Gedge "The case for Living Roofs" at WaterWise 2009)
Disadvantages	- not suitable for steep roofs - roof structure may not be sufficient for retrofitting - root vegetation maintenance - damaged to waterproof membrane more critical as water is to remain on the roof

Filter strips

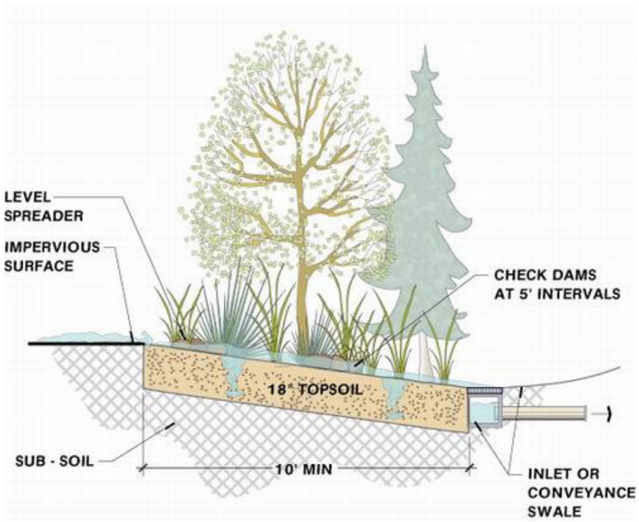


image: www.land2plan.com/Stormwater.htm

Space requirements	1 m width for every 6 m "length" of drainage area; between 6 and 15 m effective in regards to water quality performance
Drainage area	A suggested maximum length of 50 m of impervious area draining
Costs	High land-take costs, low capital and maintenance costs
Maintenance	Mainly litter/debris removal, mowing, and repair of eroded or damaged areas plus half yearly monitoring
Site suitability	Residential, commercial/industry, high density, retrofit
Performance	Medium water quality treatment and amenity & ecological potential; poor peak flow & volume reduction
Pollutant removal	Medium for heavy metals and total suspended solids, low for nutrients
Advantages	- Well-suited adjacent to large impervious area - Encourages evaporation and infiltration - Easy and inexpensive to construct - Integratable into landscape with aesthetic benefits (if designed for this purpose)
Disadvantages	- Large area required - Not suitable for steep sites - Not suitable for drainage of pollution-loaded runoff unless infiltration is prevented - No significant reduction of extreme flows

Swales

image: www.urbandesigncompendium.co.uk

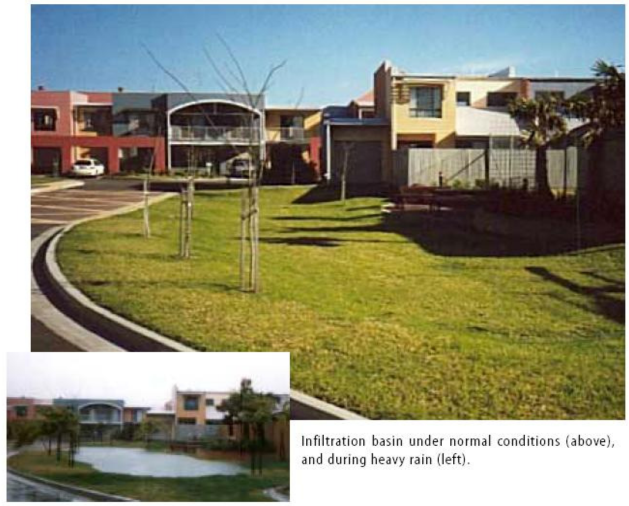
Space requirements	Difficult to incorporate into densely developed urban areas as the system requires significant land-take
Drainage area	For catchment with small impervious areas
Costs	High land-take, medium maintenance, low capital costs
Maintenance	Litter/debris removal, mowing and removal of grass cuttings, clearing of inlets, culverts and outlets from debris and sediments, repair of eroded or damages areas
Site suitability	Residential, commercial/industry, and if used with liner suitable for contaminated sites located above vulnerable groundwater
Performance	Medium peak flow & volume reduction and amenity & ecology potential, good water quality treatment
Pollutant removal	Low nutrient removal, medium removal of heavy metals, high totals suspended solid removal
Advantages	- easily incorporated into landscapes - good removal of pollutants - reduction in runoff rates and volumes - low capital costs - pollution and blockages easily detectable - maintenance can be included in general landscape management
Disadvantages	- not suitable for steep areas or areas with roadside parking - limited suitability for incorporating trees - risks of blockages in connecting pipes

Bioretention

images: www.deldot.gov/stormwater/bmp.shtml and www.flickr.com/photos/perryeck/2694571290/

Space requirements	Typically 5-10% of the overall site area
Drainage area	small catchments, larger sites can be divided up into multiple bioretention areas
Costs	Low capital costs, medium maintenance costs and high land-take costs
Maintenance	Litter/debris removal, replacement of mulch layer, vegetation management, soil spiking and scarifying, regular inspections
Site suitability	Residential, commercial/industry, retrofit and contaminated sites and sites above vulnerable groundwater if liners are used
Performance	Medium peak flow & volume reduction (good for infiltration) and ecology potential, good water quality treatment and amenity potential
Pollutant removal	High for total suspended solids and heavy metals, low for nutrients
Advantages	- landscape feature - effective pollutant remover - runoff rate and volume reduction - flexible layout - suited for highly impervious areas, if designed right - good retrofit
Disadvantages	- requires landscaping and management - susceptible to clogging if surrounding landscape is poorly managed - not suited for areas with steep slopes

Infiltration basins



Infiltration basin under normal conditions (above), and during heavy rain (left).

images: gustavesp.wordpress.com/2009/02/16/water-sensitive-home/

Space requirements	Large land-take systems which cannot be used for other purposes as their performance would be jeopardized
Drainage area	Suitable for most to all drainage areas granted appropriate pre-treatment (via SUDS management train)
Costs	High land-take costs, low capital and maintenance costs
Maintenance	Regular inspections for clogging and other blockages, litter/trash removal, inlet/outlet cleaning, sediment removal from pre-treatment
Site suitability	Residential and commercial/industrial
Performance	medium peak flow reduction, good volume reduction, water quality treatment and amenity & ecological potential
Pollutant removal	High total suspended solids and heavy metal removal, medium nutrient removal
Advantages	- runoff volume reduction - potentially efficient in removing pollutants through filtering - contributes to groundwater recharge and increase in baseflows - simple and cost-effective construction - performance changes easily observed
Disadvantages	- high failure rate if poorly designed or improper siting and maintenance - comprehensive geotechnical assessment needed to confirm suitability for infiltration - inappropriate for draining areas with pollution hotspot - large area required

Detention basins

images: retrofit-suds.group.shef.ac.uk and www.cambridgeshire.gov.uk

Space requirements	Depending on the design dual purpose possible
Drainage area	No maximum catchment area that it can be used for. For small catchments a small throttle diameter may be needed which may be prone to clogging and therefore needs special attention
Costs	Low capital and maintenance costs and medium cost for land-take
Maintenance	Litter/trash removal, inlet/outlet cleaning, vegetation management, sediment monitoring and removal as needed
Site suitability	Residential, commercial/industrial, high density, retrofit, contaminated sites and, with liner, above vulnerable groundwater
Performance	Poor volume reduction, medium water quality treatment and ecology potential and good peak flow reduction and amenity potential
Pollutant removal	Low nutrient removal and medium total suspended solids and heavy metal removal
Advantages	- suitable for a wide range of rainfalls - can be used above vulnerable groundwater (if lined) - simple to design and construct - easy maintenance - safe and visible capture of spillages - dual land use potential
Disadvantages	- little reduction in runoff volume - detention depth limited by inlet and outlet levels

Ponds

image: www.building.co.uk

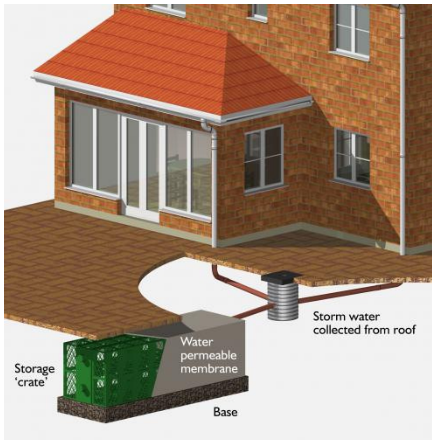
Space requirements	Typically 3-7% of the upstream catchment area
Drainage area	Small ponds may have limited benefits and higher maintenance requirements but otherwise there is no specific drainage area constraint
Costs	High land-take and medium maintenance and capital cost (high capital cost if a liner is installed)
Maintenance	Litter/debris removal, inlet/outlet cleaning, vegetation management, sediment monitoring and removal as needed
Site suitability	Residential, commercial/industrial, contaminated sites and (with liner) sites above vulnerable groundwater; unlikely to be suitable as retrofit and in high density areas
Performance	Good peak flow reduction, water quality treatment and amenity & ecology potential, poor volume reduction
Pollutant removal	Medium nutrient removal, high total suspended solids and heavy metal removal
Advantages	- suitable for all rain events - good removal capability of urban runoff pollutant - suitable where groundwater is vulnerable (with liner) - ecological, aesthetic and amenity benefits - may increase local property values
Disadvantages	- no effect on runoff volume reduction - potential for anaerobic conditions when intake is irregular - land-take may limit use in higher density areas - may be unsuitable for steeper slopes because the design requires high embankments - perceived health & safety risk may lead to instalment of fences and isolation of the pond - colonization by invasive vegetation may lead to an increased maintenance need

Stormwater Wetlands

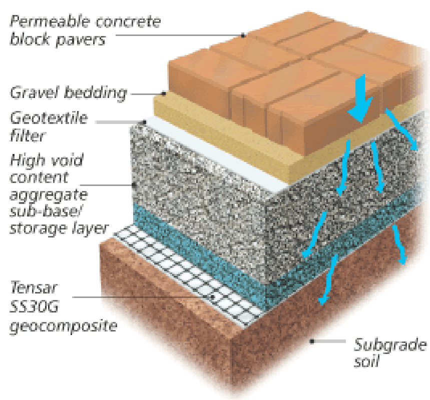
image: www.ciria.org.uk

Space requirements	Typically larger space required than for ponds
Drainage area	Continuous baseflow or groundwater seepage required
Costs	High land-take and capital costs, low to medium maintenance burden
Maintenance	Litter/trash/debris removal, inlet/outlet cleaning, vegetation management, sediment monitoring and removal as needed
Site suitability	Residential, commercial/industrial, contaminated sites and, with liner, sites above vulnerable groundwater. Unlikely to be suitable as retrofit or in high density areas due to size requirements
Performance	Good peak flow reduction, water quality treatment and amenity & ecology potential, poor volume reduction
Pollutant removal	Medium nutrient removal, high removal of total suspended solids and heavy metal
Advantages	- removes urban runoff pollutants well - if lines suitable above vulnerable groundwater - community value - ecological, aesthetic and amenity value - may increase property values
Disadvantages	- high land-take - baseflow necessary - limited depth range for flow attenuation - potential nutrient release during non-growing season - limited reduction in runoff volume - not suitable at steep slopes - maintenance increase through colonization by invasive species - performance may be jeopardized by sediment inflows - perceived health and safely risks may lead to fencing and isolation of the wetland

SUDS without vegetation

Soakaways	
 image: www.burdensenvironmental.com/sustainable-urban-drainage-systems-suds/rainwater-soakaway-systems	
Space requirements	When sub-surface no net land-take. Different sizes and shapes available to provide suitability for most sites.
Drainage area	Often used for individual properties but can be used for single large unit or linked groups of units, roads or parking areas; greater care may be needed.
Costs	Low land-take, capital and maintenance costs
Maintenance	Removal of sediments/debris from pre-treatment device, performance monitoring
Site suitability	Residential, commercial/industrial, high density, retrofit
Performance	Poor amenity & ecology potential, good peak flow & volume reduction and water quality treatment
Pollutant removal	Low nutrient removal, medium removal of total suspended solids and heavy metals
Advantages	- little land-take - improves groundwater recharge - good volume and peak flow reduction - easy construction and operation - retrofitable - good community acceptability
Disadvantages	- not suitable for soil with poor infiltration - soil tests for infiltration rates required - not suitable where infiltrating water may jeopardize integrity of the structural foundation or existing drainage patterns - inappropriate for draining polluted runoff - may increase risk of groundwater pollution - uncertainty regarding longevity of the system - potential decrease of performance during long wet periods - performance depend on operation and maintenance

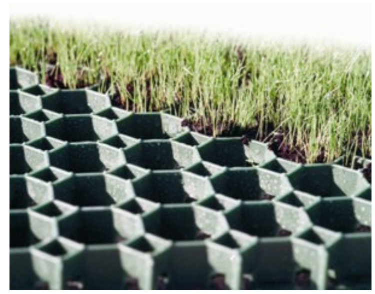
Pervious Pavement



images: www.tensarinternational.com and www.chameleonways.com

Space requirements	Used as alternative to conventional pavement so no additional space is required
Drainage area	Generally accepts rain that directly falls on its surface. If water from other areas is drained the capacity depends on the available sub-base volume
Costs	Low net land-take, net capital and maintenance cost, medium capital cost
Maintenance	Sweeping and vacuuming & brushing regularly
Site suitability	Residential, commercial/industrial, high density, retrofit, contaminated sites and (with liner) sites above vulnerable groundwater
Performance	Good peak flow & volume reduction and water quality treatment, poor amenity & ecology potential
Pollutant removal	High for total suspended solids, nutrients and heavy metals
Advantages	- effective in removing pollutants - runoff rate and volume reduction - suitable for high density areas - good retrofit - no additional land-take - low maintenance - eliminates surface ponding - good community acceptability
Disadvantages	- cannot be used where large amounts of sediments may reach the surface - risk of long-term clogging and weed growth if not properly maintained

Geocellular/modular systems

images: www.acheson-glover.com and www.grass-reinforcement.com

Space requirements	No add space needed as the system is sited underground
Drainage area	They can be designed for almost any size drainage area. Effective upstream pre-treatment; to limit silt accumulation, the area draining to a particular tank should be as small as practical
Costs	Land-take, capital and maintenance costs are low
Maintenance	Regular inspection of manholes, pipework and pre-treatment devices with removal of sediment and debris
Site suitability	Residential, commercial/industrial, high density, retrofit, contaminated sites and with liner sites above vulnerable groundwater
Performance	Poor volume reduction, water quality treatment and amenity & ecology potential, good volume reduction, if infiltration is provided, and peak flow reduction
Pollutant removal	Low removal of total suspended solids and heavy metals, no nutrient removal
Advantages	- modular and flexible - high storage capacity - lightweight - capable of managing high flow events - can be installed under high or low traffic areas, and beneath open public space - long-term stability (physical and chemical)
Disadvantages	- no water quality treatment

Water butts	
  image: www.greenandeasy.co.uk and www.langhalegardens.co.uk/shop/products/pumps/water_butt.htm	
Space requirements	Very little extra space needed (0.5 m can accommodate 0.25 m^3 unit)
Drainage area	Usage typically limited to roofs residential buildings and/or ancillary buildings
Costs	No land-take costs and low costs for capital and maintenance
Maintenance	Inspection for blockages (inlet/outlet) and silt & debris removal
Site suitability	Residential, commercial/industrial, high density, retrofit, contaminated site and sites above vulnerable groundwater
Performance	Low peak flow & volume reduction and water quality treatment, poor amenity & ecology potential
Pollutant removal	Low removal of total suspended solids, nutrients and heavy metals
Advantages	- easy to construction, installation and operation - retrofitable - inexpensive - some stormwater management benefits - provides water for non potable water usage
Disadvantages	- high risk of blockages of small throttles - limited water quality treatment - performance depend upon operation and maintenance

SUDS with or without vegetation

Infiltration and Filter Trenches

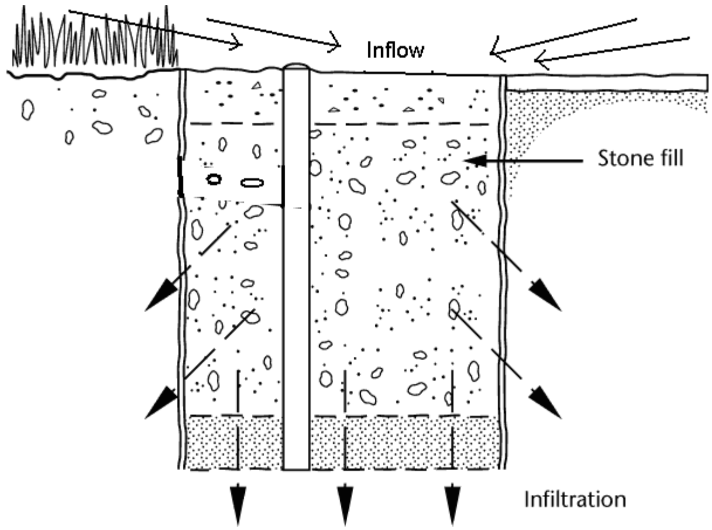


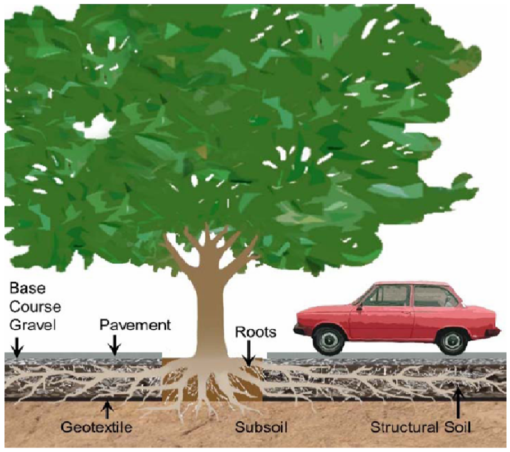
image: www.netregs.gov.uk

Space requirements	Land-take requirement may be small if designed right, system can be incorporated into landscapes and public open spaces
Drainage area	Suitable for catchments with small impervious areas
Costs	Low for land-take, medium for maintenance, capital cost low (IT) to medium (if liner is required)
Maintenance	Removal of sediments, removal and cleaning or replacement of stones, Regular inspection for clogging
Site suitability	Residential, commercial/industry, high density and retrofit
Performance	Good water quality treatment, medium peak flow reduction and poor amenity & ecology potential, volume reduction is poor for filter and high for infiltration trenches
Pollutant removal	Nutrient removal is low to medium whereas removal or total suspended solids and heavy metals is high
Advantages	- Runoff rates and volumes can be reduced - Reduction in pollution load released to water body through infiltration - Easy incorporation of trenches into landscapes and beside roads
Disadvantages	- high potential for clogging without pre-treatment, not suitable for sites with fine particled soils upstream - accumulated pollutants and blockages difficult to notice - if not maintained adequately system is prone to failure - small catchment - high cost for filter replacement in case of blockage

Sand Filter

image: ciceet.unh.edu/unh_stormwater_report_2007/treatments/sand_filter/index.php

Space requirements	Can be incorporated in to most sites as they can be surface or underground filters
Drainage area	Suitable for most catchment sizes with appropriate pre-treatment and flow management system
Costs	Low land-take costs, high capital and maintenance costs
Maintenance	Regular inspection for performance reduction, litter/debris/trash removal, inlet/sedimentation cleaning, replacement/rehabilitation of filter layer, vegetation management
Site suitability	Residential, commercial/industrial, high density, retrofit, contaminated sites and, with liner, sites above vulnerable groundwater
Performance	Good water treatment, poor peak flow & volume reduction and amenity & ecology potential
Pollutant removal	High total suspended solids and heavy metal removal, low for nutrients
Advantages	- flexible design - efficient in removing various urban runoff pollutants - suitable for high density areas and as retrofit
Disadvantages	- not suitable for areas with runoff with high sediment load - negative aesthetic value, possibly nuisance through odour - possible nitrate generation from sand filters - not suitable for large catchment areas - high capital and maintenance costs

Structural Soil [31]	
 image: Sarah B. Dickinson	
Space requirements	no additional space is required as the system is below ground
Drainage area	Generally accepts rain that directly falls onto the pavement above. If water from other areas is drained the capacity/depth of the system may have to be designed deeper
Costs	No land-take, low maintenance, medium capital costs. Excavation, mix of the substrate and implementation lead to costs that depend on location (distance to quarry etc) and design (size, depth etc)
Maintenance	Clearance of drains/pipes from litter and debris, if pervious pavement is used its maintenance may be necessary to assure function (Sweeping and vacuuming & brushing regularly)
Site suitability	Residential, commercial/industrial, high density, retrofit, contaminated sites and (with liner) sites above vulnerable groundwater
Performance	high peak flow & volume reduction, medium water quality treatment, amenity & ecology potential if used with vegetation
Pollutant removal	Medium?? Not sure how to compare to other BMPs (for suspended solids, heavy metals, and nutrients)
Advantages	- reduces runoff volume and peak flows - improves tree growth due to higher available soil volume for root exploration - no land-take as implemented below pavement - pollutant removal - can be designed for wetter and drier areas as reservoir depth can be modified
Disadvantages	- no long-term data on pollutant removal -

Rainwater Harvesting

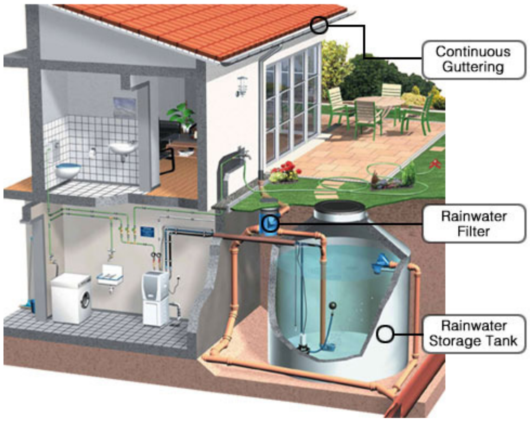


image: www.brokencitylab.org/author/josh/ and www.scarp.ubc.ca/Newsbytes/March%202003/SCARP_Newsbytes_March_2003.html

Space requirements	
Drainage area	Water from any surface can be used, depending on the usage different water quality requirements need to be met
Costs	No land-take costs, high capital and medium maintenance costs
Maintenance	Inspection and cleaning of collection systems, filters, throttles, valves and pumps
Site suitability	Residential, commercial/industrial, high density, retrofit, contaminated sites and sites above vulnerable groundwater
Performance	Poor water quality treatment and amenity & ecology potential, high volume & peak flow reduction
Pollutant removal	Low nutrient removal, medium heavy metal and high removal of total suspended solids
Advantages	- depending of the design the system can decrease runoff - reduces mains water demand
Disadvantages	- potential risk to public health - system can be complex and costly to install - can be unaesthetic when tanks are above ground

Appendix C Species adapted to particularly wet sites [37]

Deciduous	*Coniferous*
Alder buckthorn (*Frangula alnus*)	Lodgepole pine (*Pinus contorta*)
Aspen (*Populus tramula*)	Sitka spruce (*Picea sitchensis*)
Bay willow (*Salix pentandra*)	Western hemlock (*Tsuga heterophylla*)
Black poplar (*Populus nigra var. betulifolia*)	
Box elder (*Acer negundo*)	
Caucasian alder (*Alnus subcordata*)	
Common alder (*Alnus glutinosa*)	
Common osier (*Salix viminalis*)	
Crack willow (*Salix fragilis*)	
Goat willow (*Salix caprea*)	
Green ash (*Fraxinus pennsylvanica*)	
Grey alder (*Alnus incana*)	
Grey poplar (*Populus canescens*)	
Grey sallow (*Salix cinerea*)	
Hybrid black poplars (*Populus x canadensis*)	
Italian alder (*Alnus cordata*)	
Pin oak (*Quercus palustris*)	
Red alder (*Alnus rubra*)	
Red maple (*Acer rubrum*)	
Silver maple (*Acer saccharinum*)	
Sweetgum (*Liquidamber styraciflua*)	
Western balsam poplar (*Populus trichocarpa*) and cultivars	
White birch (*Betula pubescens*)	
White mulberry (*Morus alba*)	
White poplar (*Populus alba*)	
White willow (*Salix alba*)	

Species native to Great Britain [37]

Deciduous	*Coniferous*
Alder buckthorn (*Frangula alnus*)	Scots pine (*Pinus sylvestris*)
Aspen (*Populus tremula*)	
Bay willow (*Salix pentandra*)	
Bird cherry (*Prunus padus*)	
Black poplar (*Populus nigra var. betulifolia*)	
Broad-leaved lime (*Tilia platyphyllos*)	
Common alder (*Alnus glutinosa*)	
Common hawthorn (*Crataegus monogyna*)	
Common osier (*Salix viminalis*)	
Crab apple (*Malus sylvestris*)	
Crack willow (*Salix fragilis*)	
English oak (*Quercus robur*)	
Field maple (*Acer campestre*)	
Goat willow (*Salix caprea*)	
Grey poplar (*Populus canescens*)	
Grey sallow (*Salix cinerea*)	
Guelder rose (*Viburnum opulus*)	
Hazel (*Corylus avellana*)	
Holly (*Ilex aquifolium*)	
Hornbeam (*Carpinus betulus*)	
Rowan (*Sorbus aucuparia*)	
Small-leaved lime (*Tilia cordata*)	
White birch (*Betuia pubescens*)	
White willow (*Salix alba*)	

Other Species suitable as urban trees [37]

Deciduous	*Coniferous*
Bitternut (*Carya cordiformis*)	Atlas cedar (*Cedrus atlantica*)
False acacia (*Robinia pseudoacacia*)	Coast redwood (*Sequoia semperivens*)
London plane (*Platanus acerifolia*)	Corsican pine (*Pinus nigra var. maritima*)
Maidenhair tree (*Ginkgo biloba*)	Dawn redwood (*Metasequoia glyptostroboides*)
Norway maple (*Acer platanoides*)	Hybrid larch (*Larix x eurolepis*)
Pear (*Pyrus communis*)	Lawson cypress (*Chamaecyparis lawsoniana*)
Sycamore (*Acer pseudoplatanus*)	Leyland cypress (*x Cupressocyparis Ieylandii* 'Leighton Green')
Turkish hazel (*Carylus calurna*)	Norway spruce (*Picea abies*)
	Swamp cypress (*Taxodium distichurn*)
	Western hemlock (*Tsuga heterophylla*)
	Western red cedar (*Thuja plicata*)

Appendix C Proposed future roles and responsibilities for flood and coastal erosion risk management in England

(Flood and Water Management Bill Draft, 2008)

Environment Agency

Strategic overview role

- Setting National Strategy for Flood and Coastal Erosion Risk Management.
- Support and guidance to LAs, e.g in producing flood risk assessments and plans.
- Develop modelling, mapping and warning systems.
- National investment in flood and coastal erosion risk management measures.
- Report to the Secretary of State on the state of the Nation's flood risk assets.
- Powers to instigate works on non-EA assets and channels when directed to do so by the Secretary of State.
- Statutory consultee on flood (and possibly in future coastal erosion) planning applications.

Delivery/executive role

- Flood risk management on main rivers and the sea.
- Coastal erosion risk management work (concurrently with local authorities).
- Flood warnings for all sources of flooding.
- Produce and contribute to strategic plans.
- Consenting and enforcement powers for sea and main river flooding.
- Category 1 responder under the Civil Contingencies Act 2004.

Local Authorities (LAs)

Local leadership role (county councils in two tier areas)

- Setting Local Strategy for local flood risk management.
- Leadership and accountability for ensuring effective management of local flood risk from ordinary watercourses, surface run-off and groundwater.
- Production of local flood risk assessments, maps and plans including an asset register.
- Improved drainage and flood risk management expertise.
- Co-ordinate Surface Water Management Plan production.
- Drainage from non-Highways Agency roads
- Prioritising local investment.
- Consenting and enforcement powers for certain works affecting ordinary watercourses.
- Promoting partnerships with local planning authorities to produce Strategic Flood Risk Assessments.

Delivery/executive role

- Powers to do works for surface run-off and groundwater flood risk.
- Duty to undertake Flood and Coastal Erosion Risk Management functions in accordance with local and national strategies.
- LFRM decision-making integrated into local asset management and investment programmes.
- Category 1 responder under the Civil Contingencies Act including local delivery of flood warnings.

EA's Regional Flood and Coastal Committees (currently Regional Flood Defence Committees)

- Advisory/consultative role to EA and LAs on flood and coastal erosion approaches, priorities etc.
- Consent to levies for local priority flood and coastal erosion risk management work with executive responsibility for work in this area.

Internal Drainage Boards, district authorities (in two-tier areas),highways bodies, water companies

Executive/Delivery Role

- Duty to undertake Flood and Coastal Erosion Risk Management functions in accordance with local and national strategies.
- We consult in section 3 on IDB structures, powers and levy raising options.