SuDS in London - a guide

November 2016

MAYOR OF LONDON

TRANSPORT FOR LONDON
EVERY JOURNEY MATTERS

Contents

Introduction

1 Background

The risk of flooding in London increases year on year, with more frequent and intense storms and significant quantities of surface water runoff. (This is the movement of rainwater over the surfaces of the city, including the ground, streets, footways and roofs.)

London's existing network of sewers and drains is at or near capacity in many areas and the issue is exacerbated by a rapidly increasing population. This has already exceeded London's previous peak and is reflected in the scale of development in the city.

Sustainable drainage systems (SuDS) can help address flooding risks by managing surface water runoff in a way that mimics natural processes, slowing down the runoff rate while providing wider benefits, such as public realm improvements. This is consistent with TfL's overarching 'Healthy Streets' programme.

This guidance seeks to show how SuDS can be incorporated into London's streets and wider public realm. It highlights potential opportunities and constraints and aims to encourage the relevant authorities across London to consider their streetscape and the possibilities of successfully integrating SuDS.

Potters Fields Park

Broken kerb detail for bioretention

II Who is the guidance for?

Primarily aimed at a non-technical audience, with advice for those who design, build, operate and maintain London's streets and public realm, this guidance also aims to bring SuDS to a wider audience, such as design professionals, academics, road user groups, local communities, politicians and other stakeholders.

The Construction Industry Research and Information Association (CIRIA) has produced a more comprehensive and technical document: **C753 The SuDS Manual 2015** and reference is made to this document throughout.

This guidance should not be an alternative to the SuDS manual; it is a companion which seeks to inform and inspire those interested in delivering SuDS in the Capital. Although London has its unique challenges, the content will hopefully also be seen as relevant to other UK towns and cities.

III Surface water and SuDS

The Mayor's Climate Change Adaptation Strategy (GLA 2011) identified surface water flood risk as the greatest short-term climate risk to London. This occurs when the rate of flow exceeds what can be absorbed either by drainage systems (the sewers) or open ground, and is called surface water exceedance.

When the sewer network is full and rainwater cannot get into it fast enough, flooding occurs (pluvial flooding). This can occur independently or simultaneously with fluvial flooding (where rivers and streams are surcharging). The resultant flooding has a significant impact on communities, property and the highway. SuDS help reduce the speed and quantity of surface water flow to the drainage system. They include above-ground and below-ground elements and many of the above-ground elements are discussed in Chapter 3. This guidance is concerned with the integration of such measures into the public realm and therefore looks mainly at above-ground measures.

IV A SuDS approach

"SuDS are designed to maximise the opportunities and benefits we can secure from surface water management".
CIRIA C753 The SuDS Manual 2015, p6

A SuDS approach will:

- Manage surface water runoff in a way that mimics natural processes

- Deliver multiple benefits from rainwater, based on the four pillars of SuDS. These are:

    - water quantity
    - water quality
    - amenity
    - biodiversity

- Work with the natural hydrological cycle to re-use, reduce and change the flow and quality of runoff

- Use a holistic, catchment-based approach

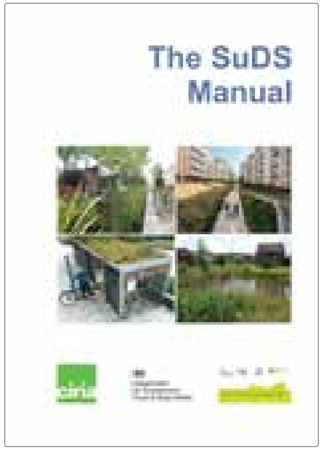
- Engage with stakeholders and communities to share knowledge and change attitudes

- Help address climate change-related issues

V How should I use the guidance?

The guidance should be used to gain a basic understanding of SuDS and how they can be applied in London. It should be read alongside CIRIA C753 The SuDS Manual 2015, which provides industry standards in this area, and other street-related TfL and Greater London Authority (GLA) guidance which give a wider understanding of London's public realm, including:

- Streetscape Guidance 2016
- London Cycle Design Standards 2014
- London Sustainable Drainage Action Plan 2016



CIRIA C753 The SuDS Manual, 2015

VI Structure of the guidance

Chapter 1: Principles of SuDS
Sets out the SuDS planning policy environment, the four pillars of SuDS, the SuDS management train, and the relationship between surface water and urban realm.

Chapter 2: The London context
Identifies the unique London context, including geology, landscape, townscape, heritage and utilities.

Chapter 3: SuDS components
Outlines the surface components of SuDS and the design requirements, benefits and maintenance implications. Case studies of SuDS components and links to further guidance are provided.

Chapter 4: SuDS in London's streets
Illustrates how different SuDS components and designs could be integrated and retrofitted into typical London streets.

Chapter 5: Case studies
Case studies from London, the UK and overseas show how these principles can be put into practice. The 24 studies identify the SuDS teams, set out project objectives, illustrate the components and describe the benefits and lessons to be learned.

Chapter 6: Implementation
Explains how to form a SuDS design team and develop SuDS designs according to CIRIA guidance.

Chapter 7: Cost benefit
Reviews cost benefit of SuDS when compared to traditional drainage designs.

Appendices
Further information relevant to each chapter, including references and a glossary of terms.

1 Principles of SuDS

1.1 Planning for SuDs

Controlling stormwater quantity and water quality to mitigate flooding and the risk of pollution respectively are the main drivers for SuDS.

Potential flooding is not limited to large one in 100 year storms; flooding in urban areas often results from the more frequent and intense rainfall we are experiencing in the Capital as a result of climate change.

When localised flooding happens, it is usually linked to surface water flows exceeding the capacity of the drainage system. It is therefore important to slow down the flow rate or hold the rainfall back, whether that be within developments or the public realm.

The aim for the reduction in flow rate – or 'betterment' – is to achieve levels that emulate a greenfield site which is supported by the London Plan (Policy 5.13). Although greenfield rates are not always achievable, the London Sustainable Design and Construction SPD reports that 'most developments referred to the Mayor have been able to achieve at least 50% attenuation of the site's surface water runoff at peak times'.

The London Sustainable Drainable Action Plan (LSDAP) also seeks to reduce surface water flows into the sewer network through a series of wide-ranging actions.

SuDS are crucial to help achieve this; they also reduce risk and address policies dealing with current and future flood issues in a sustainable and cost effective way (London Plan Policy 5.12).

Ideally, SuDS need to be delivered in a coordinated and integrated manner, subject to the constraints and considerations set out in this document.

The additional benefits that can arise from SuDS in the public realm and streetscape are discussed throughout this chapter. They can contribute positively to the character of the streets, open spaces and parks in the Capital, as well as address flood risk and pollution concerns.

Surface water flooding is the greatest short-term flood risk to London

SuDS can provide multiple benefits

1.2 Wider benefits

The ambition for SuDS in London is not based solely on reducing water runoff rates; it is also about the multiple benefits that ensue. SuDS can play a significant role in enhancing health and quality of life via better air quality, improved surroundings and other attributes embedded in TfL's Health Action Plan.

SuDS are made up of a sequence of components that:

- Control surface water flow rates
- Control flow volumes
- Regulate frequency of runoff
- Reduce contaminants to acceptable levels

CIRIA calls this sequence the SuDS management train and this terminology is widely used in the water management industry.

An important principle which influences the planning and design process is the preference that SuDS components are at or near the surface. This provides new opportunities to integrate SuDS into the urban realm, which can include:

- Creating and enhancing a sense of place
- Water management using the natural hydrological cycle as a baseline
- Enhancing catchment permeability and reducing surface water runoff
- Improving resilience to the effects of climate change
- Adaptability in managing rainfall events
- Improving air quality
- Mitigating urban heat island effects
- Long-term and effective upstream source control measures

These contributions are encompassed within the four main principles, or 'pillars' of SuDS.

1.3 The four pillars of SuDS

SuDS should be based on the four pillars of SuDS design as set out in CIRIA C753 The SuDS Manual 2015. These are:

- Water quantity
- Water quality
- Amenity
- Biodiversity

By managing quality and quantity to meet requirements on the surface, the benefits of amenity and biodiversity generally follow, assuming the SuDS components are well designed.

However, where retrofitting SuDS, or where circumstances are particularly constrained or challenging, permeable paving, attenuation tanks and other below-ground features may be the only intervention possible. Of course, in these cases, biodiversity and amenity benefits will be limited.

The following pages describe these four pillars in more detail.


Quantity: permeable paving, grit jointing


Quality: reed bed planting

Images courtesy of Jess Bastock


Amenity: community planting


Biodiversity: reed bed habitat

1.3.1 Water quantity

SuDS mitigate the impact of everyday rainfall and high-intensity storms by dealing with the same quantity of water over a longer period. This process is called attenuation.

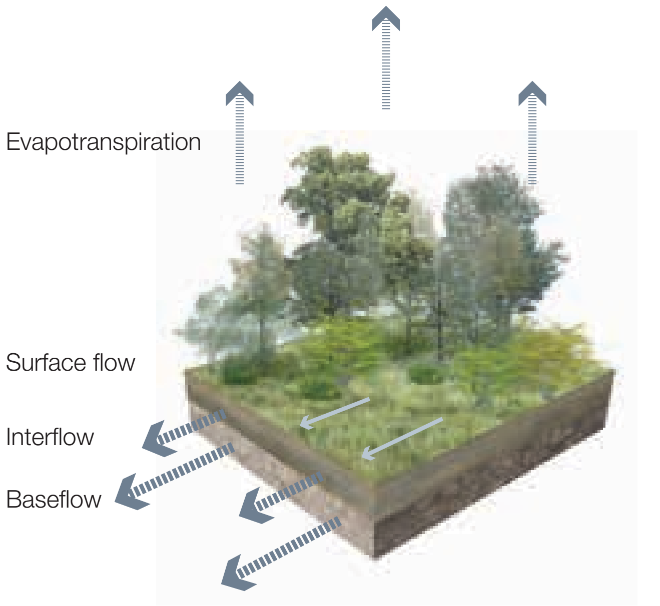
Attenuation aims to limit the rate of runoff to the rate which would have existed before the area was developed (that is a greenfield rate). Structures, such as inlets, outlets, weirs and spillways can be used to regulate flow.

Water quantity refers to the volume and flow rate of surface water runoff. Restricting the flow of surface water before it can pass through to the next stage of the system alleviates pressure on the sewer system.

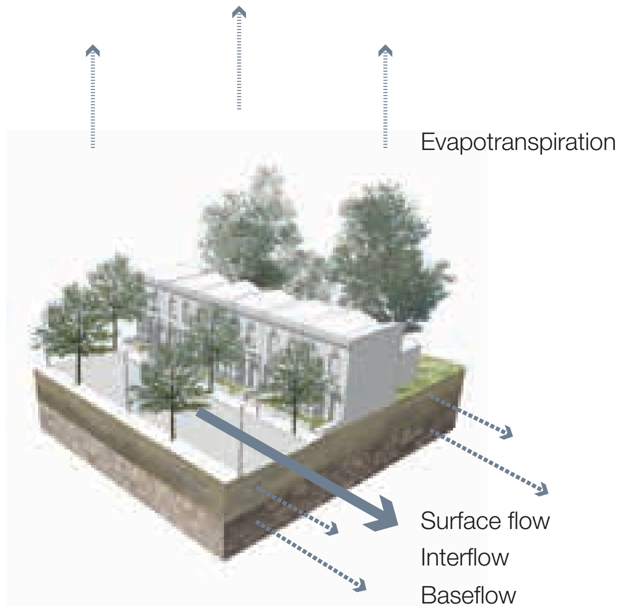
A comparison between greenfield and urban environments which demonstrates this point on the next page.

Quantity: Attenuation, Bo01 Malmö

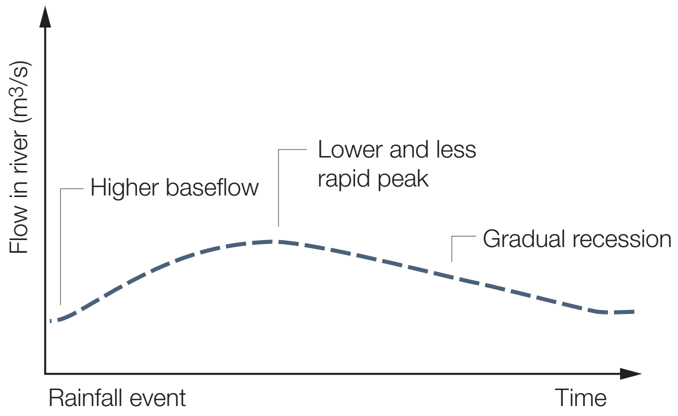
Comparison between runoff rates for greenfield and urban environments

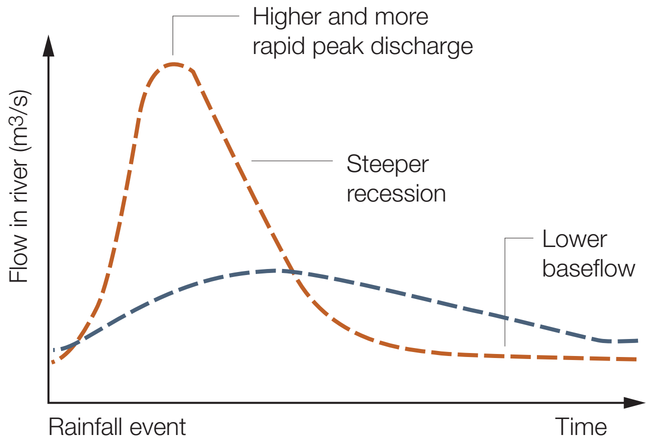


Greenfield



Urban





1.3.2 Water quality

Surface water is often polluted. Runoff from roads, for example, includes contaminants from tyre abrasion such as rubber and soot, nickel and chromium from brake pad linkings and oil, silt and iron oxide from general traffic use.

During warm, dry periods, these substances build up on sun-warmed surfaces and heavy showers can wash them into the drainage system. This creates a warm, contaminated, low-oxygen water mix, which flows into watercourses and groundwater.

Managing the quality of runoff helps protect the natural environment from pollution and SuDS can be crucial in this respect. The risk of pollution in a SuDS scheme must be assessed and a mitigation strategy proposed to determine the required number of treatment stages to ensure water is clean enough to flow to a watercourse.

SuDS can also improve the quality of water entering combined sewers, reducing pressure on sewage treatment plants.

Improvements to water quality can also contribute to amenity and the potential for for biodiversity. Reed beds, for example, which naturally slow and treat water, provide an active edge to water features and attract a wide range of birds and insects.

Designing for water quality must take account of:

- Interception and treatment methods to meet CIRIA standards
- The quality of surface water and groundwater receiving run-off
- The extent of existing pollution control systems in the catchment
- The extent to which risk management measures for spillages of contaminants, such as oil, are in place
- The proportion of permeable surfaces, green roofs, and/or surfaces discharging to a rainwater harvesting system or soil-based feature
- The proportion of the surface water management system that is on or near the surface to facilitate treatment

Reed beds can contribute to water quality

- The extent to which the design of the system incorporates sediment retention, such as forebays or hydrodynamic separators
- System resilience to cope with future demand, including allowances for climate change and urban intensification

1.3.3 Amenity

The way London's public realm looks and feels has a direct effect on people's quality of life. As London's population grows, this becomes increasingly important.

SuDS may enhance the amenity of London's public realm in a range of different ways, including:

- Contributing to integrated green infrastructure
- Enhancing character/sense of place
- Improving the quality of space
- Providing a backdrop to existing buildings and streetscape
- Supporting biodiversity
- Reducing air temperature
- Improving air quality
- Reconnecting people with the natural water cycle
- Supporting community involvement and knowledge-sharing though education, engagement and participation

By including surface drainage as part of an integrated urban design approach, SuDS can make a major contribution to the look and feel of streets and other spaces throughout the Capital.

Amenity: Thames Path, Richmond

1.3.4 Biodiversity

London's natural habitats, catchments and river ecosystems have been disrupted by urbanisation and intensification. SuDS can address this by incorporating and creating a range of habitats that benefit water quality and urban wildlife.

Aspects of biodiversity that can be addressed by sustainable drainage include:

- Habitat creation, including the significant existing and potential urban forest resource of street trees and parkland trees
- Connectivity and the ability of fauna and flora to move through the city, especially along linear infrastructure such as road, rail and canal corridors
- Source control with living roofs, green walls, trees and other green infrastructure, which can also help intercept rainwater and mitigate the urban heat island effect
- Improvements to air and water quality

Although streetscapes can lack the vegetation to absorb and release water slowly into the drainage network, a key priority in London is to integrate more green infrastructure into development and the transport network and opportunities to to this are explored in Chapter 3).

Biodiversity in pond

Biodiversity at roof level

2 The London context

2.1 What is unique about London?

This chapter explains some of the conditions particular to London, although some may also be found in other metropolitan areas. Some are unique, others less so, but all will influence the integration of SuDS into the public realm.

London is by far the UK's biggest metropolitan region, occupying an area four times that of Birmingham, and is experiencing a period of rapid intensification of use and development. The Capital sits within the Thames River Basin and contributes the largest share to the 17% of the Basin's area which is urbanised.

Hand in hand with urbanisation has come population growth. London's population exceeded its pre-war peak of 8.6 million in 2015 and is forecast to grow by 100,000 per year to 2030. Much of this growth is expected to be accommodated in the existing built-up area, putting increasing pressure on the available water supply and drainage infrastructure in the Capital.

As London develops and grows, its public realm needs to work much harder. Not only will it be more intensively used, it will also need to fulfil multiple demands, including drainage.

Responsibility for London's public realm is divided between TfL and 33 local planning authorities, plus other private landowners.

Like most UK cities, much of London's drainage infrastructure consists of piped networks. Climate change, population increase and densification all contribute to surface water runoff and increase the pressure on the network. If our drainage network is not to exceed capacity or need total replacement at significant cost and disruption, a long-term approach to surface water runoff management is needed.

The Thames Tideway Tunnel is addressing some of these issues at a strategic level, particularly in relation to events of intense rainfall. Nevertheless, many local SuDS interventions are needed to manage the process effectively.

The opportunities for SuDS, both above and below ground, will vary across London. For instance, in conservation areas designated for their landscape, architectural and historic interest, there may be more limitations than in an area of redevelopment, where a comprehensive approach to water resource management may be designed and implemented.

For the former, and significant areas of central London, this might involve the need to retrofit SuDS into the streetscape which is addressed in more detail later in this chapter.

Other factors also highlighted in this chapter, include archaeology and geology. These can both define the scope and appropriateness of the scheme and where, with the former, there is over 2,000 years of history in the heart of the city.

Well-designed and maintained SuDS can make a major contribution to public realm. They can help reduce flood risk, improve water quality, and create a sense of place. This guidance shows how this can be done.

2.2 The Thames River Basin

London sits in the Thames River Basin District catchment which covers an area of over 16,200km^2 and where over 15 million people live. The Thames basin includes all water sources including rivers, lakes, groundwater and coastal waters.

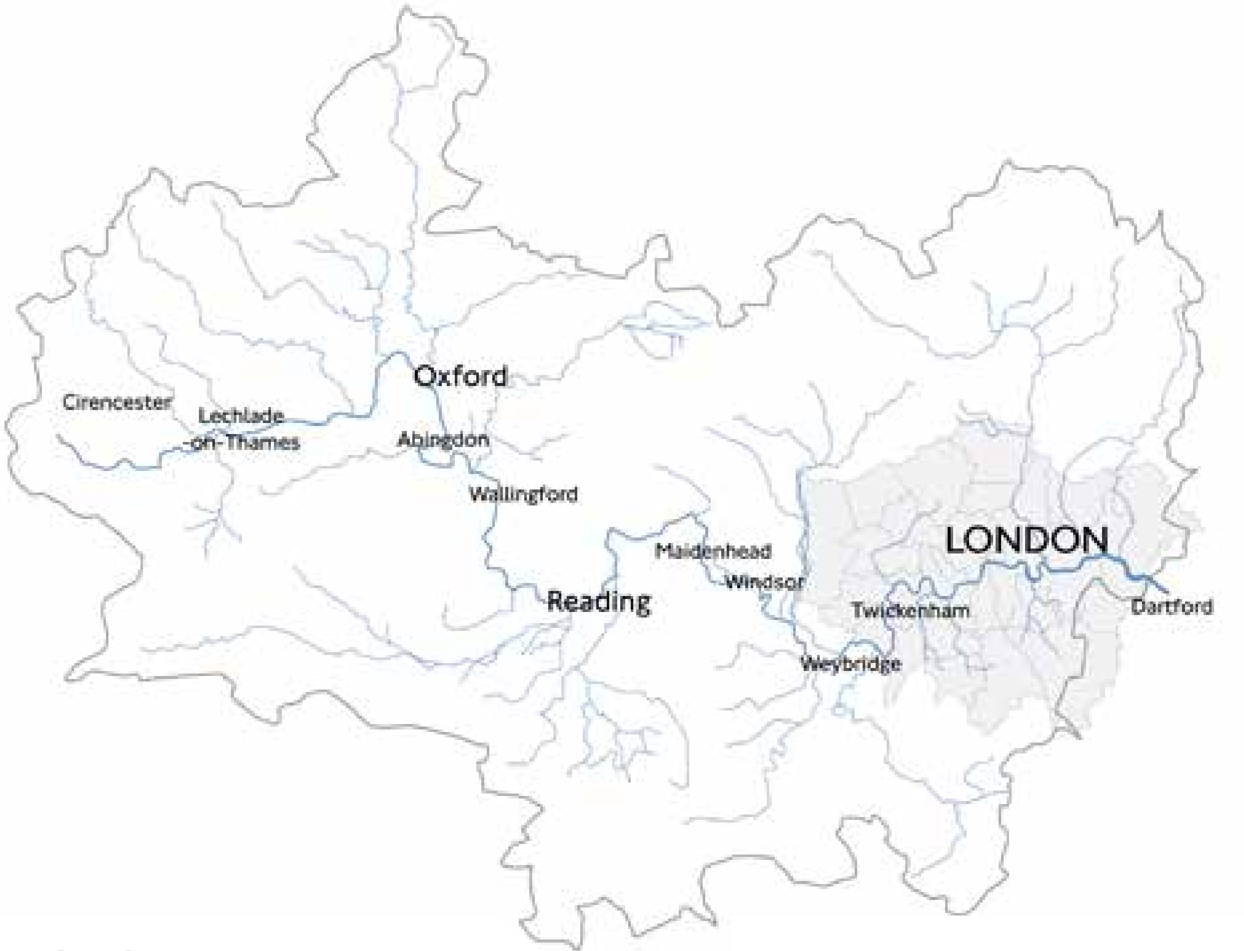
Within London there are 32 London boroughs, plus the City of London, eight areas in which catchment-based partnerships operate and 897 sub-catchments.

Reference should be made to the 'Thames River Basin Management Plan' to:

- Understand local context
- Target and coordinate interventions
- Identify or access funding for improvements within the catchment
- Ensure objectives of the Thames River Basin Management Plan and local plans are being achieved.

The Thames River Basin Management Plan also provides further information on the catchment-based approach and London's local catchment partnerships.

Further information:
Thames River Basin Management Plan
British Geological Survey



Thames River Basin

2.3 London's geological conditions

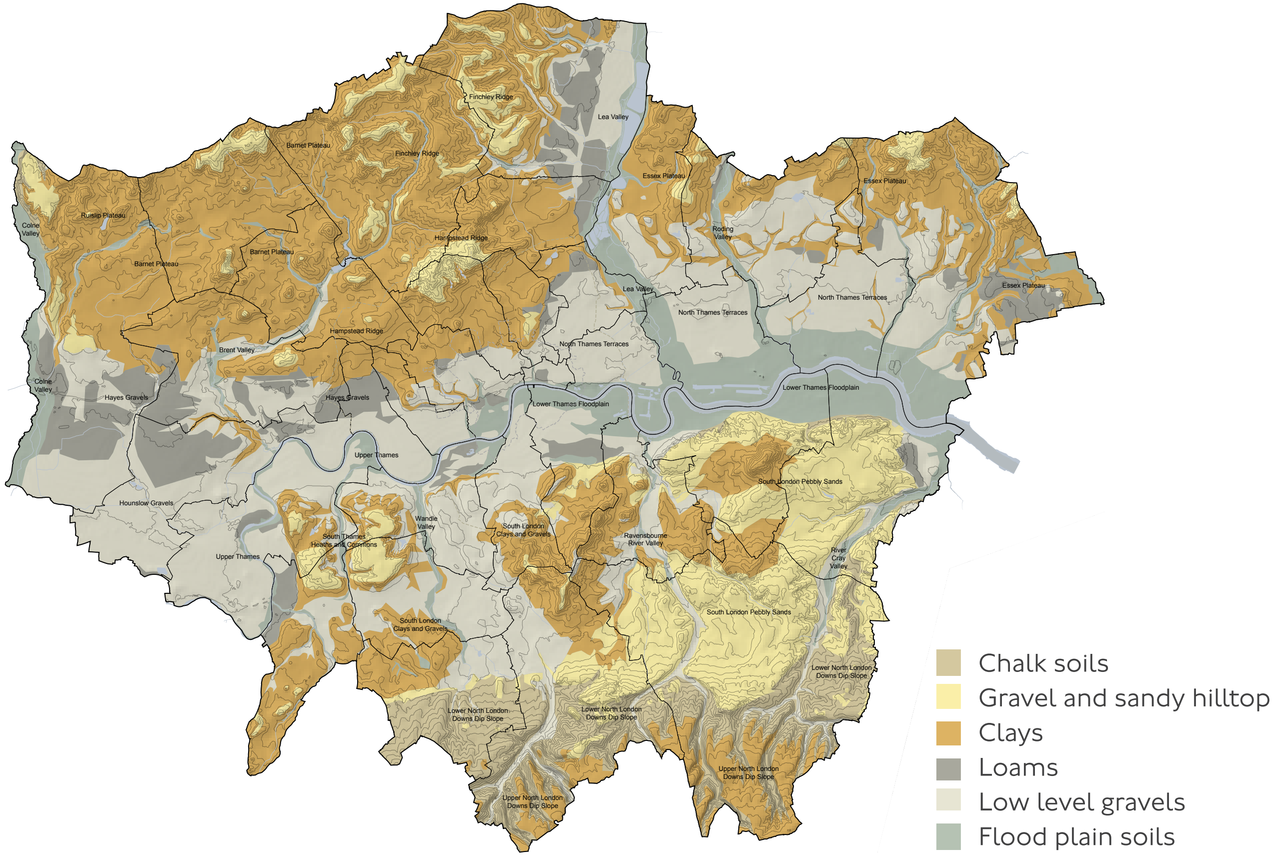
Greater London is situated in the London Basin. This is made up of layers of deposits of chalk, clays, sand, and gravel.

Understanding the geological condition of the ground is vital to the implementation of SuDS features, as different ground conditions indicate how SuDS will interact with their local environment.

For example, some of London's geological formations may present risks including: compressible deposits, collapsible deposits, shrink-swell clays, running sand, soluble rocks and landslides.

The British Geological Survey (BGS) can provide useful preliminary information. Geotechnical surveys confirm site specific geology. Such information on geotechnical properties, such as permeability, porosity and soakage, should be gathered as baseline data for any SuDS project.

Further information:
CIRIA C753 The SuDS Manual, Chapter 29
British Geological Survey
Geology of London (2012), Royse et al
Management of the London Basin Chalk
Engineering Geology of British Rocks and Soils – Lambeth Group Aquifer: Status Report 2015, Environment Agency



The geology of London, All London Green Grid, GiGL

2.4 London's chalk aquifer

Beneath London is a large chalk aquifer. This was substantially depleted during the 19th and 20th centuries due to extraction by industrial activities. This resulted in the aquifer being depleted to 88m below sea level. However, in the last 60 years, as industrial activities moved away from central London, the chalk aquifer has started to rebound by as much as 3m per year.

Some geology in London is susceptible to shrink-swell movement, caused by the presence or absence of water. This can have a substantial effect on underground structures and foundations.

Since 1992, the General Aquifer Research Development and Investigation Team (GARDIT) has licensed the removal of groundwater from London's chalk aquifer. The aim is to control and eventually stabilise the rise in groundwater levels.

The SuDS designer should take account of the chalk aquifer because:

- In areas with high groundwater levels, water can enter the SuDS component and reduce its storage capacity
- There is a risk of flotation and increased loads imposed by groundwater
- High levels of groundwater can reduce the infiltration rate of SuDS features
- Groundwater can change the stability of underground structures and foundations

Further information:
CIRIA C753 The SuDS Manual, Chapter 26 Management of the London Basin Chalk Aquifer: Status Report 2015, Environment Agency.

Exposed chalk

2.5 London's soils

London's soils are derived from the underlying geology. Across London there are variously clays, sands and gravels which are often found in a river environment. Soil management is fundamental to the successful functioning of SuDS components.

SuDS should be designed according to the geology and soils of the area. Designs should consider the availability and properties of existing soils, the surrounding ground and the requirements for imported soils. Soils should not be imported unless this is unavoidable.

Soil properties typically influence:

- Water quantity: the physical properties of soil affect the attenuation capacity as they dictate its drainage and water-holding properties
- Water quality: the filtration capacity of soils influence water quality by, for example, affecting the amount of elements such as nutrients or contaminants, taken up by the soil or dissolved into the water

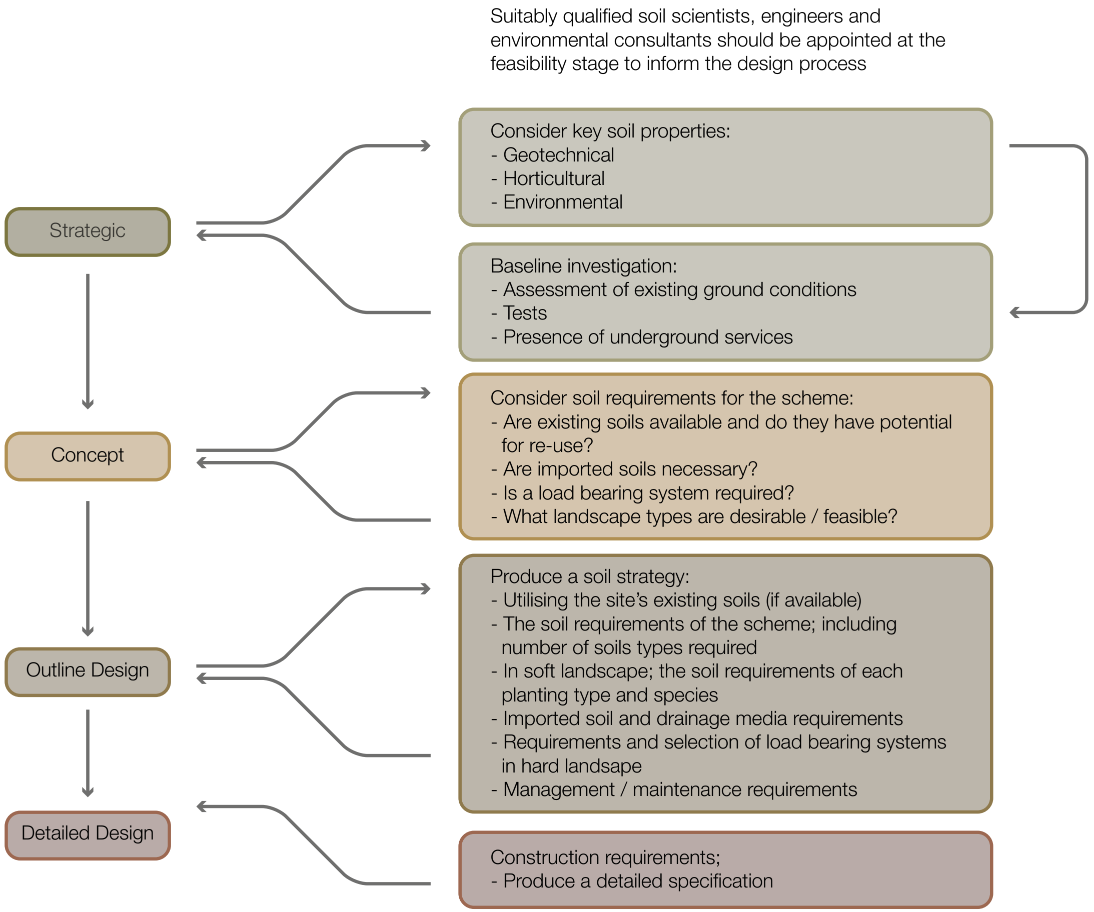
- Amenity/biodiversity: the nature and availability of soil affects plant species selection. Plants' nutrient or pH values can vary considerably

Soil specification should be bespoke to the project in hand. A suitably experienced soil scientist, engineer and environmental consultant should be sought early in the design process.

Soils in new schemes should be tested for contamination. Testing schedules should include parameters from the groups listed below (as appropriate):

- Geotechnical: permeability; bulk density; porosity; plastic/liquid limit; shear strength; California bearing ratio (a strength test)
- Potential contaminants: heavy metals; hydrocarbons; asbestos
- Horticultural: soil texture; pH value; fertility status; salinity, phytotoxic (toxic to plants) elements for SuDS schemes with planting
- Invasive species, seeds and propagules

Further information:
CIRIA C753 The SuDS Manual, Chapter 29
BS3882:2015 Specification for Topsoil
BS8601:2013 Specification for Subsoil and Requirements for Use



Suitably qualified soil scientists, engineers and environmental consultants should be appointed at the feasibility stage to inform the design process

Consider key soil properties:
- Geotechnical
- Horticultural
- Environmental

Baseline investigation:
- Assessment of existing ground conditions
- Tests
- Presence of underground services

Consider soil requirements for the scheme:
- Are existing soils available and do they have potential for re-use?
- Are imported soils necessary?
- Is a load bearing system required?
- What landscape types are desirable / feasible?

Produce a soil strategy:
- Utilising the site's existing soils (if available)
- The soil requirements of the scheme; including number of soils types required
- In soft landscape; the soil requirements of each planting type and species
- Imported soil and drainage media requirements
- Requirements and selection of load bearing systems in hard landscape
- Management / maintenance requirements

Construction requirements;
- Produce a detailed specification

Soils and the design process

2.6 Streetscapes of London

London's streetscapes vary considerably across the city, reflecting the city's size, historical development and the variety of structures and land uses that define it. Streetscape generally consists of natural and man-made elements. The opportunity for introducing natural elements can be limited, if not missing, in intensely urban areas, but greater in suburban areas. SuDS need to be designed to take account of these constraints.

Depending on specific conditions, streetscape can impact footfall, accessibility, local economic performance, air quality, public health and sense of place. Designed right, SuDS can contribute positively to all of these.

Streets are often the most resilient feature of the urban fabric. While street patterns may remain unchanged for centuries, streetscapes evolve and respond to new demands and requirements. SuDS can be a part of that process.

In some parts of central London, where space is at a premium, a more innovative approach is needed to incorporate SuDS into the public realm. For example, opportunities may occur where buildings are set back, where historical remnants exist and in the open spaces scattered throughout central London. In outer London, opportunities for SuDS tend to be far greater.

The relationship between streetscape and SuDS elements is examined in more detail in Chapter 4.

In parts of central London, more innovative SuDS solutions will need to be explored

2.7 Townscape

Townscape is the mix of physical and social characteristics that make up the urban environment. This includes its buildings, landscapes, and the way those characteristics are perceived. Townscape directly contributes to people's sense of place and identity.

London has a complex townscape that reflects its rich and diverse history, culture and built form. London's Roman origins are still visible in the City's street pattern. Further waves of expansion were created by trade, population growth, industrialisation and transport infrastructure. Having absorbed formerly separate towns and villages, London's character is inherently polycentric, with its many separate centres each having their own identities.

London's history and character is also reflected in its streetscape. Paving, pillar boxes, street furniture, stone drinking troughs, telephone boxes, sculpture, memorials and other heritage assets all contribute to a strong sense of place. This is enhanced by the Capital's green and blue infrastructure; its many parks, squares and gardens, the canals, the River Thames and its many tributaries.

SuDS interventions need to progressively complement and enhance the townscape and become a fundamental part of the character of London.

Historic England has produced a useful guide called 'Streets for All: A guide to the management of London's streets' which reviews many of these assets.

When working on London's streets there are several statutory consultees that need to be engaged. A recommended, but not exhaustive list, is contained within Appendix A.

Further information:
Historic England (2000), Streets for All: A guide to the management of London's streets, Historic England, London, UK
Jones, E. and Woodward, C. (2013), Guide to the Architecture of London, Weidenfeld & Nicolson, London

Borough Road: Victorian street tree planting

Road closure, permeable surfacing and tree planting in Waltham Forest Mini-Holland

2.8 Retrofitting

Many of the potential SuDS opportunities in London are retrofits, ie, installing the components into the existing streetscape and public realm. Depending on the available space and prevailing condition, existing streetscapes can be adapted or retrofitted with a variety of interventions, improving the quality of the public realm where possible.

When retrofitting SuDS, it is important to consider how the space will be used. If wheeled goods handling, for example, is expected, the design will need to address this in terms of smoothness, access and potential obstruction.

The following may offer opportunities to retrofit SuDS:

- During annual road maintenance works
- During road reconstruction or resurfacing
- As part of road drainage improvements
- As part of planned road modernisation
- Integrated as part of development, redevelopment or regeneration
- As part of investment in the public transport network, such as station forecourts
- Improving London’s cycle route infrastructure, eg, Mini-Hollands.
- As community initiatives, addressing private households, including front gardens

The opportunities – which will be determined above and below ground – and constraints are illustrated in Chapter 4. Retrofit initiatives, such as Twenty 4 Twenty, Greenstreets, SuDS for Schools and Life+ Climate Proofing for Housing Landscapes, offer partnership opportunities to design and deliver SuDS.

2.9 London's green infrastructure

London is one of the greenest cities in the world with 47% green space and 22% tree canopy cover.

The green and blue infrastructure of the Capital includes commons, parks, gardens, fields, street trees, woodlands, green roofs, green walls and water bodies, including the River Thames and all its tributaries.

Together, these assets define much of the character of the city. Their environmental, economic and social benefits include:

- intercepting rainfall
- attenuating surface water flow
- maintaining soil permeability
- reducing urban heat island effect
- improving air and water quality
- flood mitigation
- providing amenity space
- space for walking and cycling
- enhancing biodiversity/ ecological resilience
- creating a sense of place

Many of these benefits overlap with the aims of SuDS interventions. It is therefore vital to protect London's existing green infrastructure when designing SuDS in the Capital.

Trees in the public realm of the Queen Elizabeth Olympic Park

2.10 Trees

London benefits from a legacy of Victorian tree planting that contributes significantly to its canopy cover while intercepting rainfall. These trees were established in much more favourable, less engineered, conditions than today's high-performing pavements where space above and below ground is often at a premium. Tree planting has, however, continued in London with initiatives such as the Mayor's Street Tree Initiative, where over 10,000 trees were planted in 28 boroughs from 2012 to 2015.

SuDS schemes in London should retain existing trees where possible. Specialist advice should be sought at an early stage.

Further information:
Greater London Authority (2015), Natural Capital: Investing in a Green Infrastructure for a Future London, Green Infrastructure Task Force, London, UK.
Landscape Institute (2013), Green Infrastructure: An integrated approach to land use, Position Statement, London, UK.
Treeconomics London (2015), Valuing London's Urban Forest: Results of the London i-Tree Eco Project, London, UK.
All London Green Grid SPG 2012.
TDAG (2014) Trees and Hard Landscape: A Guide for Delivery

2.11 Working with London’s utilities

Footway and carriageway space in London is limited and often highly congested below ground with utilities that supply London’s gas electricity, water, sewerage and telecommunications. Much of this infrastructure, which was installed in the late 19th and early to mid 20th centuries is ageing, poorly documented and maintained, although its exact location is often difficult to pinpoint.

SuDS designers should work closely with utility providers because utilities can be expensive and disruptive to divert. During feasibility and option appraisal stages of SuDS design, the team should apply to each utility owner for information on their assets or associated assets. This information should be validated.

During feasibility studies and option appraisal stages of design, it is recommended that high quality surveys are obtained to identify services and avoid abortive works later in the project. Underground assets should be recorded and this information given to the relevant highway authority or landowner.

Below ground infrastructure

Contaminated soil

2.12 Contamination

In London, contaminated soil and groundwater is likely to be found when installing SuDS components because there are few places that have never been subjected to some form of development or industrial activity. However, contamination should not preclude SuDS. Early in the process, a specialist should be appointed to identify contamination risks and sources so an integrated remediation strategy can be explored. Designers should consider:

- The risk of mobilising contamination through increased infiltration
- Risk of contamination entering SuDS features and contaminating relatively clean rainwater runoff; this could have adverse effects on vegetation and materials used within SuDS components
- Excavation and disposal of contaminated soils is likely to be expensive
- SuDS should not compromise remediation systems in place to protect users from the contamination

Further information:
CIRIA C753 The SuDS Manual, Chapter 26

2.13 Archaeology

London's history covers millennia of settlement, with layers of archaeology which can be encountered when excavations occur.

When working in Greater London, it is advisable to contact Historic England's Greater London Archaeology Advisory Service (GLAAS) – or in the case of Southwark and the City of London, their own borough archaeology officers – as early as possible to understand what policy and consent requirements are in place for sites of archaeological interest and their settings and designated archaeological priority areas. All local authorities maintain a record of their archaeological priority areas.

Further information:
Historic England (2015), Guidelines for Archaeological Projects in Greater London. Greater London Archaeological Advisory Service, London, UK.
Communities and Local Government (1990), Planning Policy guidance 16: Archaeology and Planning, UK.
National Planning Policy Framework, Department for Communities and Local Government, March 2012

2.14 Crime and disorder

All designs should seek to provide safe and secure environments, as outlined in s17 of the Crime and Disorder Act 1998.

TfL's transport community safety managers located in the Enforcement & On Street Operations Directorate (EOS) provide advice to design teams on meeting their duties under the Act.

During design development, contact a police Crime Prevention Design Advisor (CPDA) to understand existing crime patterns early in the design process and ensure risks are mitigated.

Well-designed streets provide passive surveillance and feel safe

2.15 Highways and planning

When developing a SuDS scheme on a London road or street, contact the borough and TfL as appropriate, in their capacity as the local planning and highways authority.

The implementation of works which affect infrastructure below ground level are subject to the New Roads and Street Works Act 1991, which sets out a code of practice for the coordination of works. This is administered by all highways authorities, including TfL.

Under the Traffic Management Act 2004, traffic authorities must ensure road networks are managed effectively to minimise congestion and disruption to vehicles and pedestrians.

When working on the TfL Road Network (TLRN) or on any borough roads, there are requirements relating to a range of issues, including the extent of the road works, the code of conduct, lane rental schemes (in case of TLRN) and highway licences/permits.

Each highway authority has its own restrictions (such as working hours, noisy working, etc). Special consideration should be given to works planned near Underground, Cycle Superhighway or rail systems.

SuDS measures must be designed to ensure that maintenance and vehicle access requirements can be met without compromising the operation of the network in terms of safety and disruption to all road users.

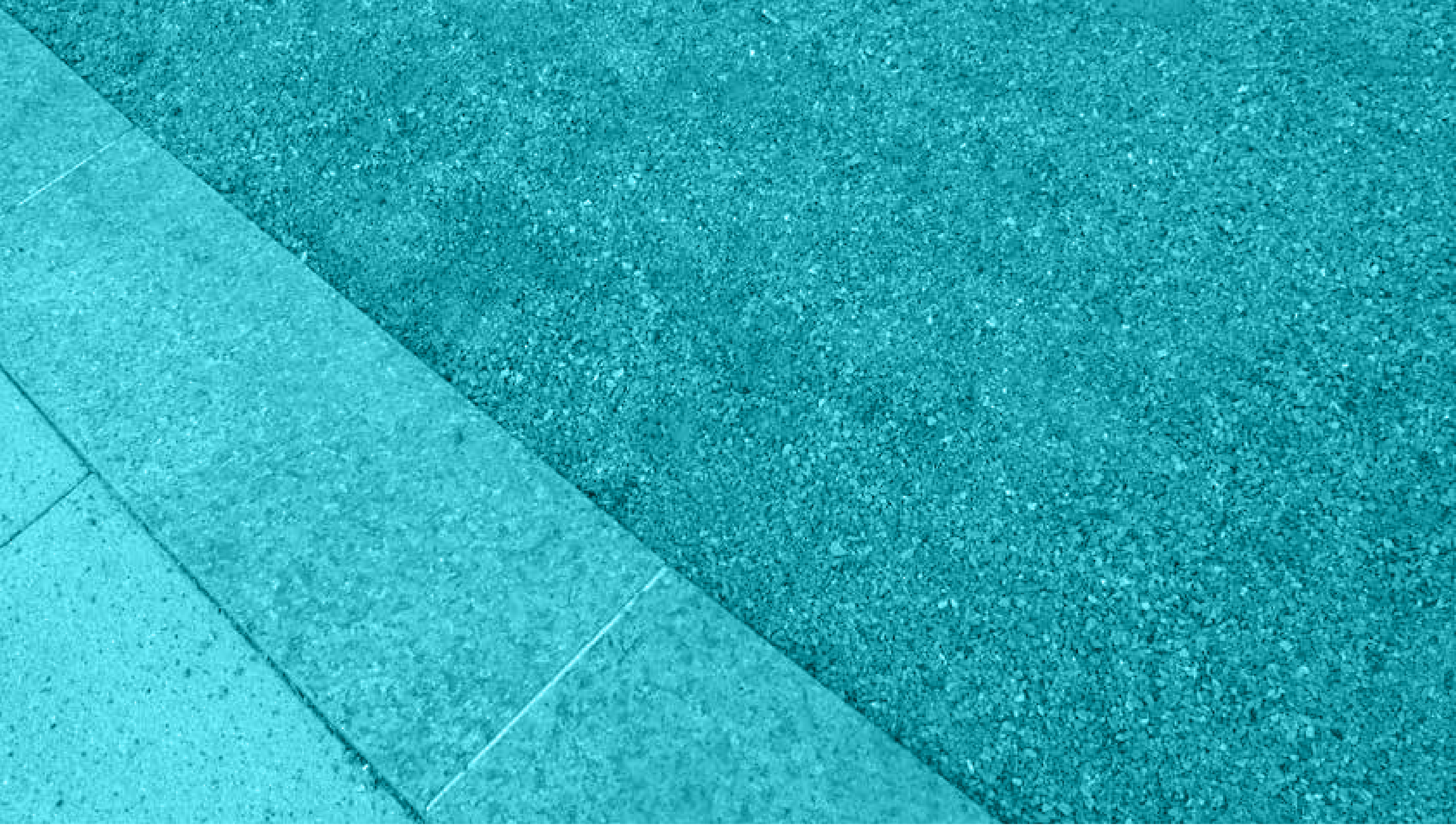
Accessible environments are inclusive to all

2.16 Inclusive design

Any SuDS measure which influences the public realm should be inclusively designed. Design teams should consider specific measures, such as raised edge protection, when the following features are proposed:

- Rain gardens
- Swales
- Open rills and runnels
- Gravel filter strips
- Detention ponds
- Other features with steep or sudden drops

This is necessary to protect vulnerable people, including children and visually-impaired pedestrians. Each place must cater to the needs of all and not restrict its use by any group or individuals. The design process must consider the needs of people under the Equality Act 2010.



3 SuDS components

3.1 Which SuDS components are suitable for London?

SuDS are a combination of components on and off-site that make the most of the benefits described in Chapter 1. This chapter explains the SuDS components that may be appropriate for use in London.

SuDS use a variety of components to manage water quality and volume and deliver amenity and biodiversity. An understanding of topography and local surface water discharge options are critical in identifying the most suitable combination of components, with particular attention to:

- Where the rainwater lands and how it is collected (source)
- Identifying conveyance options (pathway)
- Determining the most appropriate discharge points (receptor)

In general, SuDS should 'think upstream' and take advantage of specific upstream source control measures.

Integrated SuDS components: wet

Integrated SuDS components: dry

A number of case studies illustrating the application of various components from a variety of sources and locations are incorporated within this chapter.

SuDS components in the street, whether TfL or borough-owned, could include any of the following depending on the context, opportunity and site constraints:

- Permeable pavements with robust surfaces which allow rainwater to pass through them. Attenuated in granular sub-base material or below ground structures, this can replenish groundwater or discharge at a controlled rate into the drainage network
- Tree planting to intercept rainfall within the tree canopy, beneath which the ground surface may be impermeable. Trees naturally manage rainwater through transpiration, increasing soil permeability and enabling water to infiltrate into the subsurface
- Tree trenches connecting below ground rooting zones. This maximises the accessible water and soil volume to rooting systems and is beneficial to the long-term sustainability of trees and planting
- Bioretention systems or bioretention rain gardens, including a filtration layer that provides required treatment and detention before the rainwater is discharged at a controlled rate to a watercourse or drainage network
- Filter drains to collect water and treat pollution, particularly effective in combination with grass filter strips that trap silt before water reaches the filter drain
- Detention basins to attenuate in shallow, grassy depressions. These are mostly dry but can store and treat water at shallow depths with vegetation when it rains
- Hard 'basins' or lowered areas of hard landscape. These provide attenuation and temporary storage of runoff before slow release to the next component in the SuDS management train. This may be particularly appropriate in combined sewer areas where water treatment is less important
- Swales provide linear attenuation that is particularly versatile for highways and the rail network. They can be designed as a 'storage swale' and/or for water conveyance
- Pools, ponds, canals, rills and runnels can be integrated into formal or informal urban landscapes, depending on design, and used to store and treat water
- Surface water drainage soakaways and infiltration systems; these depend on the stability of ground conditions, proximity to foundations, below-ground structures and infrastructure and protection of ground water quality and geology

Some of these components are illustrated in indicative street settings in the following chapter.

Rainwater interception over the highway

Some SuDS components are linked to buildings and structures that help define the public realm. These may include:

- Living roofs' (green, brown or blue roofs) to provide source control
- Water butts and tanks to intercept and harvest rainfall by disconnecting and diverting downpipes
- Rain gardens to create temporary localised ponding for roof runoff, allowing plants and trees to benefit from that ponding
- Rainwater planters to attenuate in above ground planters, with integral storage and slow release

Retrofit cycleway and SuDS in Lyon

Other SuDS components can be delivered by better management of existing assets, including:

- De-paving, bioretention and street tree planting, retrofitted as part of already planned annual highways maintenance, repair and improvement programmes
- Re-purposing linear green infrastructure, such as verges and embankments along roads, railways and waterways
- Decompacting existing parkland soils
- Repurposing existing green space for swales, rain gardens and bioretention components
- Protecting existing assets that are already providing a SuDS function, including street trees, parks and gardens, verges and infrastructure corridors

The SuDS components are described in more detail in the order found in **CIRIA C753 The SuDS Manual**.

3.2 Structures

Roofs and walls can provide the first point of interception as part of the SuDS management train.

Living roofs are an effective way to integrate green infrastructure, no matter how intense the development. The term living roofs include 'green' (planted), 'blue' (water attenuation) and 'brown' (recycled substrate) roofs. The three types of living roofs can be characterised by:

- Extensive roofs: these have varying substrate depths and vegetation that generally includes grasses and wildflowers, creating minimal loading on structures
- Intensive roofs: these typically have deeper substrates supporting a range of vegetation. This puts larger loadings on the structure
- Blue roofs: these attenuate through vegetated substrate specification and drainage design

Green walls are vegetated walls that are supported on cables, cellular systems or self-clinging and unsupported. They can be proprietary systems with irrigation, or formed over time by planting climbing plants into the ground that are more self-sufficient.

Benefits

Living roofs and green walls provide multiple benefits and contribute to the Green Infrastructure Vision for London. They reduce rainwater runoff rates, offset the urban heat island effect and filter air pollution.

Benefits include:

- Water quantity: living roofs intercept and attenuate rainwater. They allow a reduced discharge rate through evaporation and transpiration. Green walls can use recycled water for irrigation
- Water quality: living roofs treat water through a variety of physical, biological and chemical processes within the soil and root uptake zones. They regulate surface water runoff temperature that could adversely affect ecology of local water bodies
- Amenity: living roofs can improve the look of roofscapes, while rooftop parks and gardens act as an educational and urban farming resource. Green walls soften the hard city environment, reducing air temperatures while being space efficient
- Biodiversity: Living roofs safeguard, enhance, restore and create habitat with no additional land take. They provide important habitat stepping stones and contribute to London's natural capital. In particular, they provide refuge for rare invertebrates. Green walls provide vertical habitats for nesting and food for pollinators

Proprietary green wall system

Design considerations

Living roofs can be retrofitted or designed as an integral part of a new development. The following aspects of design need to be considered:

- Exceedance: design roof drainage to cope with excessive rain
- Irrigation: rainwater should be intercepted for irrigation, where possible
- Structural resilience: living roofs add additional loading to a roof structure, depending on the material used, in the form of a dead load. This is typically around 0.7 to 5.0 kN/m, with imposed loads up to 10 kN/m
- Fire resistance: fire risks can be managed through the use of appropriate materials and design. Vegetation should be kept a minimum distance away from vulnerable areas such as openings and vents
- Substrate: varying depths of substrate, together with dead wood and aggregates within a single roof landscape, create different microclimates and the potential for habitat diversity. Soils and growing media can be formed of recycled material, which support different potential for flora and fauna
- Vegetation: living roofs support a variety of plants for amenity, biodiversity and food growing. The species selection, whether seeded, self-seeded, pre-grown or planted, should be adapted to microclimate and substrate specification

Living roof: Copenhagen

- Roof conditions are often hostile, with high winds, extreme temperatures, periodic rain and drought. Diverse dry meadow mixes, that are naturally self-sustaining in exposed environments, can be used. Natural windblown or bird-borne self-seeding is a viable and economic alternative, naturally adapted, rather than off-the-shelf, imported monocultures
- Access, safety and edge protection: outlets and drains should be easily accessible for inspection

Maintenance

Living roofs require periodic maintenance, including for irrigation, inspection of outlets and removal of invasive plants. Frequency depends on the type of system. Green walls formed by climbing plants may need to be periodically attached to supports. Proprietary products require maintenance of plants and irrigation systems and may require occasional replanting.

Useful design guidance:

CIRIA C753 The SuDS Manual, Chapter 12
CIRIA C644 Building Greener BS 120563: 2000. Rainwater outlets gutters
BS EN 13252:2001

Case study 1 – Structures

Location
London Wall
City of London

Date
2011

SuDS components
Living roof

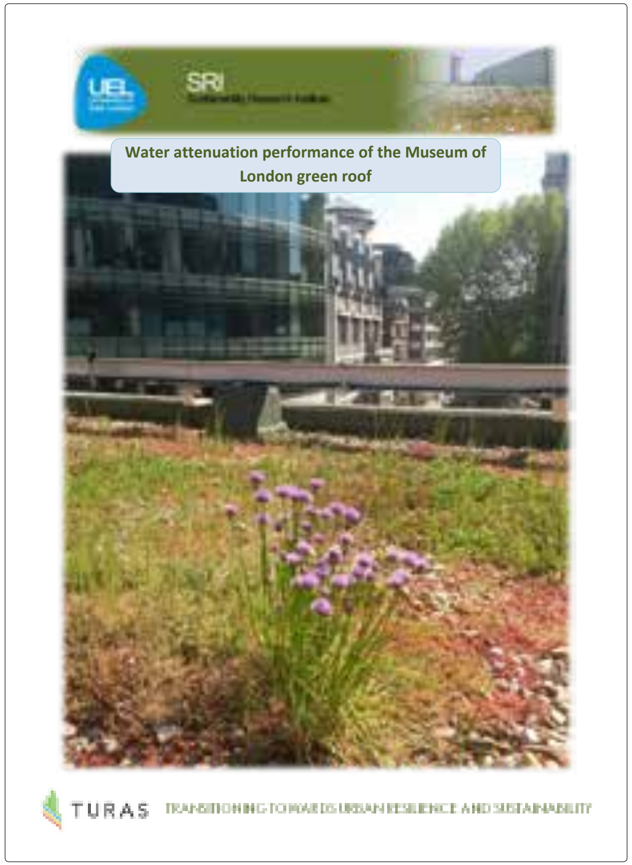
Objectives
- Attenuate rainfall
- Improve biodiversity

Outcome
As part of a sustainability initiative at the Museum of London, a series of living roofs were installed on the museum's roof as part of waterproofing works.

This installation included a range of roofs, including wildflower and sedum mat systems. The variety of scale, levels, shading and aspect produces a biodiverse urban habitat.

The roof area was divided into two by an impermeable barrier, creating two separate sub-catchments. This allowed rainfall runoff measurements on the green roof and the existing control roof. The living roof was better at attenuation than the grey roof.

The University of East London has monitored the living roof's attenuation performance



UEL

SRI

Water attenuation performance of the Museum of London green roof

TURAS TRANSITIONING TOWARDS URBAN RESILIENCE AND SUSTAINABILITY

Water attenuation performance of the Museum of London green roof

Images courtesy of University of East London

Case study 2 – Structures

Location
Goods Way
London Borough of Camden

Date
2012

SuDS components
Green wall

Objectives
This new neighbourhood is being built around a green framework where 40% of the 27 hectare development is given to open space. More than 400 new trees are being planted and walls and roofs greened

Outcome
The green wall contributes to a biodiversity network that delivers a range of economic and health benefits, encourages wildlife and reduces the risk of flooding; 200 linear metres of green walls have been planted since 2012. As part of a Living Landscape strategy, these green walls – together with the living roofs – minimise the urban heat island effect by increasing air-plant exchange and contribute to the SuDS strategy for the area by intercepting rainwater. Their contribution to the sense of place is also significant.

Planting detail

Kings Cross green wall

3.3 Infiltration systems

London's parks, gardens and green space provide large scale SuDS infiltration in the open soil, coupled with the interception that parkland trees provide. Infiltration systems also exist at a smaller scale, for example, kerb inlets, grass verges and permeable paving.

Designed infiltration systems can include the following sustainable drainage components:

- Soakaways: pits that temporarily provide storage before infiltration
- Trenches: linear soakaways and strips of grass that are predominantly dry, but in heavy rainfall, fill up and store water for a period of time before infiltration
- Infiltration basins: depressions performing the same function as trenches
- Blankets: open, flat areas of grass, allowing infiltration over a wider area than a trench or basin.

St James' Park: London's parks allow water to infiltrate. Soil compaction through high footfall may reduce permeability

These components are designed to promote infiltration where capacity and permeability of soils and the depth of groundwater allows. However, infiltration systems may not be appropriate in many parts of London due to groundwater extraction issues (see Chapter 2).

Benefits

Infiltration components allow groundwater to be replenished. They can incorporate marginal and wetland habitat. Planting slows the flow rate by improving the drainage properties of the soil, creating a more effective SuDS component. Infiltration can be used to manage overflows from rainwater collection systems, such as water butts and runoff from small areas (for example, drives and roofs).

Design considerations

Infiltration components can be retrofitted, designed as a series of small linked elements, or as a single larger one.

Runoff flow to be directed to a SuDS infiltration component can be collected laterally along the edge of an impermeable surface. Kerb openings and roadside lateral inlets help to direct, control and reduce flow velocities.

A minimum of 1m from the base of the infiltration component to maximum groundwater level is required. Upstream pre-treatment may be needed to remove sediment and silt.

Performance of SuDS components may be compromised if surface soils become compacted, so should be designed to withstand high intensity pedestrian use. Performance depends on the capacity of the soils surrounding the component. When rainfall rate exceeds the design capacity, a flow route or temporary storage should be provided.

Soil infiltration can be enhanced by:

- Managing construction traffic to prevent compaction during construction

- Mixing sand with soil to retain its drainage properties

- Adhering to tight construction tolerances

- Soil decompaction

- Reusing existing topsoil to allow the inherent seed bank in the soil to regenerate quickly, reducing erosion and enhancing the potential for infiltration

Maintenance

This can usually form part of the wider routine landscape maintenance. Control structures require periodic inspection. Existing parkland, particularly in critical drainage zones that are subject to intense use, should be periodically decompacted.

Useful design guidance

CIRIA C753 The SuDS Manual, Chapter 13

Case study 3 – Infiltration systems

Location
Streatham Common South
London Borough of Lambeth

Date
2013

SuDS components
De-paving
Tree planting
Kerb inlets

Objectives
Streatham Common South falls within the Streatham Critical Drainage Area (CDA). The project included implementation of a rain garden to alleviate flood risk and was completed within a standard highway maintenance scheme.

Outcome
Pavement SuDS, where inserted with verges, replaced concrete dished channels. These slow surface water drainage into the sewer system. Modeling undertaken has shown that the grass verge can theoretically remove 6m of surface water runoff in a one in 100 year, six-hour storm event.

Before

After

Kerb inlet and de-pave detail

Images courtesy of Owen Davies

Case study 4 – Infiltration systems

Location
50 & 60 Reedworth Street
London Borough of Lambeth

Date
2012

SuDS components
Permeable paving

Objectives
To increase the permeability of front gardens.

Outcome
The paving over of front gardens in London is a major issue and contributes collectively to the risk of surface water flooding. Permitted development rights have recently been withdrawn for homeowners wishing to pave a garden with impermeable surfacing.

This project highlighted how hardstanding can be removed without affecting parking. Residents were supported in changing materials and provided with tools, technical advice and practical assistance. The initiative has increased the permeability of front gardens and improved streetscape aesthetics.

De-paving of private front gardens

After with gravel and planting

Images courtesy of Ann Bodkin

3.4 Filter strips

Filter strips are uniformly graded, gently sloping areas of grass that allow water to flow as a sheet towards a swale, bioretention system or filter drain. They provide a simple form of source control through pre-treatment of water, to protect swales or filter drains from clogging up with silt.

Filter strips are effective at intercepting rainwater where the soil is sufficiently permeable. The grass and vegetation slows the water, allowing it to soak into the ground. The plants help evaporate water and filter out pollution.

Benefits

Filter strips create soft open space next to impermeable areas. They can either be seeded with amenity or meadow grass and managed as long or short mown grass to support biodiversity by providing:

- Foraging for birds and invertebrates
- Habitats for invertebrates
- ‘Stepping stone’ habitats, particularly in the urban environment

Design considerations

Filter strip efficiency depends on length, width, vegetation cover and soil specification. Considerations include:

- Soil permeability
- Vegetation specification
- Height of vegetation and flow depth
- Peak flow velocity in relation to particulate settlement
- Time of travel of runoff across the filter strip
- Protection of the strip from vehicular run-over and development
- Designed for management by standard landscape maintenance machinery

Filter strips should be more than 2.5m wide, and ideally laid to a 1% slope. Small filter strips that are 1-2m long create effective connections between broken kerb lines and the side slope of a swale. Lengths of greater than 5m help improve water quality performance. Filter strips should be shielded with a kerb or low-level barrier when they are next to a road or car parking.

Filter strip: Parkway retrofit

Maintenance

This can form part of the wider landscape maintenance operations, to ensure the feature meets design performance standards. Measures to prevent soil compaction are particularly important.

Useful design guidance

CIRIA C753 The SuDS Manual, Chapter 15

3.5 Filter drains

Filter drains are deep, narrow, gravel-filled trenches that collect and move water from the road. They often include a perforated pipe at the base to help drainage. Water flow through the gravel can removes some pollutants.

Benefits

Filter drains provide:

- Long and short term water storage during a storm between the aggregate particles
- Silt removal, by eliminating suspended sediment in the water
- A material that enhances biodiversity by hosting micro-organisms and providing a breeding ground for insects and amphibians

Design considerations

Filter drains must be able to accommodate high return periods (ie, one in 100 year events) without suffering damage. A geotextile (not a geomembrane) below the surface of the aggregate traps silt to prevent it clogging up the drain, while allowing permeability.

Filter drain: open gravel filled joint

Filter drains can be protected from silt by an adjacent filter strip (see 3.4) or flow spreader.

Filter drains are usually 1-2m deep, with a minimum depth of filter medium beneath any inflow and outfall (0.5m) to ensure reasonable levels of pollution removal.

These components can be placed at the bottom of embankments to intercept surface water runoff or with filter strips on the highway. Equally, they can be integrated as an architectural feature in the public realm.

Maintenance

Filter drains require routine maintenance to ensure vegetation or debris is removed from the surface.

Useful design guidance

CIRIA C753 The SuDS Manual, Chapter 9 and 16

3.6 Wet swales and dry swales

Swales are linear components that provide slow water conveyance. They provide filtration, attenuation and storage of surface water runoff from relatively small catchment areas. They can be designed to accommodate a range of rainfall events.

Generally, swales are sloping sided, flat-bottomed, vegetated open channels, constructed at a gentle gradient. Steeper gradients can be accommodated through the use of check dams. Swale design is limited by available space and is only effective when close to catchment areas. Swales can be dry or wet.

Dry swales allow surface water to infiltrate and include a filter bed with an underdrain to prevent waterlogging. They can be lined or unlined depending on groundwater levels.

Wet swales retain water, behaving like a linear wetland. They are best located where sites are level and soils are poorly drained, where they can deliver amenity and biodiversity through specific wetland planting. During intense storm events, water is retained in the swale before being conveyed to a downstream outlet.

Benefits

Conveyance: swales are a simple and effective means of collecting and distributing runoff, or as a means of conveying runoff on the surface, while enhancing open space or the roadside environment.

Filtration: engineered soils can help neutralise contaminants and sedimentation caused by runoff. Designs can include submerged anaerobic zones to promote nutrient renewal.

Attenuation: swales are typically designed to capture a one in 10 year storm event by storing water within and on top of the filtration media where the water can disperse over time.

Amenity: swales provide shallow linear planted features in the landscape that are space-efficient and adaptable to location. They integrate well alongside highways, cycleways or pathways. They allow bridging structures to enhance spatial experience, creating places for play and contact with nature.

Biodiversity: swales can be designed with a variety of marginal planting and wildlife meadow that contribute to habitat creation and connectivity.

Erosion: swales convey and/or retain flowing surface water where soft landscape is likely to erode. Reducing the velocity of water flow limits erosion through the use of measures such as weirs, check dams, erosion control matting and planting.

Design considerations

Swales should be designed to suit the scale and character of the specific location, taking into consideration orientation, aspect and proximity to other landscape or townscape features. The design of soft or hard edges depends on the urban design context.

Dry swale: Upton, Northants

Mini swales can manage small events with overflow to other SuDS components.

Ground conditions: Examine existing ground conditions and hydrology to determine the use of either a wet or dry swale. The volume of water to be stored, or infiltration capacity of the soils, allow the designer to establish the basic swale dimensions.

Image courtesy Robert Bray Associates

Dry swale

Contamination: Where there is ground contamination on brownfield sites, incorporate a liner, unless leaching can be managed to an acceptable level. The liner level should rest above the level of seasonal high groundwater level.

Edge protection: as a component that typically sits below pavement surface levels and can hold standing water, consider the edge detail.

Exceedance: swales are designed to provide a level of storage that can accommodate a one in 10 year storm event. The storage capacity of a swale depends on its size, which depends on the available space. A swale can overtop during severe storms, so build in contingency flow paths and/or provide outfalls.

Health and safety: swales are shallow surface features and should not present a danger to the general public. However, risks can be mitigated through design to address edge conditions or provide shallow side slopes and shallow flow depths.

Vegetation: planting in the swale stabilises slopes, reduces erosion and slows water flow. Swales provide an ideal location for a variety of planting that can provide amenity, habitat and foraging.

The selection of vegetation should be from native species that provide appropriate habitat for indigenous species. Where over-the-edge drainage is required, the grass level should be 25mm below the edge of the hardstanding to be drained, to ensure effective surface flow.

Trees: swales can accommodate trees within their design, provided conditions needed for growth and the hydrological effects are considered. Swales should respect the presence of existing trees and ensure root systems are not compromised. Proposals should accord with BS 5837:2015 and take account of tree preservation orders and conservation area designations.

Maintenance

Swales require routine maintenance to ensure efficient operation. Different swale construction and operation affect maintenance prescriptions.

Useful design guidance

CIRIA C753 The SuDS Manual, Chapter 9.8 and 17
HD 33/06 Surface and Sub-Surface Drainage Systems For Highways

Case study 5 – Swale

Location
Mill Pond Road,
London Borough of Wandsworth

Date
2016

SuDS components
Bioretention swales
Kerb inlets
Tree trench planting

Objectives
Mill Pond Road is a new road within a development at Nine Elms. It is constructed with a central planting bed acting as a swale to attenuate surface water.

Outcome
The surface water runoff is collected along bespoke broken kerb units and fed into the central planting zone, where it filters through to an underground collection and holding tank before being released slowly into the mains sewer system. Standing water is not anticipated for more than one or two days following extreme rainfall events; plants have been selected to be tolerant of these conditions.

Bioretention swale

Plan

Images courtesy of Camlins

Runnel

3.7 Rills, runnels and channel systems

Rills or runnels are small, open-surface water channels within paved construction. They collect water directly from hard surfaces and convey water, at a reduced flow rate, to, from or between other SuDS components. They come in a variety of designs to suit the urban landscape and have formed part of the historic streetscape environment for many years.

Rills can be planted, with rainwater bringing them to life. They provide an alternative to piped drainage, allowing the captured water to remain at the surface and for easy discharge into other SuDS components.

Benefits

Rills are an effective way to provide SuDS, including water treatment if planted, where space is at a premium.

Amenity: planted rills, interacting with rainwater, enhance the urban environment.

Conveyance: rills are effective at collecting and distributing storm water runoff, while enhancing and demarcating open space.

Filtration: flow-reducing elements, such as planting, textured paving and other features provide filtration, treatment and sedimentation from captured surface water.

Attenuation: rills can attenuate surface water by providing storage and reducing discharge rates.

Design considerations

Edge protection: typically sitting below pavement surface level, rills have hard edges and can hold standing water. Design teams should consider how pedestrians (particularly visually impaired and older people), cyclists and vehicles will interact with them, especially at crossing points and in relation to pedestrian desire lines and vehicle movement, especially in narrow streets.

Vegetation: rills can provide an ideal location for aquatic or sub aquatic planting for habitat creation.

Silting: rills can become impaired by silting. This can be prevented by placing upstream SuDS components to filter sediment.

Outlets: Rills typically discharge into other SuDS features and the way in which this occurs dictates the rill's function. Consider ways of restricting the flow at outfall, through the use of check dams, weirs and orifices.

Maintenance
Channel systems require routine maintenance of inlets and outfalls, debris and management of plant material.

Useful design guidance
HD 33/06 Surface And Sub-Surface Drainage Systems For Highways

CIRIA C753 The SuDS Manual

CIRIA publication C698: Site Handbook for the Construction of SuDS

Cambridge City Council, Sustainable Drainage and Adoption Guide 2010

Rill

3.8 Bioretention systems

Bioretention systems are a planted, soft landscaped low-spot, positioned to collect, store, filter and reduce surface runoff from frequent rainfall. As a surface water management component they are versatile and can be integrated into public realm environments through altering street geometry, creative material choices and planting.

Inlets, outlets and control structures are used to control and reduce the water flow rate through the bioretention system.

Bioretention systems are used to treat and manage storm events by collecting local surface water. Water accumulates on the surface, before filtering through vegetation and growing/filtration media. Here it either infiltrates or is collected via pipe work leading to a suitable outfall.

Bioretention tree pits and trenches can be incorporated into pavements using soils that intercept, dissipate and cool rainfall runoff.

Bioretention swales are similar to under drained swales with vegetation tolerant of likely inundation occurrences and pollutants. Rain gardens are localised, less engineered systems. They usually serve a single roof or small paved area and can create an attractive addition to the public realm.

Benefits
Filtration: engineered soil or growing media mixes and filter media can be designed to enhance bioretention treatment performance.

Attenuation: water can be stored within and on top of the filtration and growing media, allowing rainwater to infiltrate over a period of days.

Conveyance: bioretention features can be gently sloped or terraced to allow water to be conveyed at a reduced flow through the use of check dams, weirs and/or vegetation to a suitable outfall location.

Amenity and biodiversity: bioretention features can be integrated in many ways into the streetscape. Integrating planting has multiple benefits, enhancing the attractiveness, diversity and quality of the urban environment, while meeting local Biodiversity Action Plan targets.

Bioretention rain garden in Vauxhall

Design considerations

Edge protection: typically, bioretention components are sited below pavement surface levels and can hold standing water. It is therefore important that the interface with pedestrian and vehicular movement is carefully considered. Bioretention can be profiled in various ways, with soft edges and gentle side slopes, or hard edges and vertical sides.

Inlets: inlets may be necessary, especially when hard edge protection is required. Erosion at inlet points can be prevented by reducing the surface water flow velocity via a sediment trap or a reinforced and textured zone. Protection grilles should not be used unless the inlet diameter is greater than 350mm. An outfall provides overflow when heavy rainfall means infiltration into the soil is too slow.

Erosion: bioretention systems aim to catch flowing surface water. Soft landscapes may suffer erosion, so design the feature to control the surface water runoff movement through the use of weirs, check dams, erosion control matting and planting.

Pollution/contamination: pollution and contamination sources affecting surface and ground water may affect planting, so the planting specification should be designed to meet the site conditions. Bioretention systems can remediate water contaminants with the use of filtration mediums, normally sand-based material with a source of organic matter to provide nutrients for planting.

Sedimentation: slowing surface water flow allows fine particles to be removed. Design should limit excessive sediment accumulation that could reduce storage volume, filtration and infiltration rates.

Exceedance: bioretention systems can deal with only small catchment areas and are likely to be overwhelmed during heavy storms. The design should therefore allow for contingency flow paths and/or provide outfall.

Outfalls: if an outfall is required, consider the location, particularly the relative level of potential discharge locations, as bioretention system outfalls can be deep compared to conventional drainage.

Maintenance

Bioretention systems require routine site maintenance operations to ensure efficient operation. Inlets and outfalls require periodic inspection.

Useful design guidance

CIRIA C753 The SuDS Manual, Chapter 18

Case study 6 – Bioretention

Location
Swan Yard
London Borough of Islington

Date
2013

SuDS components
Bioretention planter

Objectives
A small office redevelopment has included SuDS components within a limited space to intercept and attenuate rainwater.

Outcome
Previously, roof rainwater discharged directly into the street. The most effective way to incorporate SuDS has been by diverting and disconnecting downpipes to feed rainwater into bioretention planters and water butts for irrigation.

The planting adds a small element of self-sustaining biodiversity in an otherwise hard paved yard.

Before

After

Images courtesy of J & L Gibbons

Case study 7 – Bioretention

Location
A24 London Road
London Borough of Sutton

Date
2014

Outlet detail

Planting

SuDS components
Bioretention planter
De-pave
Tree planting

Objectives
To reduce hard paving on a wide pavement and plant trees and perennials to aid water attenuation.

Outcome
Six areas were de-paved and planted with birch trees and a variety of hardy perennials. This has improved the streetscape and reduced the hard paved area contributing to surface water runoff. Each planting area has been mulched with gravel and contains an outlet. Originally envisaged as rain gardens, the design was subsequently amended to limit surface water runoff into the planting areas by installing a raised edge. The project had Local Implementation Plan (LIP) funding and was delivered by Sutton on the TLRN.

3.9 Trees

Trees in the hard landscape, parks, gardens and streets contribute to London's status as one of the greenest cities in the world. Their SuDS functions include attenuation, interception and soil permeability.

Trees provide multiple ecosystem services and mitigation from the effects of climate change, including cooling and improving air quality. Trees also benefit the urban environment in terms of heritage, amenity, and biodiversity. They reinforce a sense of place and can be used for traffic calming.

Benefits

Attenuation: tree pits can store storm water runoff through the use of structural soils or proprietary crate systems. It is, however, seldom possible to create attenuation or infiltration areas around existing trees; this may kill them.

Trees draw water from the ground through root systems to their leaves, where it is lost through evaporation.

Interception: trees intercept rainfall and store it. This reduces the amount of water reaching the ground, thereby reducing the volume of runoff.

Street trees: biodiversity

Infiltration: soil infiltration rates are improved due to root growth that also enhances soil biodiversity.

Filtration: soils and geotextiles that make up the construction of tree pits remove silts and particulates that may be present in runoff water. Through ‘phytoremediation’, trees absorb trace amounts of harmful chemicals – including metals, hydrocarbons and solvents – and transform them into less harmful substances or use them as nutrients.

Amenity: street trees are an important component of London’s townscape. London’s climate allows for a wide diversity of native and exotic species. For instance, London’s trees remove over 2,000 tons of pollution/ha/year and store 2.3 million tonnes of carbon per annum. Tree-lined streets also make cycling and walking more pleasant, enhancing the health and wellbeing of Londoners.

Biodiversity: trees constitute the largest element of biomass in the city, providing significant biodiversity value. Trees and woodlands provide food, habitat and shelter for birds, invertebrates and other species, some of which are subject to legal protection.

A large species tree, such as an oak, can host hundreds of different animals, plants and fungi, with long-term benefit to pollinators and the urban ecology.

Design considerations

Existing trees: existing trees should be retained where possible. Proposals should accord with BS5837:2015 and take account of tree preservation orders and conservation area designations.

Available space: tree pits require space below ground to successfully accommodate long-term root growth. Tree pits and trenches (connected pits) should provide adequate soil volume, water and gaseous exchange to the root system. The location of below ground services and drainage should be identified to ensure root zones, utilities and other below ground infrastructure are all coordinated. Protection for both long-term root growth and below ground infrastructure can be provided with root barriers. Guidance on delivering trees in hard landscapes is provided by The Trees and Design Action Group (TDAG).

Tree specification: tree species and diversity, provenance, mature size, clear stem height, root preparation and procurement should be carefully considered. For a more detailed description of the benefits of large tree species in urban environments, see CIRIA C712. Tree specification and soils performance criteria should be developed in parallel as an integral part of SuDS component design and long-term vision.

By combining trees with other SuDS components, the volume of rainwater interception and attenuation can be significantly increased. The London i-Tree eco project, for instance, demonstrated that the combined canopy cover of London produces an avoided runoff of 3.4 million cubic metres per year.

Soils: where possible, trees should be established within soft landscape areas, rather than confining rooting zones to restricted trenches in hard landscape.

Soil depths: the overall depth of soil should be appropriate for the tree species. Excessive topsoil depth increases the risk of anaerobic conditions (oxygen deficiency). Topsoil should therefore only be used within the upper part of the soil profile, with suitable subsoil in the lower layer. The exact depth permissible will be dependent on soil conditions, the tree specification and the type of load-bearing system (see soils: Chapter 2).

Street trees: biodiversity

Where tree planting is incorporated into hard landscape, the use of load-bearing tree planting systems may be necessary. New and retrofit SuDS schemes will require these systems, which may categorise the street as a zone of 'special engineering difficulty'. There are several systems available for planting in hard landscape, including:

- Cell systems
- Urban tree soil
- Raft systems
- Structural growing media

Infiltration rates: the rate of infiltration of a tree pit dictates the size of the tree pit required for water storage. The construction of the pit can be altered accordingly.

Pollution/contamination: pollution and contamination sources affecting surface and ground water influences tree growth. Certain species are more susceptible than others, and species selection should be specific to each site and SuDS scheme.

Inlets: surface water can be introduced to a tree in a variety of ways:

- through channels or rills as direct surface water runoff to a tree pit
- via depressions or low points directing runoff from impermeable surfaces towards the tree pit
- via permeable surfaces used to collect and convey surface water to the tree pits

Outlets: tree pits should be well drained as waterlogging during establishment can be one of the key reasons for failure. This is best achieved by infiltration if the ground properties are suitable. Where infiltration is not possible then an outfall to a surface water drainage network can be used. The discharge should be deep to prevent waterlogging.

Maintenance

Trees require a higher level of management during the first five years after planting because roots need to establish good contact with the growing medium before they can efficiently extract water.

Useful design guidance

CIRIA C753 The SuDS Manual, Chapter 19
CIRIA C712 The benefits of large specie trees in urban landscapes 2012
TDAG (2014) Trees and Hard Landscape: A Guide for Delivery

Case study 8 – Trees

Location
Hyllie Plaza
Malmö, Sweden

Date
2010

SuDS components
Tree trench attenuation
Tree planting

Objectives
To establish a 'forest' in the plaza using a species of beech typical of the area with fully integrated SuDS. The forest contributes to regional identity while intercepting and attenuating rainwater.

Outcome
The plaza was constructed as a single rooting zone below granite paving. This earthen layer consists of an 800mm thick base course of boulders that form a structural soil, 60% of which is cavities. Mulch was then watered down into the voids. Twelve parallel slots were cut into the paving and planted with beech trees. The soil in the beds was mixed with pumice, mycorrhiza and charcoal to support effective water and nutrient cycling and was informed by biological research that determined parameters on how to successfully establish the trees.

Surface water drain to root zone

Beech planted in tree trenches

3.10 Permeable paving

Permeable paving comes in various forms, including block paving, bituminous materials, grass reinforcement, and bound or unbound gravels. All promote water infiltration, whether through the porous surface of a paving material or through the joints between the paving units.

Permeable pavements are used as source control as they manage rainfall where it lands. The basic structure of permeable paving is similar to that of a standard pavement. However, the sub-base contains a coarser granular fill and geotextiles that prevent sedimentation.

Permeable paving can attenuate and convey water to a suitable outfall. In London, the potential for permeable paving is significant, provided the underlying geology is suitable.

Benefits

Attenuation: increasing the depth of the granular sub-base enables storm water to be stored beneath the surface, where it can infiltrate and/or slowly release to a suitable overflow. Geocellular units can be introduced. These are lightweight modular products that provide infiltration and storage (see 3.11). Care is needed in using proprietary systems as high stresses are placed on the units and their performance is difficult to monitor once paving has been laid.

Conveyance: permeable paving can be used to convey storm water within its construction, removing potential overland flow and puddling.

Simplicity: conventional below ground drainage features, such as gullies and pipes, are not needed, thus eliminating cost and maintenance requirements.

Filtration: permeable paving provides filtration at either surface level or within the subgrade. This removes or treats sediments, heavy metals, hydrocarbons and some nutrients. Paving filtration capabilities are largely dependent on the construction, which can have differing characteristics.

Design considerations

Catchment area: permeable paving provides source control. With careful detailing and design it can manage additional storm water, such as intercepted water from adjacent roof structures.

Silting: permeable paving becomes impaired by silting, oiling or mudding. Silting can be prevented using protective upstream SuDS components, eg, filter strips and swales. Intelligent placement and correct construction methods also reduce silting.

Compaction: over-compaction of the sub-base and subgrade affects the efficient function of the paving for conveyance and infiltration, so take care when installing.

Ground conditions: consider the existing ground conditions and hydrology to determine the possibility of the sub-base of the pavement functioning as a soakaway.

Exceedance: permeable paving can deal with most storm events but could be inundated during big storms (one in 100 year). When this happens, and the capacity of the pavement is reached, the paving conveys water as a traditional pavement. Design should incorporate exceedance flow paths and appropriate outfalls.

Maintenance

Maintenance regimes related to design aspiration and SuDS performance need to be clearly established from the outset. Permeable paving can require more care than traditional impermeable surfaces to maintain its integrity and function. Over time, detritus collects in the upper part of the joint material and surface pores. This build-up can affect infiltration capability. The performance and appearance of permeable surfacing in areas where buses, taxis and delivery vehicles stand may be affected by leaking engine oil.

The maintenance regime of permeable paving is largely dependent on the construction of the surface course. Brushing and joint material renewal is required, the frequency being determined by local conditions. The exact type of jointing grit will vary depending on the product system and contractors will need to take account of this. Weeds will need to be removed from joints, unless wildflower establishment is part of the design concept.

Useful design guidance

CIRIA C753 The SuDS Manual, Chapter 20
Interpave, the Precast Concrete Paving and Kerb Association – see www.paving.org.uk

De-paving the margins of an existing pathway to increase permeability

Case study 9 – Permeable paving

Location
Mendora Road
London Borough of Hammersmith & Fulham

Date
2016 (under construction)

SuDS components
Permeable paving retrofit

Objectives
This Thames Water Utilities Limited (TWUL) project aims to trial the retrofit of SuDS within the highway with a focus on their flood risk benefits. Three streets were selected for the trial as part of the Counters Creek SuDS Retrofit Pilot Schemes.

Outcome
Mendora Road involves the installation of permeable paving within the parking bays on each side of the road, with underground storage provided by geocellular structures on one side and aggregate on the other, with a flow control outlet to the existing sewer.

The scheme is lined to ensure monitoring data carried out by Thames Water gives an accurate representation of the scheme with no infiltration loses.

During construction

After construction

Images courtesy of Atkins

Case study 10 – Permeable paving

Location
London Borough of Newham

Date
2012 (Temporary)

SuDS components
Temporary permeable paving installation

Objectives
To provide a coach park that would have a minimal impact on the environment so the site could be returned to its original use as sports fields after the 2012 Games.

Outcome
The sub-base was designed to support Marshalls Priora permeable concrete blockpaving, using graded crushed rock aggregate to provide structural strength, integrity and voidage for attenuation. This was placed on a geogrid for additional strength. Creating a void at the joint between the Priora blocks at the surface allowed water to pass through the pavement at source. The joint void was filled with 2-6mm clean stone to provide a permeability rate of 18,750L/s/ha, to cope with any storm event. No additional positive drainage was required.

Installation complete

Aerial view of site under construction

Images courtesy of Marshalls

3.11 Detention basins

Detention basins are generally dry, low spots within a landscape. They can be designed as multi-functional spaces during dry conditions. During storm events, water is channelled to these basins where it is 'detained' before release at a controlled rate.

Basins usually require lots of space. However, as they can be designed to provide alternative functions, they can be incorporated into relatively dense urban environments as a soft or hard landscape feature.

Benefits

Attenuation: detention basins provide storage for stormwater before slow release through a restricted outlet and flow control.

Interception: detention basins provide a large surface and depth for holding surface water runoff. If landscaped with soils that are sufficiently permeable, they provide interception by infiltration of small rainfall events.

Amenity: as a multi-functional space, detention basins have a variety of uses, such as car parking, play, public open space and habitat.

Image courtesy of Urbanstein

Hard detention basin with multiple functionality for recreation

Biodiversity: soft landscaped detention basins can be planted with marginal and wetland vegetation to provide habitat and a source of food for insects and mammals. Planting that enhances the ecological value also increases the drainage properties of the soil to create a more effective component.

Design considerations

The form, depth and profile of the basin depend on topography and existing features, such as trees and vegetation. Detention basins' scale should complement the landscape and townscape character.

Detention basis with stepping stones and planting

Sedimentation: fine materials can cause sediment accumulation within a detention basin that can affect storage volume, filtration and infiltration rates. Designers should create upstream features or forebays that filter out sediments from stormwater before it enters the basin.

Infiltration: consider the existing ground material and hydrology to see if the detention basin can function as a soakaway.

Vegetation: when part of a soft landscape, detention basins allow diversity of planting to providing amenity, habitat, foraging and the potential for community growing. Aquatic vegetation can be used to provide stabilisation, prevent scour and re-suspension during heavy storms.

Erosion: detention basins can suffer erosion, especially during heavy storms. Storm water velocities can be reduced using weirs, sectioning or graded stone near the inlet.

Compaction: ensure soils are not over-compacted during construction. The compaction of pond soils can negatively impact infiltration rates and prevent vegetation root penetration.

Inlets: inlets into detention basins come in a variety of design forms. At pipework outfalls, a protection grille should not be used unless the inlet diameter is greater than 350mm.

Filtration: the primary pollutant removal mechanism is settlement. Filtration of nutrients can also occur through biological uptake by surface and submerged vegetation.

Maintenance

Detention basins require routine site maintenance operations to ensure efficient operation. Where the detention basin has a hard surface, additional maintenance may be needed to preserve the amenity value.

Useful design guidance

CIRIA C753 The SuDS Manual, Chapter 22

3.12 Attenuation and storage tanks

This is one of the most versatile sets of SuDS components because it is less dependent on the underlying geology. When the rate of rainfall exceeds the rate at which water can leave a surface, street or area, the water is attenuated on site.

This may happen at-grade or below ground and is often done using soil cells and attenuation tanks, usually located within buildings or beneath the public realm. These must be connected to mains sewers to provide an overflow.

Design considerations

Designers should follow the guidance below:

- Rate of runoff from the site should target greenfield runoff rates where practicable

- Storm water up to the one in 10 year storm event should be stored within SuDS components

- Storm water from between the one in 10 year and one in 30 year events should be managed within the SuDS network. No flooding should occur above ground within areas which are not part of the drainage system

- One in 30 year to one in 100 year storms should be managed within the SuDS network or within the site. This must not result in flooding of property, nor should it impact on the function of the street

- Where it is not possible to manage storm water from the one in 100 year storm at-grade within the streetscape or SuDS network, consider:

    - below-ground storage in proprietary crates, tanks or pipes
    - allowing an increased discharge rate from the site

Useful design guidance

CIRIA C753 The SuDS Manual, Chapter 21 and 24

Attenuation: soil cells

3.13 Ponds and wetlands

Although ponds and wetlands are commonly used where runoff cannot be managed at source, they can also be used close to source where the benefits derived can be greater. The opportunity for such features tends to be where lots of space is available; however, there is considerable value in small ponds and retention features close to and within developments.

Ponds and wetlands are not limited to the end of the system, where the demand for storage may be greatest; they can have a significant contribution at any point in the management train. They provide high value wildlife and amenity benefits to an area and effectively treat polluted water naturally.

Wetlands do not necessarily hold a permanent pool of water; this is especially true in dry conditions. The depth of water increases during storm events, attenuating and treating surface water runoff before outfall at a controlled rate to a suitable discharge point.

Benefits

Water quantity: ponds and wetlands store a lot of storm water. The more water there is, the more time there is for sedimentation, biodegradation and biological uptake.

Water quality: through the use of engineered soil mixes and additives, filter media can be created to enhance bioretention treatment performance. Designs can include submerged anaerobic zones to promote nutrient renewal. Reed beds are highly effective at bioremediation.

Amenity: permanent water features, such as ponds and wetlands, offer important aesthetic and amenity benefits. Integrating an aquatic bench, to create a shallow zone for wetland planting, increases aesthetic value and the potential for biological filtration and habitat. Ponds can incorporate features such as islands and shallows that allow greater access and interaction.

Biodiversity: design features, such as shallow and convoluted edges, uneven surfaces, woodlands, tussock grass areas and dead wood piles, increase habitat diversity. These can provide shelter, food, foraging and breeding opportunities for urban wildlife.

Pond: high in biodiversity and aesthetic value

Design considerations
Sedimentation: fine materials cause sediment accumulation within ponds and wetlands, reducing storage volume, filtration and infiltration rates. Mitigation measures can be implemented upstream or by installing a sedimentation area within the catchment.

Vegetation: ponds and wetlands are ideal spots for planting, which can provide amenity and habitat. Native species that are resilient to local conditions should be provided. Aquatic vegetation can provide stabilisation, preventing scour and re-suspension during heavy storm events.

Edge protection: ponds and wetlands hold standing water, so consider passing cyclists, motorists, and pedestrians. Trees, woodland, planting, benches or other physical obstructions provide natural protection.

Erosion: ponds and wetlands are susceptible to erosion, especially during heavy storms. Stormwater velocities can be slowed through planting and low-tech bio-engineering sympathetic to the character of the SuDS component.

Compaction: ensure soils are not compacted during construction as this can reduce infiltration rates, and prevent vegetation root penetration and establishment.

Outlets: incorporate a non-clogging, variable flow rate control structure, together with an emergency overflow. This might be a protected orifice, combined with an overflow channel protected with a weir.

Inlets: prevent excessive erosion at inlet points. Where pipework outfalls, a protection grille should not be used unless the inlet diameter is greater than 350mm.

Filtration: ponds and wetlands treat surface water runoff by sedimentation that occurs while water remains in the pond. Filtration of nutrients can also occur through biological uptake by surface, submerged and aquatic vegetation, particularly reed beds.

Maintenance
Conduct routine inspection and maintenance to ensure the efficient operation of ponds and wetlands. Maintenance regimes over and above routine on-site pond maintenance include water quality monitoring and control of algal bloom.

Useful design guidance
CIRIA C753 The SuDS Manual, Chapter 23

3.14 Management and maintenance

SuDS components require different inspection and maintenance regimes to traditional drainage systems. Like all drainage systems, life cycle management and maintenance must be considered from the start of the design process. Construction design and management (CDM) must consider the long-term performance of SuDS components as well as the need for maintenance vehicle access.

Close collaboration with local authorities through the feasibility and design process is crucial to successful delivery of SuDS schemes, particularly on adopted highways. Local authority engagement should inform design decisions and specify asset management and maintenance regimes. This will ensure that site or street management can deal with SuDS requirements.

SuDS maintenance can sometimes be undertaken alongside routine management of the public realm, particularly landscaping requirements. Many developments include open spaces and many local authorities already manage such areas. All open spaces have opportunities to include SUDS in some form.

It is helpful to engage the local community in SuDS development from the outset, particularly during retrofits. Local knowledge can help shape the design, while allowing people to appreciate what the SuDS components do. This also offers potential for the local community to take ownership, by helping to manage and maintain SuDS as part of their neighbourhood.

In London, operational constraints on management and maintenance vary between the busiest streets (managed by TfL) and the 95% that are maintained by the boroughs. Not all SuDS features will meet the criteria of Local Highway Authorities to adopt maintenance responsibilities, which needs to include long-term costs.

Maintenance requirements can be simplified by using well thought-out designs. In a rain garden, for example, soil specification and plant species selection should meet the specific demands of the SuDS, site characteristics and geotechnical conditions. Maintenance requirements will vary depending on the time of year.

For a detailed guide to SuDS maintenance, refer to CIRIA C753 The SuDS Manual, Chapter 32 (Operation and maintenance).

Component specific maintenance

Green walls: most versions require irrigation. This must be maintained rigorously. Failure of an irrigation system will result in the death of the green wall, reducing the attractiveness of the area and increasing replanting costs. Low-maintenance green walls planted directly into the ground can be just as effective.

Sweeping: detritus and sediment from pedestrian and traffic use can accumulate quickly. This can lead to a build-up of sediments to clog systems, such as joints for permeable pavements. Sweeping regimes need to support the SuDS components.

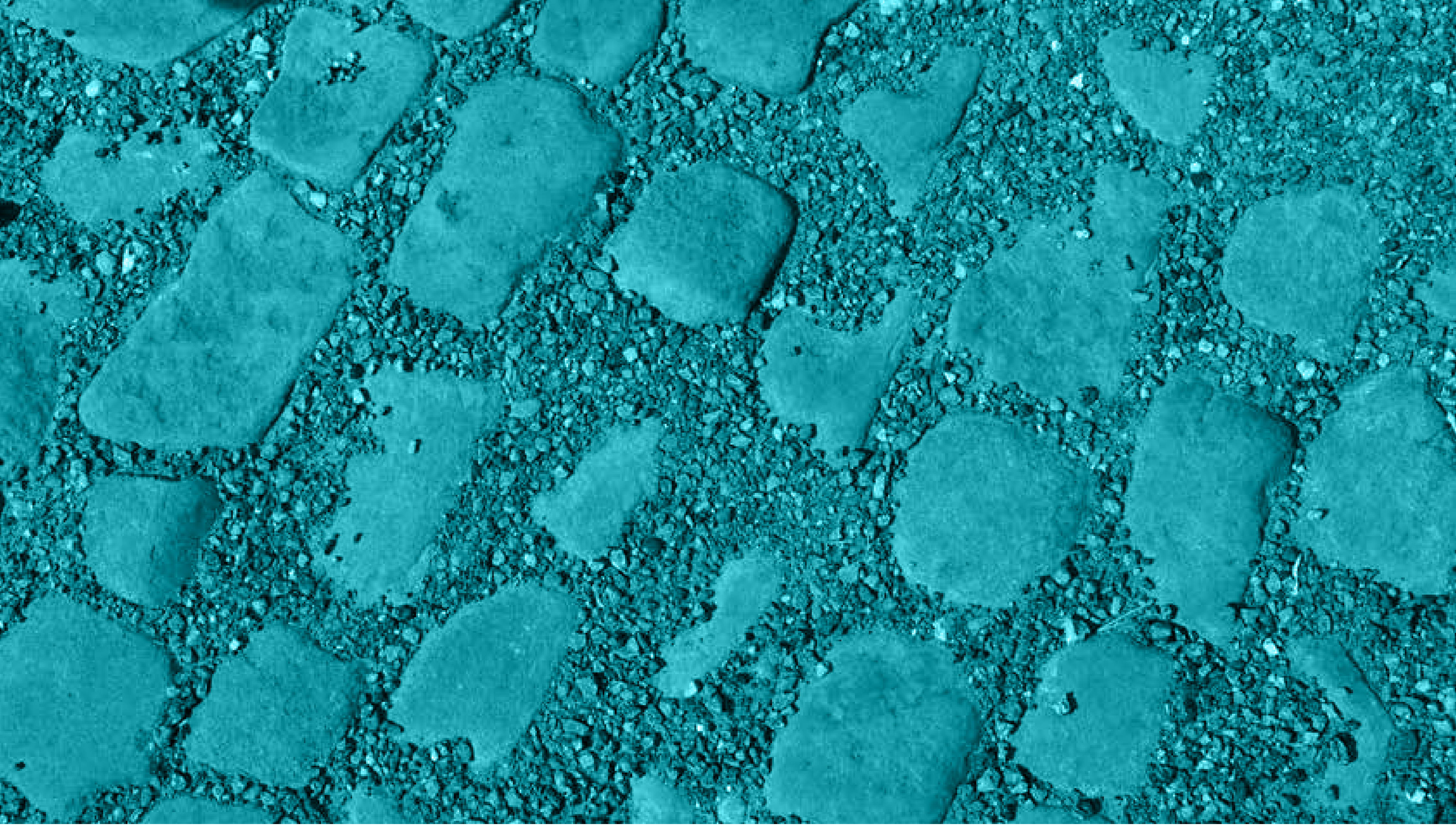
Geotextiles: Many SUDS components incorporate specific geotextiles to separate materials to separate materials to some extent. These tend to blind/clog over time, reducing infiltration/percolation rates. There is little long-term test data from the UK for public/urban situations; designers should be aware of the long-term maintenance risks that geotextiles may pose.

Compacting: for landscaped SuDS to be effective, they must be protected from both vehicle and pedestrian overrun. As a minimum, structural edges are generally necessary alongside soft SuDS that interface with pavements. Where edges adjoin carriageways or parking bays, high/double kerbs and or >450mm wide paved aprons should be provided for access to parked cars without walking in the soft feature.

Salting: where soft SuDS receive runoff containing de-icing salts, good sub-drainage is essential to prevent salt accumulation from harming plants. Sub-drainage allows most salts to drain through during the winter months when plants are dormant. Salt tolerant plants should still be selected and the ground must not become compacted.

Geocellular drainage: while useful for creating below-ground surface water reservoirs or rooting zones for street trees, geocells are complex and potentially dangerous. There are various design, certification, supervision, testing and maintenance issues that require emphasis if they are to be used safely and appropriately.

Highway structures and geo-technical structures must be designed, checked and supervised under relevant eurocodes. Most Highway Authorities will wish to manage this via their Geotechnical and Highways Structures technical approvals process.



4 SuDS in London's streets

4.1 SuDS and the urban realm

This section shows how SuDS can be integrated into the design and management of some typical London streets. SuDS should be designed in parallel with other urban design considerations, reflecting the unique opportunities and constraints created by every London street.

Streets account for 80% of London's public realm. They are not just corridors for movement; they contribute to the city's sense of place and identity and often reflect London's diverse communities.

Well designed streets are essential for London's future growth, both in terms of population level and economic activity. Their function for pedestrians and cyclists, as well as other users, is growing and the design of streets needs to facilitate this.

Improvements to streets can directly unlock wider benefits beyond movement, including health benefits for London's growing population. These benefits can be realised at a variety of levels, from minor interventions to transformations of large junctions and gyratories.

Streets are places too

SuDS are an important component of this transformation, addressing surface water flood risk, improving air quality and contributing to a higher quality of life.

Eight street scenarios are illustrated below to show how SuDS may be provided within the many different street types across London. Although based on specific examples of streets in London, the illustrations are purposefully generic, aiming to demonstrate the art of the possible in a variety of locations and environments, rather than to provide a strictly applicable set of design criteria.

4.2 Street scenarios

Street scenario 1

A roadway with large tracts of land alongside, between slip roads and interchanges. This expansive leftover space has great potential to incorporate extensive SuDS creating and linking habitats, as well as improving and using adjacent land.

Potential SuDS components

1. Wet swale, see 3.6
2. Filter drain, see 3.5
3. Filter strips, see 3.4
4. Tree planting, see 3.9
5. Ponds, see 3.13
6. Retention basins as overflow, see 3.12
7. Infiltration where conditions allow, see 3.3
8. Living roofs, see 3.2

Street scenario 2

A busy road; an important route for buses, cyclists, pedestrians and general traffic. Large areas of trafficked sealed surfaces mean SuDS need to optimise performance within limited space.

Potential SuDS components

1. Tree planting, see 3.9
2. Inlets
3. Bioretention, see 3.8
4. Soil and drainage material, see 2.5
5. Permeable paving to parking bays, where appropriate, see 3.10
6. Maintenance access strips
7. Utilities
8. Geotextile
9. Structure (green wall), see 3.2

Street scenario 3

An important focal point for business and culture. High pedestrian flows, with limited motor traffic access. This scenario offers large areas of public realm for integrating a variety of SuDS components with existing mature trees.

Potential SuDS components

1. Tree planting, see 3.9
2. Structure (green roof), see 3.2
3. Bioretention, see 3.8
4. Outfall
5. Porous bound gravel, see 3.10
6. Soil and drainage material, see 2.5
7. Utilities
8. Geotextile
9. Existing trees
10. Disconnected downpipe and rain planter
11. Structure (green wall), see 3.2

Street scenario 4

An important local route with high quality foot and cycle provision. The adjacent park provides particular opportunities for linear SuDS components. Other SuDS features in this street include downpipe disconnections from adjacent houses and flats.

Potential SuDS components

1. Green wall, see 3.2
2. Tree planting, see 3.9
3. Kerb drainage
4. Permeable paving, see 3.10
5. Dry swale, see 3.6
6. Adjacent green space used for SuDS
7. Existing trees
8. Infiltration where conditions allow, see 3.3
9. Channels to direct flow from downpipes to tree planting, see 3.7

Street scenario 5

A well-connected local centre with high footfall from people accessing shops and services. A range of opportunities are illustrated, showing how SuDS can be integrated to enhance the visual coherence and identity of the area, improve air quality and reduce temperature in the context of the street and below-ground structures.

Potential SuDS components

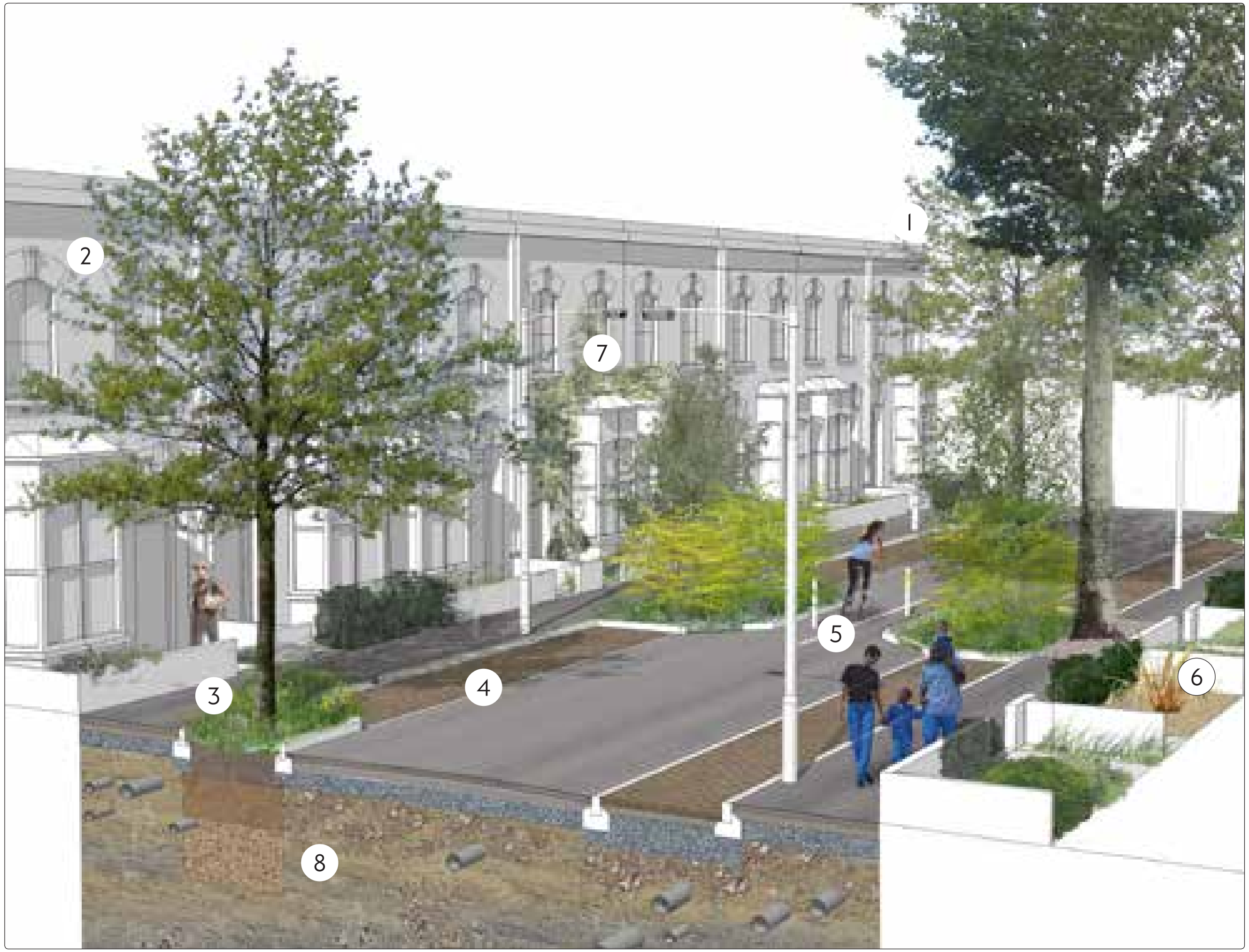
1. Existing trees
2. Tree trenches in median, see 3.9
3. Living roof, see 3.2
4. Permeable paving acting as an inlet to tree trench, see 3.10
5. Street furniture aligned with SuDS components to reduce clutter
6. Slab paving
7. Soil and drainage material, see 2.5
8. Geotextile

Street scenario 6

A traditional, quiet and safe residential street. Pedestrian and vehicular traffic is mostly local, with provision for cyclists. There is potential to integrate many SuDS components in front gardens, as well as the street.

Potential SuDS components

1. Existing trees
2. Tree trenches, see 3.9
3. Bioretention, see 3.8
4. Permeable paving to parking bays, see 3.10
5. SuDS components aligned to provide traffic calming measures
6. De-pave and permeable paving to front gardens, see 3.10
7. Green wall, see 3.2
8. Soil and drainage material, see 2.5



Street scenario 7

A local shopping street in a residential area that mainly caters for pedestrian and cycle movement. Restricted access for service vehicles. SuDS components are integrated into the street furniture and public realm, creating an attractive and welcoming place.

Potential SuDS components

1. Existing trees
2. Tree trenches, see 3.9
3. Bioretention planters to the base of disconnected downpipes, see 3.8
4. Channel to bioretention, see 3.7
5. Slab paving
6. Permeable paving to discrete areas, see 3.10
7. Porous surfaces over existing trees
8. Bioretention, see 3.8
9. Cell systems, see 3.11
10. Soil and drainage material, see 2.5

Street scenario 8

A civic square. This is a place of street activity with a high concentration of cultural, commercial and entertainment uses. A place with restricted vehicular access, providing the opportunity for a wide range of large and small scale SuDS components, carefully considered in respect of the heritage setting and significance.

Potential SuDS components

1. Existing trees
2. Permeable paving where appropriate, see 3.10
3. Amenity areas acting as detention basins, see 3.12
4. Outfall
5. Soil and drainage material, see 2.5
6. Geotextile
7. Attenuation tanks, see 3.11
8. Bioretention planters to the base of disconnected downpipes, see 3.8

5 Case studies

Case study index

The following case studies include local and strategic examples of SuDS to show the versatility of sustainable drainage in various contexts. Most are examples from London, but there are also exemplar national and international studies which may have some application in the Capital. They are described and ordered by size.

London under 500m^2

5.1 Priory Common 85 m^2
5.2 Upminster Bridge swale 400 m^2
5.3 Kenmont Gardens 435m^2

London under 2000m^2

5.4 Derbyshire Street 765m^2
5.5 Renfrew Close 900m^2
5.6 Islington Town Hall 1000m^2
5.7 Rectory Gardens 1000m^2
5.8 Talgarth Road 1200m^2
5.9 Mile End Green Bridge 2000m^2

London over 0.2ha

5.10 Queen Caroline Estate 0.23ha
5.11 Bridget Joyce Square 0.26ha
5.12 Crown Woods Way 0.26ha
5.13 Hackbridge 0.27ha
5.14 Goldhawk Road 0.27ha
5.15 Firs Farm 0.48ha
5.16 Salmons Brook 0.77ha
5.17 LuL depot roof, Middlesex 125m^2
5.18 Coulsdon Bypass 34ha
5.19 London Sustainable Industries Park, Dagenham 142ha

National & international

5.20 Great Kneighton/Clay Farm, Cambridge 109ha
5.21 Alnarp, Sweden 0.37ha
5.22 Benthemplein, Netherlands 0.95ha
5.23 Rue Garibaldi, Lyon, France15ha
5.24 Bo01, Malmö, Sweden 85ha

5.1 Priory Common rain meadow

Location
Priory Common
London Borough of Haringey

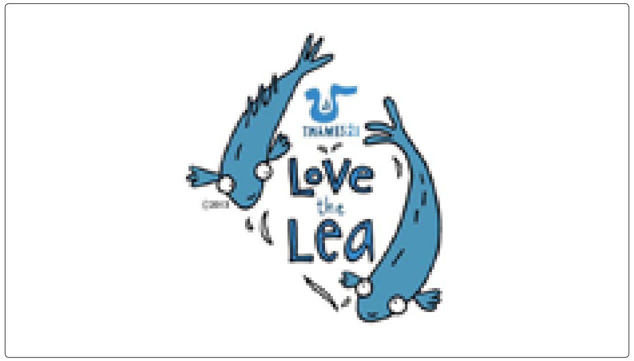
Extent
85m²

Cost
£48,000 (construction only)

Date
2016

Credits
London Borough of Haringey
Thames21
Robert Bray Associates

SuDS components
Filter strip
Infiltration basin
Channels



Love the Lea campaign, Thames 21

Summary

Green space enhancement and re-purposing for surface water interception and infiltration.

Project description

Next to Priory Road is a linear green space with mature plane trees planted along the roadside. The verge is about 75m long and was highlighted as a site to deal with surface runoff from the road, via a sewer connection directly to the River Moselle. This project is part of a suite of SuDS schemes locally that will cumulatively improve water quality.

Objectives

- Intercept road runoff pollutants at source and use the existing landscape to allow ‘interception loss’ (ie, prevent water from reaching the ground) for everyday rainfall

- Clean and cool runoff during summer when the watercourse is most susceptible to the effects of pollution and water temperature increases (which inhibit the ability of water to carry dissolved oxygen)

Priory Common after installation

Actions and results

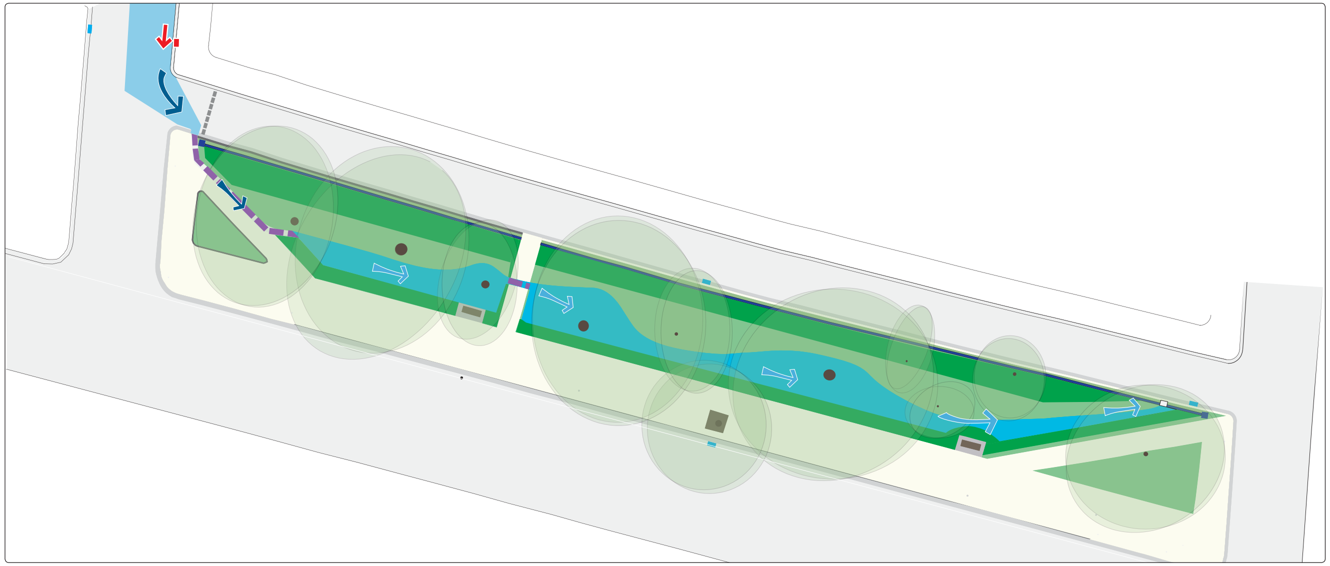
- Runoff is diverted at the surface into a gully in Redston Road and collected in a five-sett channel that directs water onto the grass verge along Priory Road
- Verge re-profiling carries water for its full length until it reaches the sewer
- Early observations indicate that water flows quickly into the rain meadow but slows as it travels through the grass, soaking into the tree-lined verge before reaching the letterbox outfall to a road gully
- Performance will improve as the meadow grows
- The client partnership with Thames21 and Haringey Council are considering monitoring opportunities

Benefits

- This simple SuDS retrofit shows how an existing urban green space can bring significant benefits to unprotected urban watercourses
- Surface collection of runoff avoids any significant excavation or spoil for removal
- Surface dressing with topsoil and low earth banks (bunds) has minimum impact on the trees, with simple wildflower meadow seeding for open soil areas
- The river is within the sub-catchment area of the line and, to a lesser extent, nearby roads. This has implications both for pollution and bank stability of the River Ingrebourne as well as the reliability of the line
- High intensity summer storms will be diverted from the sewer and cooled before release to the river
- Monitoring will show the extent of interception loss and the protection offered to the River Moselle

Lessons learned

- Importance of contractor selection
- The value of expert supervision
- How sites, that might otherwise be considered unsuitable for SuDS, can provide benefits with minimum intervention



Images courtesy of Robert Bray Associates

Conveyance of water through the scheme

5.2 Upminster Bridge swale

Location
Upminster Bridge
London Borough of Havering

Extent
400m²

Cost
Trial scheme

Date
2015

Credits
London Underground
Environment Agency
Green Infrastructure Agency
Environmental Scientifics Group
Environmental Protection Group
SEL Environmental
ITM Monitoring

SuDS components
Swale
Outfall/runoff interception

Summary

Swale construction for increased on-site attenuation and water treatment.

Project description

Upminster Bridge Station serves the District Line and is 3.5km west of the M25. The adjacent River Ingrebourne is vulnerable to flooding and has been deemed an at-risk river by the Environment Agency. The river is within the sub-catchment area of the line and to a lesser extent, nearby roads, with implications for both pollution and bank stabilisation of the River Ingrebourne and reliability of the line.

A London Underground Power Upgrade Project, involving the construction of a new substation, presented the opportunity to trial an experimental SuDS scheme. This included two swales with associated tanks and v-notch weirs. One receives water from the new substation roof, the other from adjacent London Underground tracks. Funding was provided by the Environment Agency with a London Underground Limited contribution in kind.

No disruption to service during construction

400m² swale under construction

Objectives

- Manage water quality by improving remediation capabilities
- Mitigate rail infrastructure flood risk
- Enhance local biodiversity

Actions and results

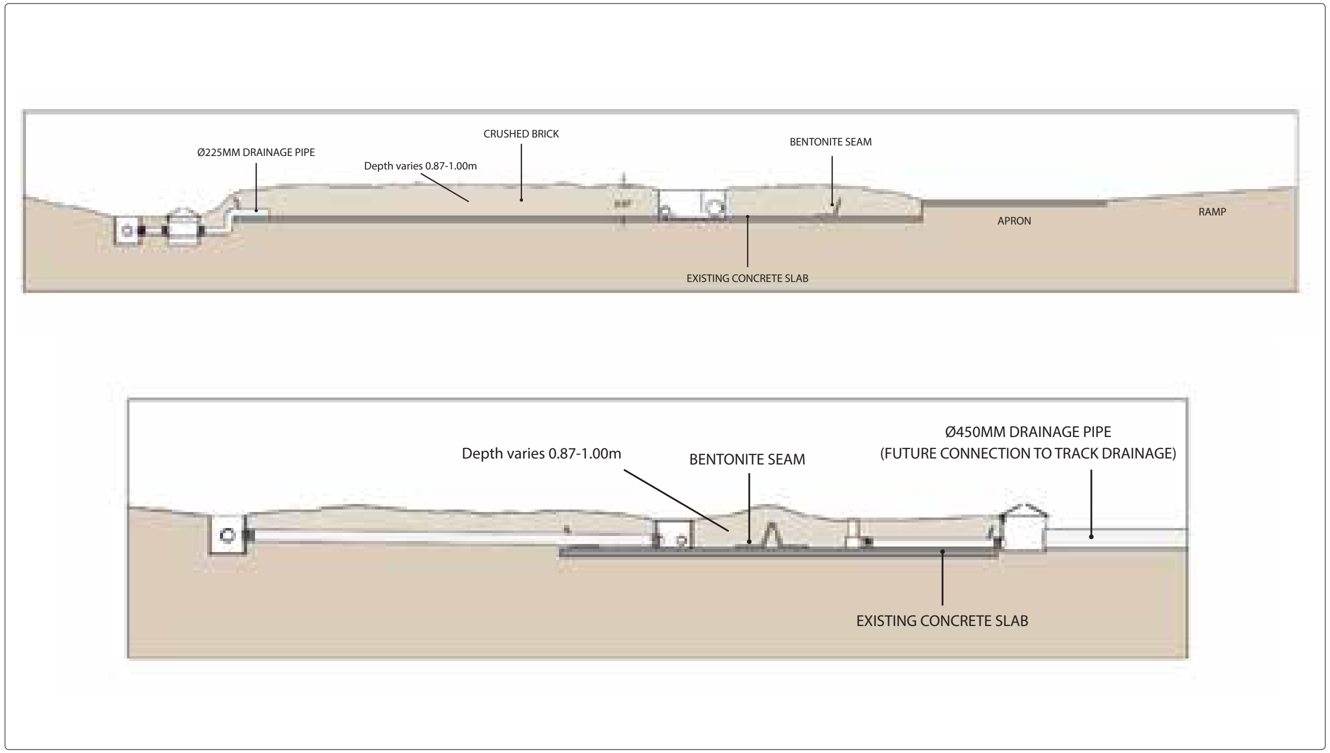
- Surface water from the railway lines and from the outflows of the sub-station roof is attenuated. This has enhanced the site's flood resilience and reduced saturation of the soil on the slopes by the River Ingrebourne. Slope stability has improved as a result
- Monthly remote monitoring provides data on water quantity. Data loggers are attached to sampling chambers. These contain water chambers which house water level sensors
- Plant establishment is being monitored
- Water quality is being sampled monthly from five locations and analysed.

Benefits

- Ability to withstand a one in 100 year flood event of 59L/sec
- Improved water quality
- Reduced waste from building demolition through the reuse of waste rubble for swale construction
- Enhancement of outlook over rail infrastructure from residential areas
- Any outflow from the scheme is conveyed to River Ingrebourne, not to rail infrastructure
- Enhanced local biodiversity

Lessons learned

- Design required an interface with conventional drainage systems



Images courtesy of LU Infrastructure Protection

Swale sections

5.3 Kenmont Gardens

Location
Kensal Green
London Borough of Hammersmith & Fulham

Extent
435m²

Cost
£300,000 (total scheme)

Date
2015

Credits
London Borough of Hammersmith & Fulham
Project Centre Ltd
FM Conway
Green Blue Urban

SuDS components
Permeable paving
Rain gardens
Geocellular storage
Tree planting

Summary
Transformation of highway to neighbourhood garden.

Project description
The garden was previously a carriageway that had been pedestrianised. The carriageway still existed, but had been closed off with bollards.

The project is a Neighbourhood and Corridor Scheme, developed to incorporate SuDS. It is funded through a combination of TfL LIP Funding and Lead Local Flood Authority Funding.

Objectives
- Improve an under-used area through public realm works, including planting, paving and lighting improvements

- Incorporate SuDS features within the design

- Retrofit SuDS to the existing drainage system of a deep combined storm and foul sewer, fed by gullies that were formerly in the carriageway

Actions and results
- Surface flow is directed towards rain gardens and trees

- Trees are planted in linked trenches that incorporate below-ground attenuation

- Water flow is held and slowed within attenuation features before passing through control chambers and into the existing drainage system

- Permeable paving allowing infiltration

- Community involvement throughout the project, with concept designs sent out for public consultation in September 2014, from which a positive response was received and a preferred option selected. A dialogue was maintained with College Park Residents Association (CoPRA) and Kenmont Primary School throughout the process

Benefits
- The design restricts runoff to greenfield rate for events up to the one in 10 year average recurrence interval (ARI) with exceedance routes

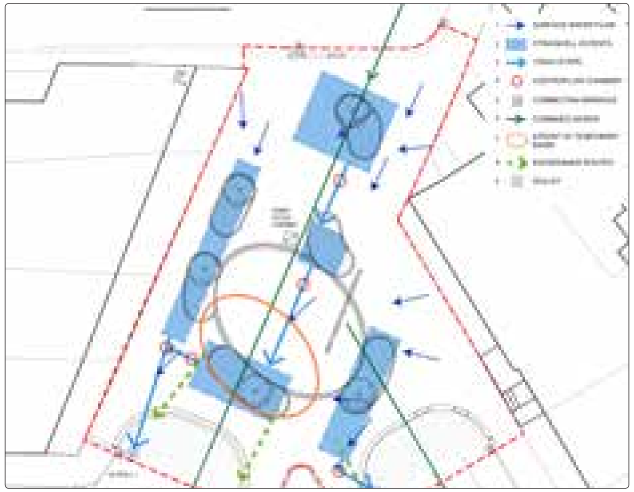
- CoPRA and Kenmont Primary School were heavily involved in the latter stages, with pupils of the school creating clay tiles under the supervision of a professional potter, which were then installed in the new space

- Engagement throughout the process and a planting event ensured community buy-in

Community planting workshop

After

Images courtesy of George Warren



Plan

After

After

5.4 Derbyshire Street Pocket Park

Location
Bethnal Green
London Borough of Tower Hamlets

Extent
765m²

Cost
£120,000 (total scheme excluding officer time)

Date
2014

Credits
London Borough of Tower Hamlets
Greysmith Associates
Oxford House
Mayor of London's Pocket Park Initiative
JB Riney
The Grass Roof Company
Thames Water Utilities
RBMP

SuDS components
Permeable paving
Bioretention basins
Green roofs
Tree pits

Summary
Transformation from roadway into community shared space.

Project description
Derbyshire Street is in a densely populated part of east London, next to a park and the Oxford House community and arts centre. Before the redesign, the street was a dead-end with parking issues, anti-social behaviour and fly-tipping.

The potential of the site's south-facing aspect, existing trees and community involvement helped develop a consensus for streetscape improvement. A key aspect of delivery was the partnership between the local highway authority, the flood management teams and the community. This grassroots approach enabled funding from the Mayor of London's Pocket Park initiative.

Objectives
- Improve facilities for community use
- Onsite water management through SuDS


Before


After

Images courtesy of Greysmith Associates

Community event

Actions and results

- Green roofs on bike sheds and a bin store increases the attenuation storage capacity, improving the streetscape's ability to mitigate impacts during high and/or prolonged peak flow events
- Disconnecting downpipes on Oxford House increased attenuation storage capacity by redirecting water away from the combined sewer overflow and conveying it into bioretention basins and a new swale
- Permeable paving allows water to seep into the ground. During high and/or prolonged peak flows, additional runoff is attenuated by the surrounding SuDS scheme
- A network of rain gardens, swales and engineered tree pits has increased the attenuation storage capacity of the streetscape
- A bespoke information board communicates the streetscape and community benefits of the scheme leading to continued community buy-in to the maintenance and monitoring of the scheme

Benefits

- Inhibits the flow of storm water runoff into the combined sewer system
- Community partnerships have safeguarded future management and maintenance
- New community resource created
- Native and edible plants promote biodiversity and a social capital
- Able to withstand a one in 100 year rainfall event

Lessons learned

- Active engagement between the community and local authority has social and economic value
- SuDS can help define and enhance public realm improvements that relate to pedestrian and cycle routes
- Permeable block paving is susceptible to gathering litter fragments, so the jointing of paving systems needs consideration
- Connectivity with Weavers Field could have further enhanced the scheme

5.5 Renfrew Close

Location
London Borough of Newham

Extent
900m²

Cost
£43,000 (construction only)

Date
2015

Credits
Groundwork
Environment Agency
Robert Bray Associates
Greatford Garden Services

SuDS components
Detention basins
Bioretention basins
Tree planting
Channels
Downpipe disconnection
Swales

Summary
Transformation of green space to multi-functional green infrastructure for the estate.

Project description
An existing communal green space between residential blocks was retrofitted with a SuDS scheme. The rain gardens receive water from hard surfaces at roof and ground level and from soft surfaces at ground level.

Objectives
- Provide a sustainable drainage function and alleviate flooding
- The rain gardens should create attractive, productive and biodiverse green spaces for the residents

Actions and results
- Bioretention basins designed to take road and roof runoff
- Downpipes and rainwater conveyed to swales and bioretention basins
- Swale network to accommodate different sized rainfall events
- Visual amenity provided by rain gardens


Images courtesy of Robert Bray Associates

Channel outflow into swale and bioretention basin

Benefits

- Can withstand a one in 100 year + 30% storm event
- Runoff from 750m^2 of roof and 165m^2 from roads are attenuated in the scheme
- 12-hour delay between rainfall event and pressure recording in the basin
- 16-hour delay between peak rainfall and peak pressure in rainfall basin for first event

Lessons learned

- Monitoring system installed and used to support the design of future SuDS retrofit projects should try to direct flows from known problem areas into bioretention basins to prevent surface flooding
- Maintenance agreements need to be in place along with a clear method of reporting

After

Channel detail

5.6 Islington Town Hall

Location
Upper Street
London Borough of Islington

Extent
1,000m²

Cost
£100,000

Date
2011

Credits
London Borough of Islington
J&L Gibbons

SuDS components
Permeable paving
Large specie tree planting
De-paving

Before

Summary
Transformation of a car park into a green public space for community and ceremonial events.

Project description
Islington Town Hall is on Upper Street which is populated by shops, bars and cafes and attracts heavy footfall. Before the redesign, the forecourt of the town hall was a car park with impermeable surfaces. This had implications for the management of stormwater runoff onto Upper Street's carriageway and for combined sewer overflow.

A political incentive to 'green' the town hall forecourt initiated the scheme as part of Islington's sustainable agenda.

This was coupled with recognition of the poor presentation of the building to the street. These were key factors in the project gaining support.

It shows how small public realm interventions can address car parking issues and storm water runoff, while transforming a space and improving the public realm.

Objectives
- Enhance the town hall's setting as a key civic location
- Provide a high quality public realm on Upper Street
- Address car parking issues, while maintaining a suitable setting for ceremonial events
- Plant large species trees for long-term benefit

Actions and results
- Permeable paving surfaces allow water to seep directly into the sub-base, thereby redirecting excess and polluted water away from the combined sewer
- Trees and planting provide canopy cover, increasing the interception of rainwater and enhancing biodiversity
- De-paved and planted surfaces increases attenuation by maximising areas for infiltration

Images courtesy of J & L Gibbons

After

Benefits

- Increased attenuation storage capacity
- Improved water quality
- Enhanced public realm and green infrastructure
- Enhanced civic function of the forecourt
- Tree-planting for improved air quality

Lessons learned

- Permeable surface treatments can successfully address shared space requirements
- An integrated SuDS scheme can have environmental and economic benefit

After

5.7 Rectory Gardens

Location
Hornsey
London Borough of Haringey

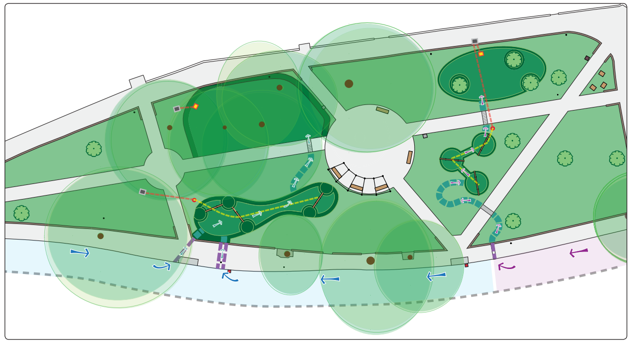
Extent
1,000m²

Cost
£80,000

Date
2016

Credits
Haringey Council
Robert Bray Associates
Thames21
Hugh Pearl (Land Drainage) Ltd

SuDS components
Retention basins
Detention basins
Planted channels



Plan

Summary

Retrofit and transform green space to manage road runoff.

Project description

Runoff flows directly to the River Moselle via a surface water sewer connection.

An existing local park was identified for accommodating SuDS components that enhanced amenity and biodiversity value.

Objectives

The project aims to collect all the runoff from a defined road catchment and show how the full SuDS aspiration of 'managing quality and quantity aspects of runoff while delivering amenity and biodiversity benefits' can be met in an existing urban park setting.

Actions and results

- Runoff from the road is collected in three bespoke, cast iron inlets that replace gully pots and perform like chute gullies, delivering the dirty surface water into two SuDS management drains
- System A to the west, delivers runoff to a silt interception forebay basin
- In System B, runoff travels along a grass channel, which is planted so oils and silts are concealed but is easily accessible to remove solids
- The 'source control' features are followed by wildflower meadow basins that can hold significant amounts of reasonably clean runoff to the one in 10 year return period
- An under-drain below the basins allows water to leave the site at a greenfield rate. This flow is governed by a protected orifice control chamber.
- In larger storms, up to the one in 100 year return period, with a 30% allowance for climate change, these basins overflow into further grass storage basins. The second basins are managed as amenity grass so are accessible most of the time
- The wildflower meadow basins have balance beams so that even when wet or filled with water they can be used for adventure play

Benefits

- Retrofit demonstrates how polluted runoff can be practically managed in an existing local park or urban green space, while enhancing amenity and biodiversity
- The small interception forebays provide a simple way of trapping and removing pollutants, such as silt and heavy oils
- The changes of level in the park landscape enhance the quality of the space, while defining the SuDS and biodiversity features
- The under-drain ensures the basins are dry most of the time, but the rainwater irrigates both trees and the meadow, particularly in summer when many urban park landscapes suffer drought
- Water-play in a safe place helps the community relate positively to normal rainfall and to appreciate the impact of heavy storms in summer when the basins fill
- Signs provide information about the components and benefits of SuDS to passers-by

Lessons learned

- The project was undertaken with the Priory Common rain meadow (case study 5.1) and therefore benefited from sharing expert site supervision and a knowledgeable contractor
- Protecting planted channels where water entered the SuDS and the relatively flat basins reduced erosion to a minimum
- Physical protection of the basins was considered but not used for reasons including visual quality, risk of vandalism and cost. It may be necessary to overseed the basins when germination of the wildflower seed is inspected
- The client partnership (Thames21 and Haringey Council) are currently considering monitoring opportunities
- It would be useful to estimate natural losses at different times of year in different weather conditions
- The quality of runoff should be easy to assess by collecting it as it passes through the control chambers

After

Swale

Images courtesy of Robert Bray Associates

5.8 Talgarth Road

Location
Talgarth Road
London Borough of Hammersmith & Fulham

Extent
1200m²

Cost
£240,000 (total scheme)

Date
2016

Credits
London Borough of Hammersmith & Fulham
FM Conway

SuDS components
Bioretention basin
Tree planting

Summary

Green infrastructure enhancements on the highway to improve air quality.

Project description

This project saw green infrastructure installed alongside a footway and cycle path along Talgarth Road between Butterwick and Shortlands, to the north of the Hammersmith Flyover. The project intends to reduce the exposure of pedestrians and cyclists to the poor air quality in Hammersmith town centre, while incorporating SuDS and providing a safe and secure setting. The aim is to replicate this approach elsewhere in the borough.

Objectives

- Improve air quality with integrating SuDS

- Planting Miscanthus (silvergrass) to act as a filter to traffic emissions. This grass grows to 1.8m and provides a soft, visibly permeable border, to ensure a sense of safety

Actions and results

- Some trees along this stretch were in a poor state and needed to be replaced. Others were removed to allow a cycle path to be repositioned

- A 26m section of the roadside planting has been designed to accept runoff from the highways and footway, thus reducing the surface water flow to the combined sewer and providing additional capacity within the Counter's Creek Catchment

- The bioretention basin will be deeper than the other stretches of planting to provide underground attenuation for the surface water flows, with a controlled release to the sewer

- Exceedance flows, during extreme events, are directed towards the existing road gully

- Roadside bioretention basins incorporate bespoke roadside inlets

- A border of herbaceous groundcover will be planted between the Miscanthus and the bicycle path

Benefits

- Air quality monitors, placed on either side of the grass, measure particulate matter and nitrogen dioxide levels, to demonstrate the extent of air quality benefits from the greening.

Lessons learned

- The bioretention basin will include the same plant species as the rest of the roadside planted areas to test how these species perform when experiencing runoff from the surrounding area, compared to conventional planting beds

- Should the species thrive in this environment, the aim is to repeat this along other stretches of highway within the borough to help tackle air quality and flooding issues

Under construction

Complete

Images courtesy of George Warren

5.9 Mile End Green Bridge

Location
Mile End Road
London Borough of Tower Hamlets

Extent
2000m²

Cost
£75,000

Date
2010

Credits
Design for London
London Borough of Tower Hamlets
Mile End Park
muf architecture/art
Tim O'Hare Associates
J & L Gibbons

SuDS components
Green roof/bridge
Tree planting
Soil amelioration

Summary
Reinstatement of soils and planting on green bridge.

Project description
The bridge provides a key connection within Mile End Park by spanning the Mile End Road.

As part of High Street 2012 works, the existing green bridge was rejuvenated to incorporate more planting.

The proposals had to consider the requirements of the A11 below. Traffic flows on this part of the TfL road network could not be impeded during the works or maintenance operations once planting was established.

Objectives
- Enhance park connectivity
- Increase the impact of the planting from the road below and the parkland above
- Improve soil infiltration
- Encourage biodiversity

Actions and results
- The soil required de-compacting and amelioration to increase its capacity to retain water
- Soil depths were increased by 250mm to allow for greater root-zone and better plant establishment
- Trees were planted at a high density to improve their resilience to the shallow soil profile
- The central median was removed to create greater openness

Benefits
- The young plant stock established faster than previous semi-mature tree planting
- The dense blocks of planting and mix of species provide increased biodiversity
- The planting had immediate impact due to its density and educational interest as an emerging 'upland' ecology
- The bridge is more successfully integrated into the park landscape
- The planting creates a distinctive feature and is more visible from the A11 below

Lessons learned

- Stability of high level planting, achieved through young stock able to adapt rooting structure to specific soil depths
- Parapet planting proposals have to take into account the restricted access for planting and maintenance
- Early engagement with TfL necessary to prevent contract delays
- Early engagement of soil scientist to avoid delays due to soil testing

Before

Images courtesy of J & L Gibbons

Green Bridge from the Mile End Road

After

5.10 Queen Caroline Estate

Location
Hammersmith
London Borough of Hammersmith & Fulham

Extent
0.23ha

Cost
£226,000 (total scheme)

Date
2015

Credits
Groundwork
London Borough of Hammersmith
& Fulham
Greater London Authority
EU LIFE+ Programme

SuDS components
Green roofs
Bioretention basin
Detention basin
Permeable paving

Summary
Estate regeneration through integrated SuDS design.

Project description
Queen Caroline Estate is bound by the River Thames and the Hammersmith Flyover. The estate is a mixture of paved carriageway surfaces for access and parking, plus grassed areas. The challenges of the site made it an appropriate development for the LIFE+ Climate proofing social housing project that provides low cost, retrofitted SuDS to improve community resilience to climate change.

Objectives
- Reduce surface water flood risk and frequency
- Improve the condition of the estate's infrastructure
- Address deprivation and vulnerability to climate change on the estate

Images courtesy of Groundwork

Garage green roof

After

Paving strip

Actions and results

- Green roofs were installed to increase attenuation storage capacity where it has not been possible to disconnect downpipes that run internally. The green roofs were installed on bin stores and pram sheds; these are visible at ground level and from above
- A bioretention basin was built to attenuate rainwater. This flow comes from surrounding impermeable surfaces and from the roof of an adjacent building
- Permeable paving has increased the volume and rate of infiltration into the subsurface, helping to maintain the effectiveness of bioretention and detention basins by limiting the water flowing to them

Benefits

- The works were delivered at the same cost as conventional landscape improvement when compared to other housing estate works
- Landscape has been transformed into multi-functional space
- 142m² of green roof has been installed, improving biodiversity
- Run off from 900m² of impermeable surface has been conveyed into a SuDS
- A community growing area of 32m² has been created

Lessons learned

- Engaging residents in the development of proposals ensured a detailed understanding of how the streetscape functioned, thereby maximising the reach of project benefits
- Despite CAT and radar scans, some below ground services were not identified and required designs to be revised to accommodate them

Bioretention basin outside homes

5.11 Bridget Joyce Square, Australia Road

Location
White City
London Borough of Hammersmith & Fulham

Extent
0.26ha

Cost
£950,000 (total scheme)

Date
2015

Credits
London Borough of Hammersmith & Fulham
Robert Bray Associates
Thames Water
TfL
GLA
McCloy Consulting
F M Conway

SuDS components
Permeable paving
Bioretention basins
Rills
Rain gardens
Tree planting
Downpipe disconnection

Summary

Transformation of the road into a shared 'urban oasis' for pedestrians and cyclists.

Project description

Australia Road is in the heart of the White City Housing Estate, in the northern section of Shepherds Bush, south of the A40 Westway.

This stretch of Australia Road has a school on one side and playgrounds on the other – potentially hazardous for children crossing the road between parked cars.

The street lies within the Counters Creek Sewer catchment, which is exceeding its capacity, resulting in the flooding of properties downstream. Hydrological modelling of the borough has also shown that this stretch of Australia Road is susceptible to significant surface water flood risk.

Objectives

- Create a landscape that serves a vital drainage function in providing flood resilience against surface water and sewer flooding issues and that provides climate change adaption benefits

Before

After

Images courtesy of George Warren

- Instill a sense of pride within the local community
- Provide a multi-functional space that could be used for a variety of events
- Provide educational potential, while being safe for the children who use the site on a daily basis

Actions and results

- Permeable block paving (1,320m²) allowed retention of existing site levels, negating the need to excavate the existing concrete road slab. The 180mm permeable pavement depth can cater for heavy loads
- The permeable paving and the disconnected downpipes from the surrounding school and playground buildings direct rainwater to heavily planted bioretention basins and rain gardens, providing over 55m of additional attenuation
- The scheme uses sculpture to replace traditional downpipes to make the scheme distinctive. The sculpture also provides an important security deterrent against those trying to access the school roof
- Flow controls are designed to restrict flows to below 1 L/s (less than the 5 L/s generally adopted by industry) and retain flows on site for longer. This is achieved, in part, by designing drainage outlets that minimise the risk of blockage, yet ensure easy access and safety for council staff to inspect and maintain
- Interpretation boards explain the design; monitoring equipment provides performance evidence

Benefits

- Carriageways adaptations have made the use of community assets safer
- Reduction in local and wider flood risk
- The attenuation of water and its associated vegetation have contributed to air quality (principally NOx and PM) and water quality (hydrocarbons and total suspended solids)
- The ecological considerations (hydrological and vegetative) have provided a site for biodiversity that will increase as the scheme matures, while providing an educational resource and community buy-in to monitoring and maintenance

After

- Annual flow volumes into the combined sewer overflow have been reduced by 50%

Lessons learned

- Supervision of SuDS construction by designers was essential to successful delivery
- Involvement of the construction contractors early in the design process ensures the best outcome

5.12 Crown Woods Way

Location
Eltham
London Borough of Greenwich

Extent
0.26ha

Cost
£23,000 (total scheme)

Date
2015

Credits
London Borough of Greenwich
Trees for Cities

SuDS components
De-paving
Kerb drainage
Bioretention basins

Summary
Enhanced streetscape and flood risk resilience through bioretention.

Project description
Crown Woods Way is a residential street, south of the A2 East Rochester Way and is within a high flood risk area. Narrow grass verges and a crematorium next to the site made limited contribution to water management. The proximity of a busy carriageway also meant the site was subject to high levels of noise and air pollution.

The programme to address these conditions was fronted by a partnership between the Royal Borough of Greenwich and Trees for Cities, who adopted a holistic approach to improve the function and quality of the streetscape.

Objectives
- Reduce flood risk

- Address concerns about the environmental impact of air and noise pollution

After

Actions and results

- Two rain garden bioretention basins have increased the attenuation storage capacity of the streetscape, reducing the likelihood of water being conveyed to the combined sewer overflow. This measure allowed 30% more water to infiltrate into the subsurface, compared with a conventional grassed area of comparable size
- Trees were planted within the de-paved rain garden areas. This addressed the hydrological balance of the site and the impact of noise and air pollution by providing a physical noise barrier and zone for air exchange and particulate accumulation. Special consideration was given to the drainage and growth capacity of each tree

After

Benefits

- Reduces street flood risk by increasing attenuation storage capacity
- Reduces noise and air pollution
- Establishes a new carbon sink through tree planting

Lessons learned

Modest public realm improvements can promote partnerships between a range of stakeholders

After

5.13 Hackbridge

Location
Hackbridge
London Borough of Sutton

Extent
0.27ha

Cost
£920,000 (total scheme)

Date
2014

Credits
London Borough of Sutton
Civic Engineers
Adams & Sutherland

SuDS components
Permeable paving
Bioretention basins
Tree planting
Filter drains & rills
Downpipe disconnection

Summary
Transformation of street function and traffic flow with integrated green infrastructure.

Project description
The public realm around the junction of Hackbridge Road and London Road was previously dominated by busy carriageways, with pedestrians confined to narrow footways fronted with shops. Traffic on the carriageway was fast-moving, adding safety concerns to those around noise, air pollution and health and safety. The low-lying topography of the area meant the site was susceptible to surface water flooding.

Objectives
- Reconfigure the streetscape to make it safer and better for pedestrians

- Manage water runoff by installing SuDS

- Mitigate air and noise pollution

Actions and results
- Bioretention basins, including tree planting, provide attenuation for runoff from the reconfigured streetscape

- Rills and filter drains with flow control devices regulate the flow of water into tree-rooting zones that provide bioretention

- Permeable paving allows for water infiltration into the subsurface, improving capacity during prolonged or high peak flow rainfall events. Up to 40% of the carriageway has been reallocated to permeable paving

- Reduced traffic speeds have also improved the pedestrian environment

Benefits
- Traffic calming; shop frontage enhancement

- Surface water flooding in the area has not been observed since the scheme was installed

Lessons learned

- Detailed surveys of underground services and features are necessary in retrofit situations
- A project approach that can adapt to unforeseen constraints makes the construction process more efficient
- Crossings and parking bays should be clearly marked

Tree planting along the carriageway

Permeable paving

Images courtesy of Civic Engineers

5.14 Goldhawk Road

Location

Shepherd's Bush
London Borough of Hammersmith & Fulham

Extent

0.27ha

Cost

£100,000 (construction only)

Date

2015

Credits

London Borough of Hammersmith & Fulham
Robert Bray Associates
McCloy Consulting
GreenBlue Urban
FM Conway

SuDS components

Kerb inlets
Tree pit attenuation
Flow control

Image courtesy of George Warren

Under construction

Summary

Tree trench planting for attenuation.

Project description

Street tree planting within the pavement on a busy London high street using a modular structural tree soil system, combined with kerb inlets and flow-control devices.

Objectives

To provide SuDS functionality and to protect the combined sewer.

Actions and results

- Each tree is planted within a 1.8m x 1.8m tree pit with tree grille, located within a much larger soil-filled rooting zone beneath the pavement, aiming to provide between 10-20m^3 of soil per tree

- Runoff from the adjacent road and footpath flows directly into the tree pit at road level, via a custom kerb inlet

- The soil level in the tree pit is lower than the road. It is surrounded by a raised polypropylene weir to allow initial water storage. This ensures the trees get water every time it rains and allows sediments and litter to drop out of the water

- During heavier rainfall, when the tree pit fills above the weir level, the water flows into a sub-base replacement layer covering the rooting zone just beneath the paving build-up. This distributes the water over the whole rooting zone, allowing it to infiltrate into the soil

- Specialist soil with a 25% void ratio allows rainwater storage

- Perforated pipes in the base of the construction collect water and direct it to a flow control chamber, which discharges to the combined sewer. The flow control chamber allows water to build up in the rooting zone when it rains to be released slowly once the peak in runoff has passed

- Integrated protected overflows ensure the system can discharge freely to the sewer once storage capacity has been reached. Flow rates are designed to reduce the risk of combined sewer overflow events

Benefits

- Combines benefits of large tree rooting zones with their ability to store runoff, with little modification
- SuDS scheme introduced in a demanding, fully-paved urban location

Lessons learned

- Detailed surveys of underground services and features and careful analysis is essential in retrofit situations

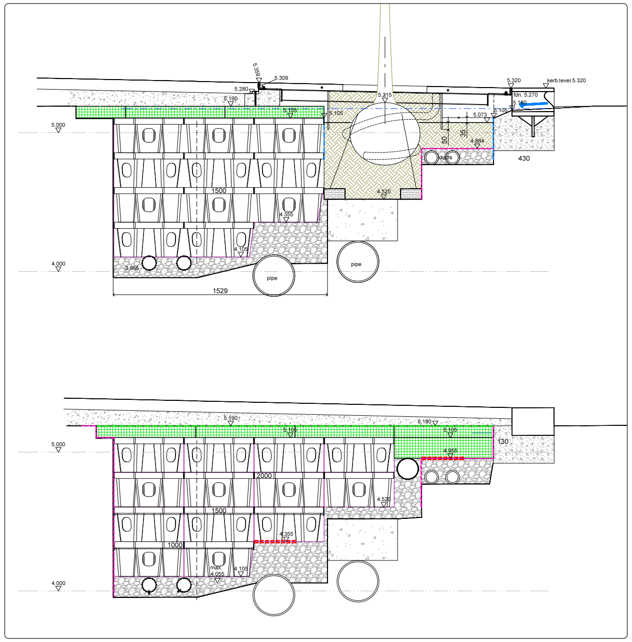
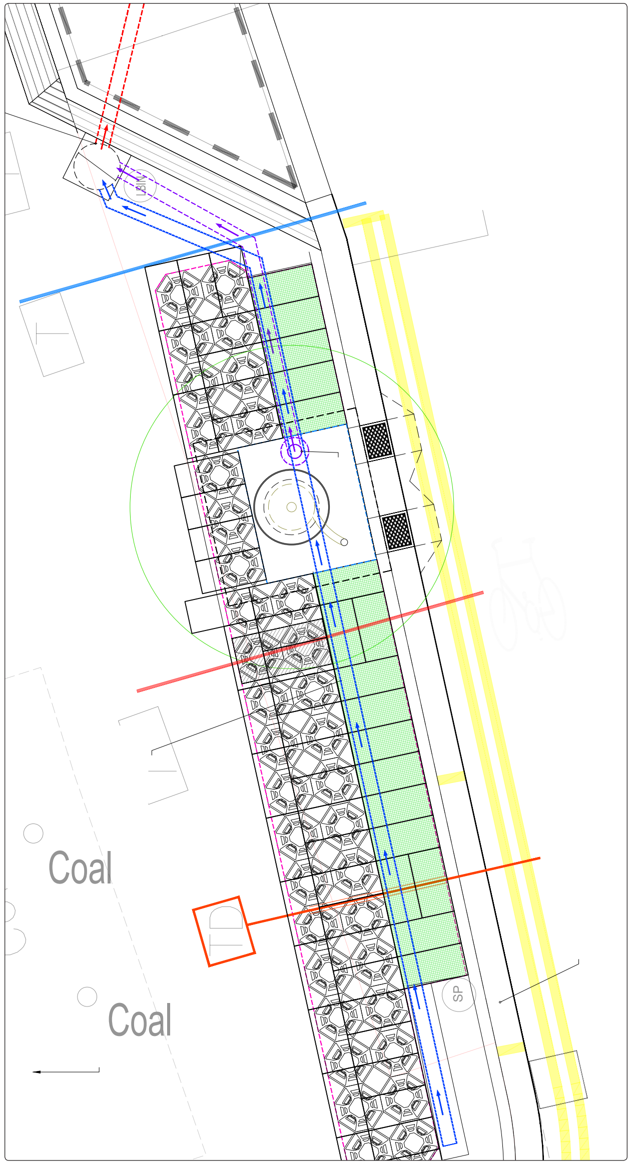


Image courtesy of Robert Bray Associates

Tree pit details



Plan showing modular soil system

Image courtesy of LBHF

Completed scheme

5.15 Firs Farm Wetlands

Location
Winchmore Hill
London Borough of Enfield

Extent
0.48ha

Cost
£900,000 (total scheme)

Date
2016

Credits
Enfield Council
Environment Agency
Thames Water
TfL
Sustrans
GLA
Thames 21
Friends of Firs Farm

SuDS components
Ponds and wetlands

Summary
Open space transformation with wetland habitats to improve water quality outflow.

Project description
The main driver for the wetland creation was Enfield Council's desire to improve water quality in Pymmes Park Lake, where Moore Brook outfalls before entering Pymmes Brook. Moore Brook is a lost watercourse within a surface water sewer. Firs Farm was identified as a space suitable for the creation of a wetland scheme. The watercourse was de-culverted and diverted to a series of open watercourses, wetlands and ponds to improve water quality.

Objectives
- Improve water quality alongside flood alleviation, habitat enhancement, community space provision and creating cycleway links

- Provide intensive monitoring programme to be carried out by Thames21/Enfield Council over next two to three years to determine the impact of wetlands on reducing diffuse urban pollution. This data will be used to optimise future management of the two sites

Actions and results
- Northern and southern branches of Moore Brook are diverted from their culverted courses to three combined wetland cells

- Cells channel the water for treatment through flow paths

- A watercourse downstream connects to a fourth cell which is built as a pond, before continuing downstream in an open channel to the original culvert

- Surface water is treated at the surface before re-entering the culvert downstream, improving the quality of the water which outfalls at Pymmes Park Lake

- A further diversion to four more wetland cells at Pymmes Park upstream of the lake provides further treatment

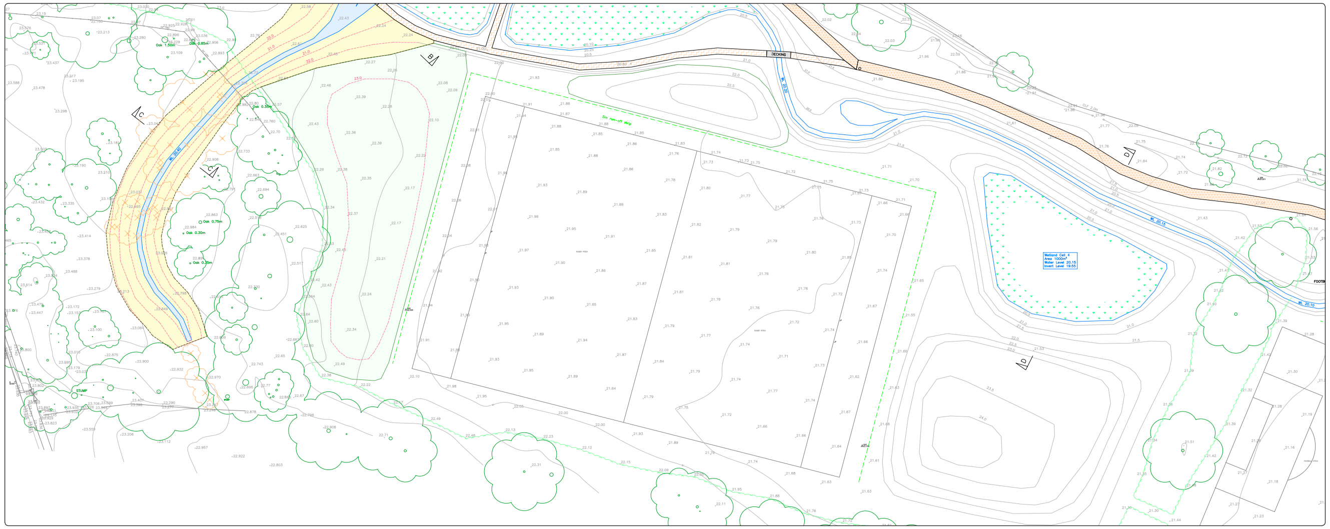
Benefits
- Water quality improvements before discharge to river further down the catchment

- A surface system allows for issues to be identified and easily dealt with due to the size and location of the SuDS elements

- Transformation of a previously underused open space to an area with an enhanced natural habitat and for the local community to focus activities. A local 'Friends' group and a waterway charity Thames21 have generated community-based interest in the site. This included help with consultation, volunteers for planting and outdoor learning, and assisting in future funding bids
- A range of amenity areas, including seating, an outdoor classroom and dipping ponds
- Opportunity for many disciplines to work together across the council and other organisations
- Provided opportunities to combine other objectives, such as the provision of cycleway transport infrastructure
- Biodiversity enhancements

Lessons learned

- Importance of working alongside other land uses, in this case sports pitches
- Pre-treatment measures upstream of the wetland would be beneficial



Plan

Wetland basins and planting

Outlet into wetland area

Images courtesy of Graham Campbell

5.16 Salmons Brook Glenbrook Stream

Location
Salmons Brook
London Borough of Enfield

Extent
0.77ha

Cost
£15.3m (Total scheme)

Date
2014

Credits
Thames 21
Environment Agency
Enfield Council
Robert Bray Associates
Maydencroft

SuDS components
Bioretention basins
Kerb Inlets
Swale
Weirs

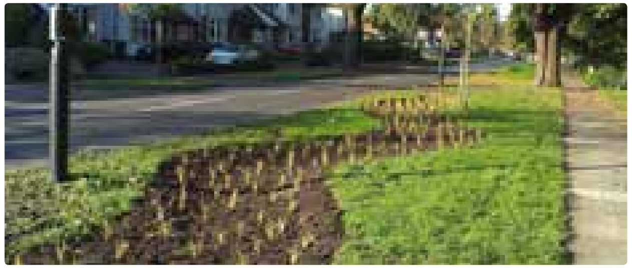


Image courtesy of Thames 21

Roadside swale at The Spinney

Summary

Transformation of existing green space into wetlands.

Project description

Salmons Brook is a tributary of the River Lea that flows through wasteland, industrial parks and Deepham Sewage Treatment Works. Salmons Brook receives polluted wastewater from misconnected plumbing and road runoff from residential and industrial sources within the catchment. This jeopardises the quality of the watercourse and those downstream and affects the Salmons Brook's ability to alleviate flooding in surrounding streets.

EU water quality standards were not being achieved so the Environment Agency and Thames21 devised a scheme to improve the watercourse.

Objectives

- Create a wetland system to treat and remediate polluted water before it enters Salmons Brook

- Promote change through education about the urban water cycle

- Enable the community to access and benefit from their local waterway

- Assess the impact of the scheme on Salmons Brook and surrounding infrastructure in the catchment

Actions and results

- Bioretention basins were integrated and existing features improved. This has made the existing wooded landscape more efficient at attenuating and slowing the conveyance of water. The wetland basins also encourage the growth of plant and bacterial communities, which helps remediate polluted water

- Weirs allow control of water flow through the SuDS scheme and any subsequent discharge into Salmons Brook.

- The base level of the area has been lifted to further control flow; this increases the effectiveness of the sub-catchment via the wetland bioretention basin system.

- By raising the base level, opportunities for stepping stone and weir crossing points were created. This has improved access.


Image courtesy of Robert Bray Associates

Weir detail at Grovelands Park


Image courtesy of Robert Bray Associates

Treatment wetland at Grovelands Park

- Swales slow the flow of water through the system and ensure that, with the weirs and wetland bioretention basin, the higher concentrated polluted water is discharged into the wetland, rather than Salmons Brook

- Kerb inlets allow rainwater to be conveyed away from the combined sewer overflow and into the swales and through the network of weirs and wetland basins

Benefits

- Salmons Brook water quality improved

- Flood risk reduced and road runoff management improved

- An area of greater recreational value created

- Reduction in house insurance costs for surrounding properties

- Public awareness of the reality of waste and pollution in their environment that might otherwise remain unnoticed

- A sense of ownership has been fostered through scrub clearance and wetland planting days

Lessons learned

- The value of local community involvement

- Managing woodland structure is crucial in ensuring that light levels are sufficient for the establishment of vegetation


Image courtesy of Chaoming Li

Swale incorporating existing mature trees

5.17 LuL depot roof, Middlesex

Location
Ruislip Depot
Middlesex

Extent
125m²

Cost
£30,000 (Trial project)

Date
2012

Credits
London Underground Limited
GLA
University of East London
GRC

SuDS components
Green roofs

After Installation

Summary
Retrofit green roof and monitoring of source control.

Project description
A small-scale trial to evaluate the effectiveness of retrofitted green roofs, for LUL depot environments. From the results it will be decided whether LUL could benefit from a broader application.

Objectives
- Introducing environmentally-friendly measures to address runoff from depot roof
- Achieve low maintenance
- Address Mayoral policy for SuDS by installing a green roof source control
- Ensure retrofitting on operational railway followed the rigorous assurance and safety procedures of London Underground, without interruption of service

Actions and results
- Biodiverse extensive green roof types, each 18.5m x 3.3m, have been installed on a section of flat roof
- One section (south) has a drainage board with 65mm of extensive green roof substrate. The other section (north) uses recycled wool fibre instead of drainage board
- Both roofs are vegetated with sedum cuttings and seeded/planted with annual and perennial wildflowers
- The two trials are separated by an impermeable barrier to facilitate the measurement of runoff. Total saturated loading is less than 100kg/m²
- With the assistance of the University of East London, monitoring devices have been installed in two downpipes of a green roof and two downpipes of a conventional control roof to measure water attenuation
- GLA support has been provided through Drain London. A small fund enables monitoring performance

Images courtesy of LU Infrastructure Protection

Programme of monitoring

Early green roof growth within 6 months

Benefits

- LUL will examine the process of installation, maintenance and performance and the cost-benefit analysis in terms of waterproofing performance and drainage control for a larger scale application
- LUL will also assess: longevity of the waterproofing layer; improved working ambiance and environment; structure insulation; air quality improvements; biodiversity enhancements
- The trial will allow better understanding of the mechanism and potential areas for improvement

Lessons learned

- The use of wool as a recycled drainage material was an important outcome
- Monitoring of water attenuation is complete and will inform future green roof schemes
- Organic material used as a drainage board has performed consistently better than the conventional plastic one
- Maintenance is minimised due to planting selection of wildflowers

5.18 A23 Coulsdon Bypass, Farthing Way

Location
Coulsdon
London Borough of Croydon

Extent
34ha

Cost
£33m (Total scheme)

Date
2006

Credits
TfL
Atkins

SuDS components
Kerb drainage
Soakaways
Filter strip
Filter drains

Filter strip gravel

Summary
Highway runoff attenuation.

Project description
A groundwater extraction borehole at Smitham Pumping Station is located in Coulsdon Town Centre. The new section of A23 between Marlpit Lane and Smitham Station passes across the inner Source Protection Zone (SPZ) for the extraction borehole and has been designed to direct runoff appropriately.

Objectives
- The drainage design redirects runoff flowing from the new A23 away from the inner SPZ

- Attenuation was needed to ensure the area receiving the runoff can cope with the volume of water it now receives

Actions and results
- The new A23 is drained, via a piped system with kerbs and gullies, into spillage containment devices and a full retention fuel/oil separator, before discharging into soakaways

- To the west of the new A23, the existing ground rises steeply; being chalk downland, there is likely to be significant runoff when it rains heavily. A separate system, not linked to the highway drainage, collects this runoff and discharges it into soakaways

- Non-piped drainage components within the site principally relate to linear soakaways at the bottom of the embankment adjacent to footways where water is caught at a low point

Benefits
- The design maintains the flow of previously-existing drains and watercourses

- The design of the drainage components allows them to be maintained in a safe and efficient manner

- Surface water is able to drain into soakaways on adjacent land

Lessons learned
- Localised design changes were necessary, due to the unexpected presence of services

- The specified kerb drains were made smaller during construction due to the high retaining wall footing and the 600mm wide narrow verge

- Deep-bored soakaways were used extensively throughout the project. During the construction of some soakaways, the piling contractor met some obstructions. This was overcome by relocating the soakaways, but only small changes in the positions were needed

Carriageway filter strip

Surrounding carriageway context

Plan

5.19 London Sustainable Industries Park, Dagenham

Location
Dagenham
London Borough of Barking and Dagenham

Extent
142ha

Cost
£30m (Total scheme)

Date
2009-10

Credits
Civic Engineers
T. R. Collier & Associates
Sergison Bates
Vogt Landscape
Price & Myers
URS
GHP

SuDS components
Swales
Managed wetland and woodland
Bioretention
Water recycling

Summary

An integrated water management and infrastructure plan for an industrial park.

Project description

The London Sustainable Industries Park (LSIP) is part of the Thames Gateway regeneration at Dagenham Dock in East London. It is an international exemplar, created with the goal of making Thames Gateway the UK's first Eco Region.
The site is south of the A13 and close to Dagenham Dock Railway Station and the Barking Reach Power Station. The Gores Brook receives outflow from the site which then discharges into the River Thames. Consideration of the hydrology of the site was crucial to achieving a successful scheme.

Objectives

- Install a water management system for the LSIP

- Transform the existing infrastructure onsite to create a self-sustaining exemplar of green infrastructure design and planning

Actions and results

- Swales and bioretention basins allow water to be conveyed from roofs, roads and other features into a system of components with a high attenuation storage capacity. This limits the outflow of water into Gores Brook at a rate of 12 L/s/ha during prolonged and/or high peak flow rainfall events

- Water quality is improved by allowing suspended solids to settle out and other pollutants, such as hydrocarbons, to be treated or their discharge limited

- Attenuation tanks allow rainfall to be recycled for use by services that use 'grey' water

Benefits

- Negates the need for costly remediation systems, such as petrol interceptors

- The volume of low water quality run off from carriageways and other built infrastructure on the industrial park has been reduced

- BREEAM 'Excellent' rating achieved (2010)

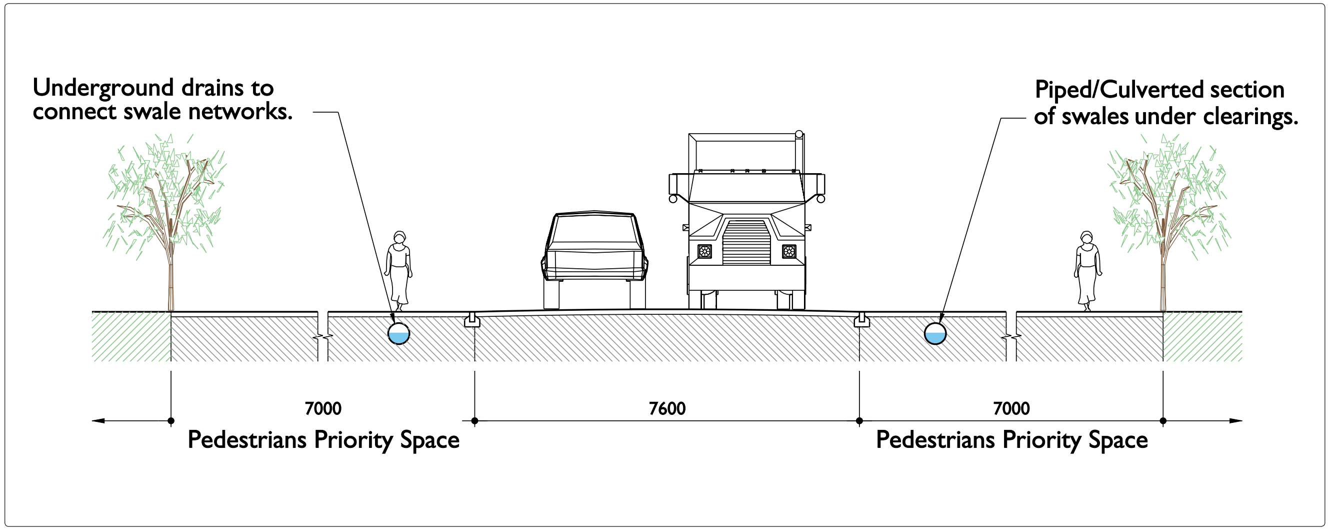
- The cost of utilities and maintenance has been reduced
- Enhanced ecological value

Lessons learned

The installation of an adaptable and resilient water drainage network can provide infrastructure for a range of future uses depending on plot uptake and industry requirements.

Aerial visualisation

Plan



Cross-section

5.20 Great Kneighton / Clay Farm, Cambridge

Location
Cambridge

Extent
£45m

Cost
109ha

Date
Final phase: 2020

Credits
Cambridge City Council
Countryside Properties
Bovis
Cala Homes
Crest Nicholson
Skanska
Aecom
PEP
BBUK Studio
James Blake Associates
Environment Agency
Hobson's Conduit Trust

SuDS components
Soakaways
Detention basins
Bioretention basins
Swales
Rills
Permeable paving
Rainwater harvesting
Green/brown roofs

Summary

Holistic integration of water management into major new development.

Project description

Great Kneighton, previously Clay Farm, is former green belt land 4km south of Cambridge. The site is typical for Cambridgeshire – flat, low-laying terrain, crossed with brooks and land drainage channels. The mixed use development site of Great Kneighton suffered from poorly draining clay soils and a high water table, 1m below ground. The site is within the catchment of the historic Hobson's Conduit, which dictated stringent control measures for runoff from the development.

Cambridge City Council, along with project partners, wished to install an integrated water management system within a designated strategic open space that forms part of the Cambridge Green Corridor.

Objectives

- Control outflow into Hobson's Brook at 2l/s/ha
- Install a SuDS code of conduct across the development site
- Withstand one in 100 year flood event, with 30% extra to allow for climate change
- Provide amenity and ecological value to development


Image courtesy of Simon Bunn

Permeable paving and tree planting

Actions and results

- Plot-wide rainwater harvesting system intercepts rainwater, reducing the amount being conveyed to the subsequent stages of the SuDS scheme
- Detention basins increase the attenuation storage capacity of the scheme and slows water flow, particularly during prolonged and/or high peak rainfall

Image courtesy of Tim Crocker

Completed residential unit

- Swales increase the attenuation storage capacity of the scheme and provides vegetated landscape of hydrological, aesthetic and biodiversity value
- Hydrodynamic vortex separators inhibit the discharge of sediment and hydrocarbons into the Hobson's Conduit outflow. This is of particular note due to the downstream function of Hobson's Conduit in Cambridge
- Bioretention basins allow water to be attenuated on the east side of Hobson's conduit, preventing low quality water from discharging into the watercourse. Water is conveyed from the development to the west, underneath Hobson's Conduit into the bioretention basins, creating a series of ponds and wetlands of hydrological, recreational and ecological value
- Permeable paving increases the permeability on the site, where below-ground conditions allow
- Sub-catchments syphons underneath the brook discharge into a series of ponds and detention ponds
- Pre-cast concrete rills convey water into bioretention basins in the local square

Benefits

- Impact of development on surrounding drainage infrastructure is minimised through the management of water on site
- Outflow of water quality and volume controlled
- Can withstand a one in 100 year flood event
- Predominantly above-ground nature of the SuDS features contribute to the recreational and aesthetic value of the development
- 20,000m² of wetland habitat created
- Installation of a landscape of multiple benefits

Lessons learned

- Engaging developers and project teams early in the development process allows the benefits of SuDS to be shared
- Treat each site within the development individually to capture the variations in soil type and topography

5.21 Alnarpsgården Swedish University of Agricultural Sciences

Location
Alnarp
Sweden

Extent
0.37ha

Cost
£170,000 (construction only

Date
1997

Credits
Anders Folkesson,
Landscape Architect LAR/MSA
Vasajorden AB

SuDS components
Ponds and wetlands
Disconnected downpipes
Permeable paving
Channels & rills
Retention basin

Wildflower seeded joints

Summary
Campus courtyard redevelopment to focus on sustainable drainage while creating a social hub.

Project description
Alnarpsgården is a rural campus hosting the Institution of Landscape Architecture, Planning and Management at the Swedish University of Agricultural Sciences (SLU). Part of a historic estate, it consists of buildings converted from agricultural use and new builds, set within a forested landscape. The focus of the campus is the inner courtyard, which has been redeveloped with SuDS principles in mind.

Objectives
- Slow water runoff from roofs and hard surfaces of Alnarpsgården
- Provide a first step of water cleaning
- Enhance the appearance of the yard
- Demonstrate an open stormwater system to the landscape architect students of SLU

Actions and results
- Water from downpipes is collected in channels running along the facades, then led to a retention basin (a former manure container). At the bottom of the concrete basin are 'seams' in which aquatic plants grow in a strict pattern. From the retention basin, water runs in a ditch towards the Íresund coast
- Grit-jointed granite setts form permeable paving, over-seeded with wildflowers

Benefits
- The courtyard design repurposed existing features, such as the old manure container and dung grooves, as SuDS features
- The redevelopment of the courtyard has created a social hub, well used by students and visitors
- The success of the SuDS components of the courtyard make them a valuable educational tool

Lessons learned

- Previously, the yard's ground was slightly concave, the middle of the yard being slightly lower than the ground along the facades. To channel all the stormwater from the yard to the gutters along the facades, the middle of the yard was raised. Adjusting the topography has affected the quality of the space

Threshold detail

SuDS pond acting as a central recreational feature

Images courtesy of Anders Folkesson

5.22 Benthemplein (Water Square)

Location
Rotterdam
Netherlands

Extent
0.95ha

Cost
£3.175m (Total scheme)

Date
2013

Credits
City of Rotterdam
Schieland and Krimpenerwaard
Urbanstein
Wallaard
ACO
Topcourts

SuDS components
Detention basins
Rills

Summary

Multi-functional public realm regeneration.

Project description

Benthemplein is in central Rotterdam, north-east of Rotterdam Centraal station. It is bounded by major city roads and enclosed by medium rise buildings.

The low permeability paving of the site meant it was not fulfilling its potential of relieving localised flooding in adjacent areas. This put pressure on the combined sewer overflow of the Nieuwe Maas.

Due to the proximity to areas of flooding and the opportunity for restructuring of space, the City of Rotterdam and stakeholders, including church and student communities, looked to re-imagine the function of the square, as part of the Rotterdam Climate Initiative.

Objectives

- Reduce flood risk

- Provide recreational opportunities

Actions and results

- Detention basins increase the attenuation storage capacity of the site to 1,700m^3. Uniquely, the three detention basins provide a recreation space that is transformed as water is attenuated in the basins

- Rills convey water from the surrounding ground surfaces and buildings into the detention basins. Each basin has its own sub-catchment taking runoff from certain surfaces and buildings and incorporates waterfalls, fountains and an outside baptistery for use by the church

Benefits

- Water management has the added benefit of creating a novel multiple-use public realm space

- Approximately 4,000m^2 of existing parking and street access has been kept to allow space for vehicles

- Interventions such as the baptistery, sports goals and shaded seating has allowed for a range of stakeholders' needs to be addressed

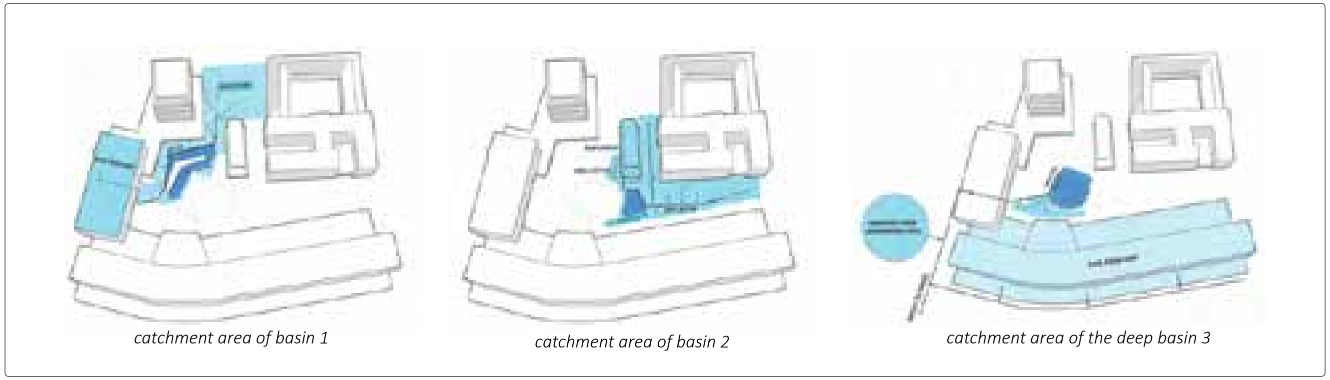
Lessons learned

- Attention to detail during planning and design phases and supervision during construction is crucial in achieving a scheme with complex sub-catchments
- By fulfilling city authority climate objectives, it is possible to receive extra funding for similar schemes. Rotterdam raised an extra £700,000

Detention basin

Images courtesy of Urbanstein

Overview of completed scheme



Catchment areas

5.23 Rue Garibaldi

Location
Lyon
France

Extent
15ha

Cost
£19.3m (Total scheme 1st phase)

Date
1st phase 2014

Credits
Grand Lyon
Atelier des Paysages

SuDS components
Retention basins
Swales
Soakaways
Depaving

Integrated cycleway and SuDS

Summary
Transformation of an urban motorway to a planted boulevard and high quality civic space.

Project description
Rue Garibaldi, east of the River Rhine, is a north to south six-lane carriageway, constructed in the late 1960s. It is fronted with high storey buildings and features that were characteristic of an urban motorway. The environment for pedestrians and cyclists is hostile.

The configuration and high capacity of the streetscape exacerbated the effects of urban heat island. Air (principally NOx and PM) and water quality was low (principally hydrocarbons and total suspended solids).

Runoff into the combined sewer overflow was high, particularly during heavy or prolonged peak rainfall, considering the sub-catchment area of 65,000m^2.

These conditions, coupled with a carriageway reconfiguration proposal, presented the opportunity to reconsider hydrological management of the 2.6km stretch of highway

Objectives
- Minimise runoff into the combined sewer overflow by installing a SuDS scheme

- Improve connection between districts bordering Rue Garibaldi by design and planning consideration, within the wider green space context of the area

- Reduce maintenance and utility costs by installing a water recycling system

- Reconfigure carriageway function by installing separate carriageways for public transport, pedestrians, cyclists and other vehicles

- Improve management of water quality and mitigate urban heat island effect by planting trees and installing a SuDS scheme

Actions and results
- Retention basins were created from the redesign of an existing underpass. An automated pumping system was installed to allow water to be recycled for street cleaning vehicles and irrigation for public realm planting.

Rill and de-paving

This has reduced local authority utilities and maintenance costs and increased the attenuation storage capacity of the streetscape. Water treatment capabilities also feature, due to the oxidative capacity and bacterial activity of the retention basin

- Swales with 4,500m^3 of vegetation increase the attenuation storage capacity. These have been integrated into the reconfiguration of the carriageways to create vegetated separation between carriageways with different functions. This has significantly enhanced biodiversity in the streetscape
- Soakaways have increased the infiltration rate by aiding conveyance of water into the ground, contributing to the 1300m attenuation capacity of the scheme
- Trees have mitigated urban heat island effects by increasing the interception of solar radiation and increasing evapotranspiration. Tree planting has contributed to the effectiveness of the SuDS scheme and helped reconfigure the streetscape by creating a separation between carriageways and enhancing the sense of place. Sensors have been installed to quantify the cooling effect provided by the vegetation

Benefits

- Reconfiguration of carriageway to align with Grand Lyon's sustainability objectives
- Provision of extra parking for taxis, deliveries and public road users
- Creation of new green links through Lyon
- Re-purposed existing infrastructure
- Peak outflow into the combined sewer system is 5 L/s/ha
- Monitoring during the first phase of construction has helped inform the development of phases two and three
- On-site availability of recycled water for street cleaning
- Automated irrigation reduces maintenance commitment and cost
- Water and air treatment capability

Lessons learned

- Ensure clear agreement between local authority services for management and maintenance responsibilities on cyclical and periodic regimes

5.24 Bo01 Võstra Hamnen

Location
Malmö
Sweden

Extent
85ha

Cost
£3.3m (landscape construction only)

Date
2001

Credits
City of Malmö
Government of Sweden
Sydkraft AB (E.ON Svergie)
Lokala
Investeringsprogram
European Union
Lund University

SuDS components
3Downpipe disconnection


Permeable shared surface

Summary
Transformation of an industrial site to a neighbourhood with integrated off-grid sustainable water management.

Project description
The city of Malmö has developed SuDS schemes since the late 1990s. The Võstra Hamnen area is on a former industrial site and is in a key strategic location to accommodate city growth. The site was prone to flooding and its soil contaminated. The international housing exposition, Bo01, framed the first phase of development and allowed the City of Malmö to instigate an exemplar in sustainable urban regeneration. The project featured a new housing district of 500 apartments, with the public realm a significant contributor to achieving sustainability goals.

Objectives
- Manage flood risks with an open storm water system
- Create an exemplar in sustainable urban design
- Achieve off-grid sustainable drainage
- Use a scoring system to achieve balance between development demands

Actions and results
- Swales and bioretention basins created high attenuation storage capacity and made an off-grid drainage system possible.
- The network of swales and basins complement the well-connected streets and spaces that characterise the foot and cycle networks in the area.
- Meadows, woodlands, seashore and marine biotopes serve hydrological functions in relation to the SuDS and added a variation in site conditions for an abundance of species


Rill

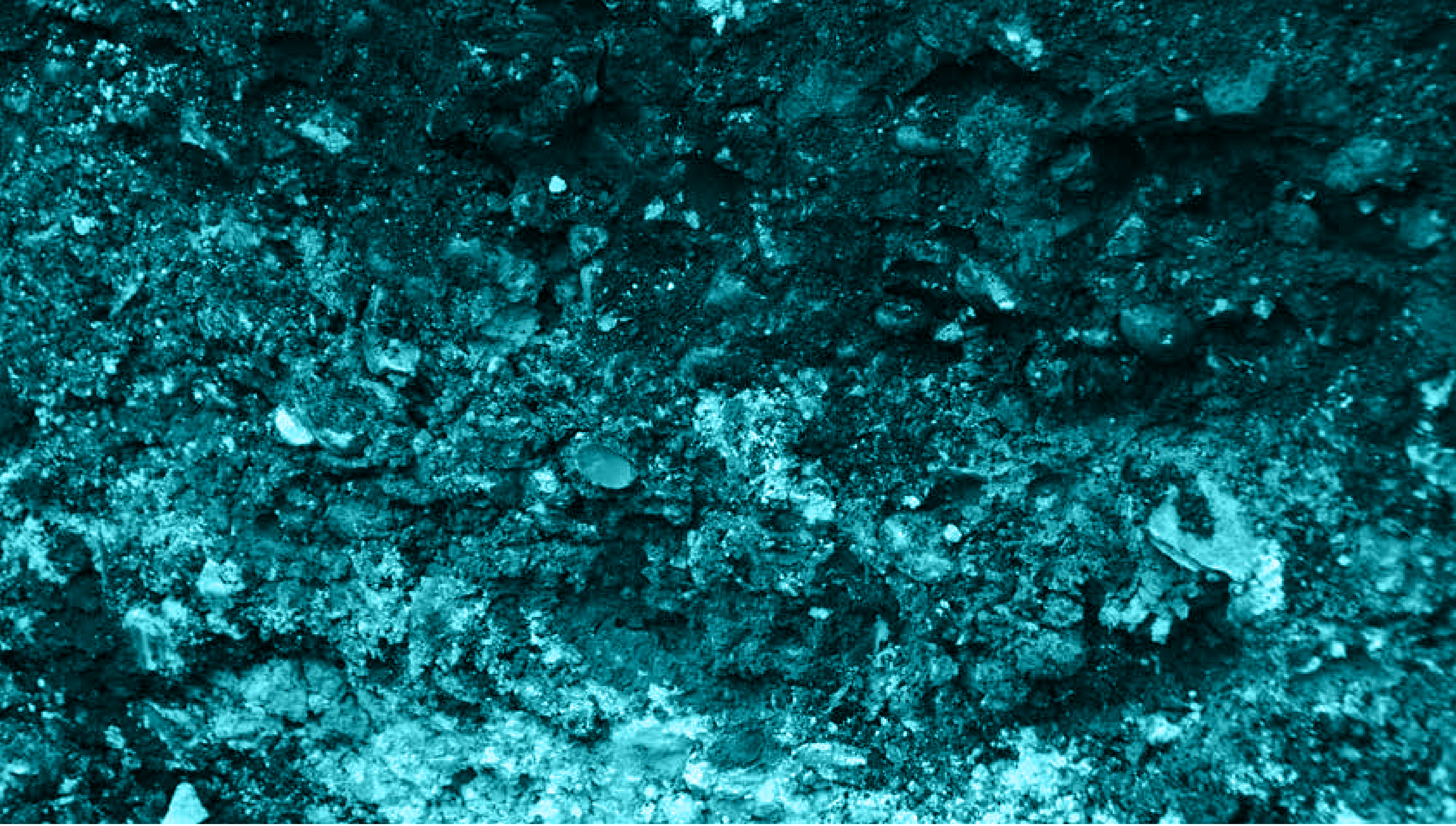
Benefits

- Off-grid SuDS system – no pressure on existing drains
- A cross-disciplinary approach during development allowed for the revision of planning tools
- Popular contribution to the character and function of the public space
- Innovative scoring system used to quantify greenspace factors and give weight to ecological and aesthetic considerations
- The scoring system used to quantify green space factors works in a UK context

Lessons learned

- Development-wide consideration of topography crucial to success
- Incorporation of water features such as fountains can be achieved by recycling water collected by SuDS

Retention pond



6 Implementation

6.1 Implementation

In Chapter 3, the range of components which can be used in London were explored, while Chapter 4 illustrated how these might be applied to a variety of indicative street scenarios. Although much of this guidance highlights opportunities to implement SuDS in London, this chapter describes the requirements for a SuDS team and recommends the design process to follow.

Much of the detail can be found in the CIRIA 753 The SuDS Manual, from which the design process diagram has been adapted.

6.2 SuDS design team

The SuDS design team must be assembled at project inception and operate collaboratively. The team is likely to include:

- Highways engineer for the planning, design, construction, operation and maintenance considerations
- Landscape, urban design and landscape management to guide the form, shape and long-term sustainability of features, particularly early in the process
- Drainage engineer to ensure the proposed design will provide effective drainage
- Ecologist and/or arboriculturist to enable maximum biodiversity benefit to be delivered
- Soil scientist, in particular to examine the potential of existing soils to accommodate SuDS infrastructure and street tree planting. This will also inform the below-ground specification

Meadow planting: low maintenance, high biodiversity, deep rooting erosion control, less mowing and less compaction

Multi-disciplinary collaboration is fundamental to achieving integrated and sustainable drainage within London's streets. It ensures innovative ideas can be tested and assessed, while minimising impact on the decision-making process and maximising opportunity and benefits. This requires a range of specialists, technical staff and stakeholders to work together.

The team can be led by the highway engineer, landscape architect/urban designer, or drainage engineer working with specialist consultants. Schemes that form part of wider initiatives can be led by a

Kings Cross LWT: Camley Street

A soil scientist is part of the SuDS team

private developer's team, working with the Highways, Planning and Lead Local Flood Authorities.

The Surface Water Management (SWM) objectives should be set and underpinned by:

- SuDS design principles
- Townscape and landscape character
- Local planning policy
- Functional demands of the street
- Evaluation of any existing SuDS features
- A long-term outlook

The planning and drainage design process should include:

- Agreeing with the planning authority the level of detail required and any aspects that require a planning condition
- Identifying a way to ensure the designs are delivered according to specification
- Community and stakeholder engagement

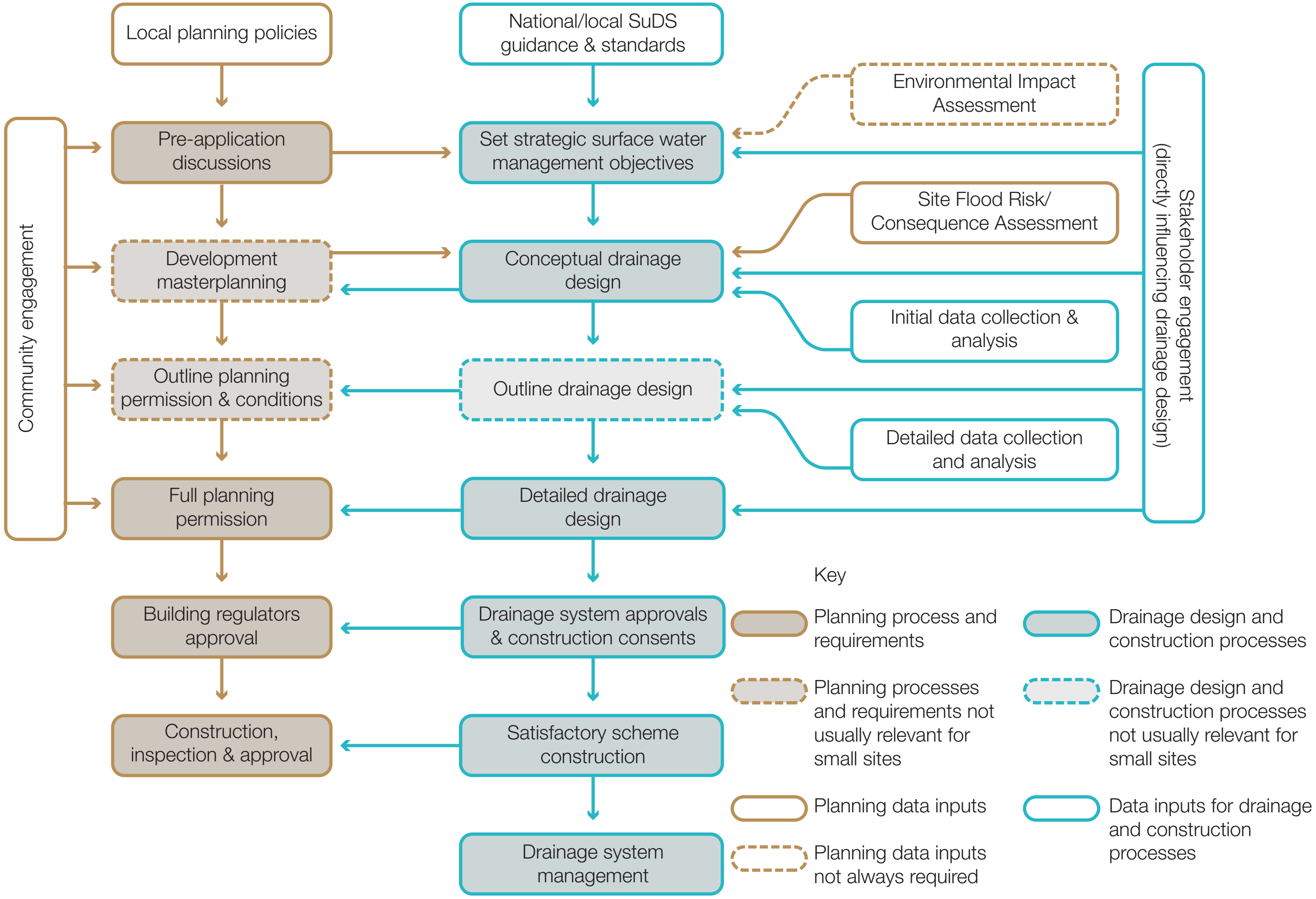
To start, the design process should consider the various site-specific constraints, as these will be one of the biggest design drivers. Baseline data will be vital, possibly requiring the need to commission surveys and investigations. These will influence design consideration of source control, pathway and receptor (see Chapter 2).

Community engagement is a vital part of a successful project. Working with communities through the design, planning and delivery processes is essential for finding the best design and building support for the project. Community engagement can also act as a catalyst for partnership, working to benefit long-term management and maintenance mechanisms, as well as funding regimes.

The aim should be to achieve the maximum benefit, accepting that there will be practical constraints to consider. This is particularly relevant as SuDS is an evolving practice, with complex regulations and potentially high numbers of stakeholders involved.

Refer to **CIRIA C753 The SuDS Manual, Chapter 7** for a detailed description of the SuDS design process.

Design process diagram adapted from CIRIA C753 The SuDS Manual



6.3 Drainage hierarchy

SuDS designs should generally be developed according to the CIRIA process diagram on the previous page. This process may vary, depending on local conditions

When working in London, water should be managed by using the following drainage hierarchy, as described in the London Plan:

1. Intercept and store rainwater for later use: examples of this include water tanks and butts, or as well as abandoned and repurposed subterranean pedestrian passageways below urban roadways.

2. Use infiltration techniques, such as permeable surfaces: these offer simple and relatively low cost surface water absorption capacity. Permeable surfaces collect, store and release water at different rates, depending on the sort of soil present. Local geological makeup and hydrology should take account of buried infrastructure (such as that associated with London Underground) to ensure chambers do not become water conduits.

1. Disconnected downpipe to water butt

3. Attenuate rainwater in ponds, green or blue roofs or open water features for gradual release: ponds, linear wetlands and basins can create attractive features that provide ecological habitat as well as amenity. There is also scope to incorporate SuDS into green space alongside London's highways.

2. Grit jointed permeable paving

3. Attenuation in planted rill

4. Attenuation in tree trenches

4. Attenuate rainwater by storing in tanks, sealed water features, permeable paving and tree trenches for gradual release: Although these systems can be configured to suit a variety of below-ground conditions, carefully consider utilities to avoid damaging long-term tree-rooting potential. Surface water can potentially be re-used in tree trench planting.

5. Discharge rainwater directly to a watercourse: this can offer a low-cost option for surface water dispersal, provided the surface water is pollutant-free. Liaise closely with water body authorities as they may put limits on how much water can be discharged into the conveyancing system.

5. Discharge to watercourse

6. Discharge rainwater to a surface water sewer/drain: this has traditionally been London’s default approach to rainwater management. However, London’s sewer network is so intertwined with the foul network that there is a need to segregate conveyance systems to minimise contamination and effluent treatment costs.

7. Discharge rainwater to the combined sewer: the economic justification needs to be set exceptionally high to mitigate the commercial demand for such a choice. In retrofit scenarios, the combined sewer may be the only option. If so, control of discharge rate and water quality will be critical.

6. Surface water sewer outfall

7. Combined sewer outfall

7 Cost benefit

7.1 Cost benefit

The Greater London Authority's (GLA's) document 'Natural Capital Investing in a Green Infrastructure for London' highlights two key challenges:

1. Unseen value (usually expressed environmentally or socially, rather than monetised, typically regarded as intangible)
2. A lack of a revenue-raising mechanism to offset management and maintenance.

The emphasis of the London Sustainable Drainage Action Plan (LSDAP) has been to 'identify opportunities for implementing sustainable drainage techniques that have limited financial impact'. This focuses on situations where other works are likely to be undertaken. Integrating SuDS would therefore be a component of a wider project.

The LSDAP also notes that options to increase London's drainage system capacity using conventional underground piped networks, such as the Thames Tideway Tunnel (under construction), are becoming increasingly complex and prohibitively expensive. This is due to the requirement for large-scale and widespread excavations in many streets, and the need to work in and around other buried infrastructure.

Green infrastructure and sustainable drainage (as opposed to hard-engineered techniques) have many benefits, such as reducing air pollution, reducing noise, improving biodiversity, reducing summer urban heat island effects and creating places with identity and character.

These benefits can be challenging to monetise. Some evaluation tools use an ecosystem services framework as a starting point to convert benefit to monetised outcomes. The City of Philadelphia, for instance, has identified the net benefit of using surface drainage techniques at almost $3bn compared to $100m for the piped alternative. The $3bn includes benefits such as changes to property value, green job creation, reduction in greenhouse gas emissions and reduced crime through an improved environment.

Four cost benefit references are:

- CIRIA's SuDS Tool (BeST) which provides monetised values to tangible and intangible benefits applicable to the UK's drainage systems
- i-Tree Eco, a system related to valuing trees in terms of ecosystem services. This has estimated, for instance, the economic value of London's urban forest at almost 3.5million m^3/annum of storm water alleviation, worth £2.8m/annum
- TfL's Valuing the Urban Realm Toolkit. This has identified a positive, significant and consistent relationship between the quality of streetscape and benefits for users and property owners. For further information, contact urbandesign@tfl.gov.uk
- The Government's Natural Capital Committee which has developed an accounting framework. This is currently being trialled.

7.2 Methodology

Cost benefit estimates have been made based on the eight street scenarios in Chapter 4

Models of conventional drainage and SuDS components are considered for each of the eight scenarios illustrated in Chapter 4. The following assumptions have been made:

- The scheme constitutes new development – retrofits are generally more expensive
- There is no upstream source control
- The total area under consideration is 1,000m²
- A single gully will typically provide adequate drainage capacity for an area of 200m²
- The volume of attenuation required to achieve 50% improvement, as defined by CIRIA, for the one in 100 year event, plus climate change storm event for an area of 1,000m², would be approximately 31m³ of water
- In a conventional drainage system, this could be provided through provision of approximately 35m³ of proprietary tank system (assumes 90% free volume)
- The proposed SuDS components could provide an equivalent storage capacity and would therefore negate the need for any conventional drainage or storage systems
- Both systems are subject to the same access constraints and require the same amount of traffic management
- Surface water flows to a surface water sewer
- The ground is unsuitable for infiltration
- The same number of trees, where the SuDS option counts for an integral tree pit providing 30% water attenuation capacity, and the conventional is based on a proprietary tank system
- The SuDS technologies under consideration are dry swales, permeable paving and bioretention components For the direct cost comparison some other costs have been excluded, because:
  - costs are pro rata, therefore would have no bearing upon the percentage range
  - costs will vary between schemes and, without a specific design, a figure could not be applied

Exclusions apply, including construction overheads, fees, VAT and inflation. Site-specific costs, such as those relating to statutory costs, utility and below ground infrastructure works, are also excluded.

7.3 Design life

Delivering Benefits Through Evidence – Cost estimation for SuDS' was published by the Environment Agency in 2015. It examines the design life of SuDS.

This shows that most SuDS have a long design life. However, their component parts, such as control mechanisms and infiltration surfaces, need replacing between five and 50 years. Specific maintenance, such as decompaction, may also be required. Replacement depends on site characteristics, system design and the degree of maintenance undertaken.

There is relatively low risk of structural failure occurring. This contributes significantly to the SuDS design life.

7.4 Cost comparison

Designing and constructing surface drainage systems involves a lot of variables, all of which have a bearing on cost, including:

- The site, whether retrofit, re-development or new development
- The location and geotechnical context to which the solution is being applied.

Each scenario within a given streetscape will be bespoke, considerations being:

- Scale and size of development
- Hydraulic design criteria, ie, volume of storage, impermeable catchment area
- Inlet/outlet infrastructure, ie, volume and velocity of anticipated flows, capacity of the drainage system beyond site
- Water quality design criteria
- Soil types, ie, permeability, depth of water table, porosity, load bearing capacity
- Materials
- Density of planting and trees including existing trees, which might require specific attention
- Specific utility requirements and other below ground structures
- Proximity to receiving watercourse or sewer
- Amenity, public education and safety requirements

Rates applied to the components are presented as a range. This is due to the variances of procurement, ie, type, contract, market conditions, location and time. It also takes into account the differences of each street scenario where relevant, ie, size and economies of scale, bespoke nature of the location, surrounding infrastructure, buildings and ground conditions.

The comparison between conventional drainage systems and SuDS is expressed as an indicative percentage range, rather than absolutes. The figures on the next page in red brackets show potential percentage savings in implementing SuDS over conventional drainage; black text indicates potential percentage cost increase.

Street scenario 1	(55%) – (49%)
Street scenario 2	(32%) - (5%)
Street scenario 3	(20%) – (4%)
Street scenario 4	(38%) – (3%)
Street scenario 5	(26%) – (25%)
Street scenario 6	(29%) – (1%)
Street scenario 7	(20%) – (30%)
Street scenario 8	(9%) – (5%)

This analysis indicates that the implementation of SuDS is potentially more cost-effective than conventional drainage in construction cost terms alone. The range in the percentages is due primarily to variables in the costs of paving specifications.

Many schemes within London will require retrofitted design solutions. In these cases, costs may be incurred in removing or adapting existing infrastructure.

SuDS projects often form part of wider development proposals, where the cost of sustainable drainage would be integrated from the start and economies of scale apply. In all situations, adjacencies create variability when dealing with different ownerships and boundaries.

Nine Elms linear park: SuDS as part of wider development proposals

Image courtesy of Camlins

🟧 Podium Level Courtyards - Potential permeable paving using drainage mats (indicative)

🟩 Permeable Surface/ Planting area - Rain water will be absorbed, no water to enter into underlying controlled waters

■ Swale - Water collected locally from roads and paths and connecting into wider drainage system

🟦 Attenuation Basin - Overflow storage system for rainfall event in excess of 1 in 30 year storm

▨ Underground Storm Cell - Attenuating rainfall from roof and paving before water enters the drainage system. This can reduce peak runoff flows to the allowable green field run-off rate

7.5 Best value

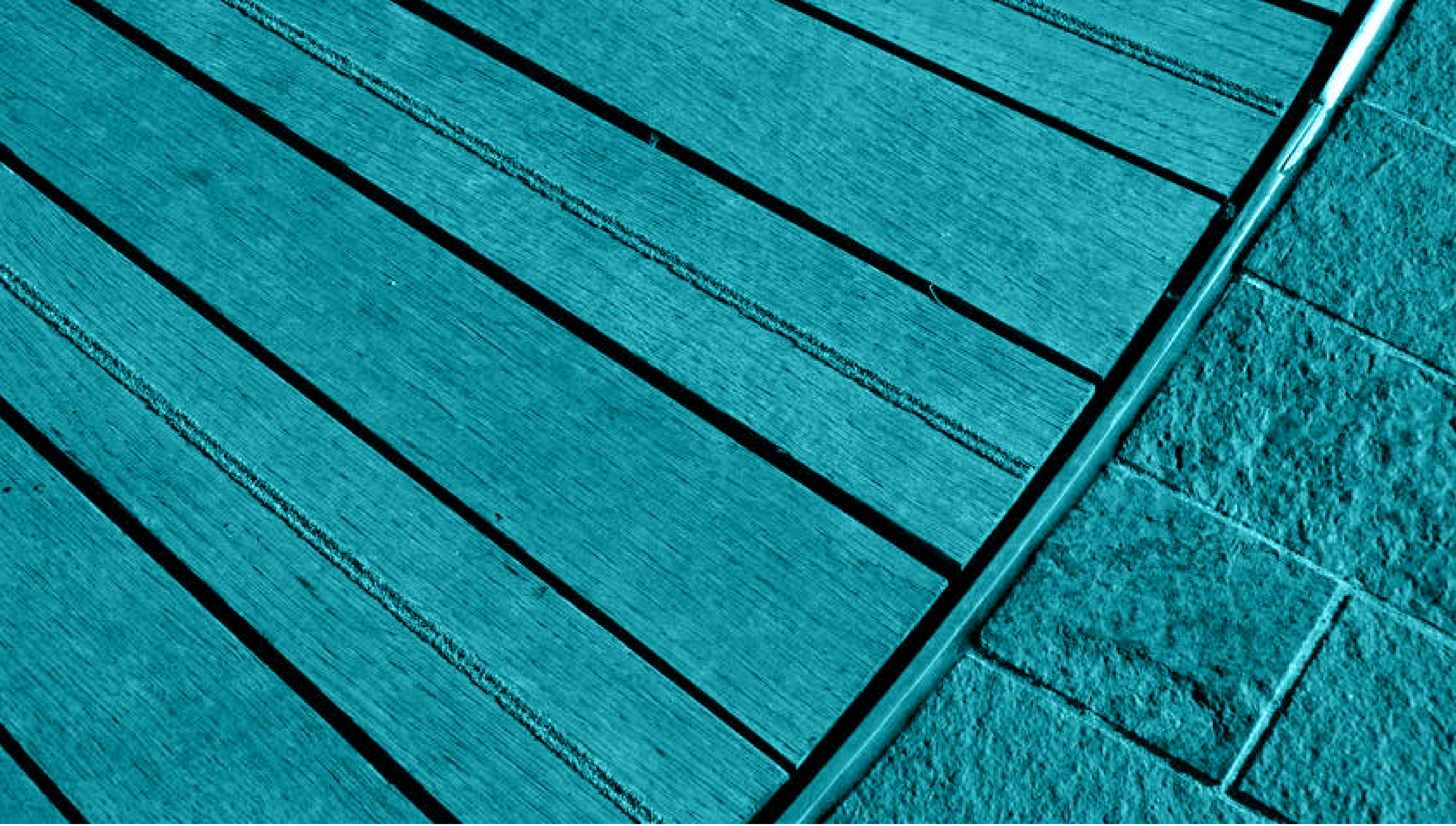
Natural capital is defined by the Natural Capital Committee (NCC) as 'those elements of nature which either directly provide or underpin human wellbeing'. Liveability and wellbeing influence how value for society is perceived.

CIRIA Research Project RP993 states that best value is not about cheapness. It is the opportunity to seek and obtain best overall value.

A SuDS approach can be cheaper than piped solutions; it can also deliver considerable wider benefits, as this guidance illustrates. Sustainable surface water management can contribute to a step-change in the resilience of London's drainage infrastructure and the quality of its urban realm.

Further information:
London Sustainable Drainage Action Plan
CIRIA C753 The SuDS Manual Chapter 35

Ashwin Street: SuDS components contribute to the quality of the urban realm



Appendices

Further information

B Woods Ballard, et al CIRIA C698 Site Handbook for the Construction of SuDS

Bartens et al. (2008) Can Urban Tree Roots Improve Infiltration through Compacted Soils for Storm Water Management?: http://www.ncbi.nlm.nih.gov/pubmed/18948457

British Geological Survey, Natural Environment Research Council: https://www.bgs.ac.uk

Cambridge City Council, Cambridge Sustainable Drainage Design and Adoption Guide

Centre for Ecology & Hydrology (1999 updated May 2016) Flood Estimation Handbook

CIRIA (2015) CIRIA C713 Retrofitting to Manage Surface Water

CIRIA (2015) CIRIA The SuDS Manual C753

CIRIA (October 2013) CIRIA Research Project RP993, Demonstrating the multiple benefits of SuDS – A business case (Phase 2) Draft Literature Review City of Philadelphia, City of Philadelphia Green Streets Design Manual

Defra (2010) Environmental Permitting Guidance: Water Discharge Activities (England and Wales) Regulations

Defra (December 2011) National Standards for sustainable drainage systems, Designing, constructing, operating and maintaining drainage for surface runoff

Defra / Environment Agency (October 2013) Delivering Benefits through Evidence, Rainfall Runoff Management for Developments Report SC030219

Drain London: https://www.london.gov.uk/what-we-do/environment/climate-changeweather-and-water/drain-london

Environment Agency (2009) Thames Catchment Flood Management Plan

Environmental Agency (2013) Groundwater Protection: Principles and Practice GP3

Flood & Water Management Act 2010

Forestry Commission, Forest Research(2010) Benefits of Green Infrastructure. Hydrological Benefits. URGP Evidence Note 005

GLA (2009) London Regional Flood Risk Appraisal

GLA (2010) Mayor's Transport Strategy para 528, 555, 62

GLA (2011 updated 2015) London Plan Policy 6.2

GLA (2011 updated March 2015) London Plan

GLA (2012) All London Green Grid SPG

GLA (2015) London Infrastructure Plan 2050, Consultation report

GLA (2015) London Sustainable Drainage Action Plan Draft Consultation

GLA (2015) Natural Capital Green

Infrastructure Task Force Report

GLA A Barry, Letter to Defra, Consultation of National Standards for SuDS

GLA Economics (June 2003) Valuing Greenness, Green Space House Prices and Londoners' Priorities

Groundwork Climate Proofing Housing Landscapes: http://www.groundwork.org.uk/Sites/london/pages/lifeplus-lon

Highways Authority and Utilities Committee (HAUC) Advice Note 2009/07, Special Engineering Difficulty Section 63 and Schedule 4 i-Tree Eco Project (2015) Valuing London's Urban Forest: http://www.forestry.gov.uk/

International Institute for Sustainable Development, Water Quality Monitoring Systems Design (2015) Chapter 6: http://www.iisd.org/library/water-quality-monitoringsystem-design

Interpave (May 2014) SuDS Permeable Paving

J D Phillips (2007) Fluvial Sediment Storage in Wetlands no. 89007 Water Resource Bulletin

K V Heal and S J Drain (2003) Sedimentation and Sediment Quality in Sustainable Urban Drainage Systems

Kennedy et al. (2005) 'Psychological' traffic calming, TRL Report TRL641

Landscape Institute (2014) Technical Guidance: Management and maintenance of Sustainable Drainage Systems (SuDS) landscapes Interim Technical Guidance Note 01/2014

Liu Jia et Al (2014) Review and Research Needs of Bioretention Used for the Treatment of Urban Stormwater

NHBC (November 2015 | Issue 19) Technical Extra

Old Oak and Park Royal Development Corporation (February 2016) Integrated Water Management Strategy

RSPB / WWT (December 2012) Sustainable Drainage Systems, maximising the potential for people and wildlife: http://www.rspb.org.uk

Susdrain (Fact Sheet January 2015) Designing Attenuation Storage for Redeveloped Sites

T Armour et al (2012) CIRIA C712 The benefits of large specie trees in urban landscapes: a costing and management guide

TDAG (September 2014) Trees and Hard Landscape A Guide for Delivery: http://www.tdag.org.uk

Thames Catchment Based Approach Group: http://www.catchmentbasedapproach.org/thames

TfL (2015/16) Surface Transport Plan

TfL (2016) Streetscape Guidance Third Edition V1

TfL (March 2014) Roads Task Force progress report

TfL (October 2012) Code of Practice Fourth Edition, New Roads and Street Works Act 1991

TfL response to Roads Task Force (July 2013) Delivering the vision for London's Streets and Roads

TfL Roads Task Force (April 2015) progress report

Thames Water Wastewater services: http://www.thameswater.co.uk/developers/592.htm Thames21 SuDS Highway (formerly Greenstreets): http://www.thames21.org.uk/greenstreets/

UK Groundwater Forum: http://www.groundwateruk.org

United States Environmental protection Agency (EPA 832-F-99-012) Storm Water Technology Fact Sheet Bioretention

Water UK (2013) Sewers for Adoption 7th Edition

Wildfowl & Wetlands Trust (WWT) Environment Agency Thames Water, SuDS for Schools Project: http://sudsforschools.wwt.org.uk/theproject/

Glossary

Amenity
The quality of a place being pleasant or attractive, ie, its agreeableness. A feature that increases attractiveness or value, especially of a piece of real estate or a geographic location.

Anaerobic
An absence of oxygen

Anthropogenic soil profile
Where the upper profile of soil is changed by human intervention and activity.

Appraisal period
The agreed time over which the costs and benefits are assessed and then discounted.

Attenuation
An intervention to reduce peak flow and increase the duration of a flow event.

Attenuation tank
A vessel which retains excess water and slowly releases it in a controlled discharge to a combined drain or watercourse.

Base flow
The normal level of subsurface water.

Basin
A ground depression acting as a flow control or water treatment structure that is normally dry, but is designed to detain storm water temporarily.

Benefit cost ratio (BCR)
The net present value divided by the costs (normally the capital and operational costs).

Biodiversity
The diversity of plant and animal life in a particular habitat.

Bioretention area
A depressed landscaping area that collects runoff and percolates it through the soil below the area into an underdrain; this helps remove pollution.

Blue infrastructure
Describes all waterways, both natural and man-made, in and around towns and cities.

BREEAM
The Building Research Establishment's Environmental Assessment Method. It sets best practice standards for the environmental performance of buildings.

Brownfield site
A site that has been previously developed.

Catchment
The area contributing surface water flow to a point on a drainage or river system. Can be divided into sub-catchments.

CIRIA
The Construction Industry Research and Information Association.

Combined sewer
A sewer designed to carry foul sewage and surface runoff in the same pipe.

Contaminated ground
Ground that contains substances that, when present in sufficient quantities or concentrations, can have detrimental effects on the surrounding area.

Control structures
Components of a SuDS scheme which control the rate at which water flows along and out of the system.

Conventional drainage
The traditional method of draining surface water using subsurface pipes to remove water as quickly as possible.

Conveyance

Movement of water from one location to another.

Depositional environment
Describes the combination of physical, chemical and biological processes associated with sediment.

Design codes
Detailed guidance to influence the designs of building and public realm; may be enforced as a planning condition.

Design criteria
A set of standards agreed by the developer, planners and regulators that the proposed system should satisfy.

Designing for exceedance
An approach that aims to manage exceedance flows during periods of heavy rainfall, eg, the use of car parks during extreme events.

Detention basin
A vegetated depression that is normally dry except following storm events. Constructed to store water temporarily to attenuate flows. May allow infiltration of water to the ground.

Detention pond/tank
A pond or tank that has a lower outflow than inflow. Often used to prevent flooding.

Diffuse pollution
Pollution arising from land use activities (urban and rural) that are dispersed across a catchment, or sub-catchment. This is different from process effluent, municipal sewage effluent, or an effluent discharge from farm buildings.

Drain London
London Mayoral programme which helps to predict and manage surface water flood risk in London.

EA
The Environment Agency.

Ecology
All living things – such as trees, flowering plants, insects, birds and mammals – and the habitats in which they live.

Ecosystem
A biological community and its physical environment.

Ecosystem services
The resources and processes that are supplied by natural ecosystems.

Environment
Both the natural environment (air, land, water resources, plant and animal life) and the habitats in which they live.

Erosion
The group of natural processes, including weathering, dissolution, abrasion, corrosion, and transportation, by which material is worn away from the earth's surface.

Evapotranspiration
The process by which the earth's surface or soil loses moisture by evaporation of water and by uptake and then transpiration from plants.

Everyday events
Events with a return period of less than one year (100% chance of occurring in any one year).

Exceedance
When heavy or extreme rainfall causes a flow that is greater than the capacity of the drainage system.

Extreme events
Events of greater than 30 year return period (3.3% chance of occurring in any one year). Can often lead to major flooding with substantial damage.

Filter drain
A linear drain consisting of a trench filled with a permeable material, often with a perforated pipe in the base of the trench to assist drainage.

Filter strip
A vegetated area of gently sloping ground, designed to drain water evenly off impermeable areas and to filter out silt and other particulates.

Filtration
The act of removing sediment or other particles from a fluid by passing it through a filter.

Flora
The plants found in a particular physical environment.

Flow paths
The course rain water takes naturally.

Forebay
A small pool located upstream of a larger body of water, designed to act as a buffer, trapping sediment and silt

Interception forebay
A small basin or pond upstream of the main drainage component which traps sediment.

Geocellular structure
A plastic box structure used in the ground, often to attenuate runoff.

Geographical information
A system designed to capture, store, manipulate, analyse, manage and present data about the planet's natural and man made features.

Geotechnical survey
Information on the physical properties of soil and rock.

Green corridor
A strip of land in an urban area that allows wildlife to move along it and can support habitats. Typically includes cuttings, embankments, roadside grass verges, rights of way, rivers and canal banks.

Green infrastructure
A network of green spaces, trees and green roofs that is planned, designed and managed to provide a range of benefits including amenity, healthy living, biodiversity enhancement and ecological resilience (natural capital).

Living roof
A roof with plants growing on its surface, which contributes to local biodiversity. The vegetated surface provides a degree of retention, attenuation and treatment of rainwater, and promotes evapotranspiration. Sometimes referred to as a green, blue or brown roof.

Green space
The 'green lungs' of towns and cities, land that is that is wholly or partly covered with vegetation.

Grey infrastructure
Sometimes referred to as hard or traditional infrastructure, are man-made, engineered components of a system such as drains and gutters.

Groundwater
Water that is below the surface of the ground in the saturation zone.

Gully pots
Part of a surface water drainage system; large containers that remove solids from runoff.

Habitat
The area or environment where an organism or ecological community normally lives or occurs.

Heat island
Describes urban built up areas that are significantly warmer than surrounding rural areas.

Highways Agency
The government agency responsible for strategic highways in England, ie, motorways and trunk roads. This function is devolved to Transport Scotland, Department of Economy and Transport in Wales and the Northern Ireland Roads Service.

Highways authority
A local authority with responsibility for the maintenance and drainage of highways maintainable at public expense.

Hydrodynamic vortex
Storm water management device that uses cyclonic separation to control water pollution. It uses flow-through structures with a settling or separation unit to remove sediment from surface water runoff.

Hydrology
The branch of science concerned with the properties of the earth's water, and especially its movement in relation to land.

Impermeable
A material that does not allow liquids or gases to pass through it.

Impermeable surface
A surface that does not allow water to pass through it, thus generating a surface water runoff after rainfall.

Infiltration (to the ground)
The passage of surface water into the ground.

Infiltration basin
A dry basin designed to promote infiltration of surface water to the ground.

Inundation
An overwhelming amount of water resulting in a flood.

Linear assets
Linear infrastructure such as pipes, roads, rail, canals, etc.

LUL
London Underground Limited.

Media
Natural topsoils, subsoils and manufactured soils.

Micropool
Pool at the outlet to a pond or wetland that is permanently wet and improves the pollutant removal of the system.

Mini-Hollands
TfL programme to transform three outer London boroughs (Enfield, Kingston & Waltham Forest) to prioritise walking and cycling while improving the quality of the urban realm.

Monetised costs & benefits
These are easy to understand and measure financially, eg, the price of land or reduced damage (tangible) costs to property.

Monitoring plan
Sets out the approach, timing and resources to monitor measures adopted.

Multifunctional space
An area that has more than one use, one being to manage surface water.

National Standards for Sustainable Drainage
A regulatory document providing standards and guidance on the design, construction and maintenance of SuDS for approval and adoption by the SuDS Approval Body.

Natural capital
Natural assets which include geology, soil, air, water and all living things within an ecosystem.

Net present value (NPV)
The difference between the discounted costs and benefits over the appraisal period.

NOx PM
Oxides of nitrogen particulate matter, especially atmospheric pollutants as a result of fuel combustion.

Opportunistic retrofitting
Where the opportunity to retrofit storm water management arises on the back of other drivers, such as regeneration or small scale improvements. These may occur within a neighbourhood, or locally on a plot level.

Orifice control chamber
A chamber within a drainage system which controls discharge rates.

Pathway
The route by which potential contaminants may reach targets or by which water (and pollutants) are conveyed either below or above ground.

Pavement
The road or car park surface and underlying structure, usually asphalt, concrete or block paving. Note: the path next the road for pedestrians is the ‘footway’ (the UK colloquial term being 'pavement').

Percentage runoff
The proportion of rainfall that runs off a surface.

Permeability
A measure of the ease that fluid can flow through a porous medium. It depends on the physical properties of the medium, eg, grain size, porosity and pore shape.

Permeable pavement
A permeable surface that is paved and drains through voids between solid parts of the pavement.

Permeable surface
A surface that is formed of material that is impervious to water but, by virtue of voids formed through the surface, allows infiltration of water to the sub-base through the pattern of voids, eg, concrete block paving.

Phytoremediation
Use of living plants to clean up soil, air, and water contaminated with hazardous chemicals.

Pluvial flooding
Flooding that results from high intensity, extreme rainfall-generated surface water flow.

Pollution
A change in the physical, chemical, radiological, or biological quality of a resource (air, water or land) caused by man’s activities that is injurious to existing, intended or potential uses of the resource.

Pond
Permanently wet depression designed to retain storm water above the permanent pool and permit settlement of suspended solids and biological removal of pollutants.

Porosity
The percentage of void space in a material.

Porous paving
Surfacing material that contains voids, allowing water to pass through it.

Potable/mains water
Water company/utility/authority drinking water supply.

Prevention
Site design and management to stop or reduce the occurrence of pollution of impermeable surfaces; to also lower the volume of runoff, by reducing impermeable areas.

Public sewer
A sewer that is vested and maintained by the sewerage undertaker (see s 219(1) of the Water industry Act 1991).

Quietways
Proposed network of radial and orbital cycle routes through London, linking key destinations via direct back-street routes, through parks, along waterways or tree-lined streets.

Rain garden
A planted basin designed to collect and treat surface water runoff.

Rain meadow
A field or drainage reserve that is capable of flooding to absorb excess rainfall.

Rainwater butt
Small scale garden water storage device that collects rainwater from the roof via the drainpipe.

Rainwater harvesting or rainwater use system
A system that collects rainwater from where it falls, rather than allowing it to drain away. It includes water that is collected within the boundaries of a property, from roofs and surrounding surfaces.

Receptor
A location that is subject to an impact, either through flooding or pollution. Certain types of measures can be retrofitted at such locations.

Recharge
The addition of water to the groundwater system by natural or artificial processes.

Retention pond
A pond where runoff is detained long enough to allow settlement and biological treatment of some pollutants.

Rill
A shallow channel or watercourse.

Risk
The chance of an adverse event. The effects of a risk is the combination of the probability of that potential hazard being realised, the severity of the outcome if it is, and the numbers of people exposed to the hazard.

Risk assessment
A carefully considered judgment requiring an evaluation of the consequences that may arise from the hazards identified, combining the various factors contributing to the risk and then evaluating their significance.

Runnel
A small river channel or course.

Runoff
Water flow over the ground surface to the drainage system. This occurs if the ground is impermeable, saturated or if rainfall is particularly intense.

Soakaway
A subsurface structure that surface water is conveyed into, designed to promote infiltration.

Source control
The control of runoff at or near its source.

Stockholm soil
Soil made from angular rock, specified soil mix and water.

Storm events
Events occurring between one in a year (100% chance of occurring in any one year) and one in 30 years return period (3.3% chance of occurring in any one year). These events are typically what urban drainage systems (below ground) are designed up to, and at which flooding occurs.

Strategic Flood Risk Assessment (SFRA)
Provides information on areas at risk from all sources of flooding. The SFRA should form the basis for flood risk management decisions and provides the basis from which to apply the sequential text and exception test (as defined in CLG, 2010) in development allocation and development control process.

Sub-catchment
A division of a catchment, to allow runoff to be managed as near to the source as is reasonable.

SuDS
Sustainable drainage systems; a sequence of management practices and control structures designed to drain surface water in a more sustainable fashion than some conventional techniques.

SuDS management train
The management of runoff in stages as it drains from a site. This is CIRIA's preferred term.

Surface water
Water that appears on the land surface, ie, lakes, rivers, streams, standing water and ponds.

Swale
A shallow vegetated channel designed to conduct and retain water, but may also permit infiltration. The vegetation is able to filter particulate matter. Treatment improving the quality of water by physical, chemical and/or biological means.

SWM
Storm water management.

TfL
Transport for London.

TLRN
Transport for London Road Network.

Topographical survey
Used to identify and map the contours of the ground and show all natural and man-made features on the surface of the earth or slightly above or below the earth's surface.

Treatment stage
A component of a sustainable drainage system that improves the quality of the water passing through it.

Waste
Any substance or object that the holder discards, intends to discard, or is required to discard.

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

Watercourse
All rivers, streams, ditches, drains, cuts, culverts, dykes, sluices and passages that water flows through.

Water table
The point where the surface of groundwater can be detected. The water table may change with the seasons and annual rainfall.

Wetland
Flooded area where the water is shallow enough to enable the growth of bottom-rooted plants.

Team

The guidance has been produced by J & L Gibbons with Civic Engineers, Robert Bray Associates, Tim O'Hare Associates, DWD and Jackson Coles for Transport for London (TfL). A steering group provided support, with representatives from appropriate parts of TfL and the following external stakeholders:

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