A simple guide to Sustainable Drainage Systems for housing

NHBC Foundation

Housing research in partnership with BRE Trust

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July 2010

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Photographs

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Figure 1: Adapted from an original illustration in Martin P, Turner B, Dell J, Payne J, Elliott C and Reed B (2001) *Sustainable urban drainage systems – best practice manual*, C523, CIRIA, London (ISBN: 978-0-86017-523-0). See www.ciria.org.uk/suds/suds_management_train.htm

Figure 2: Stephen Wielebski, Miller Homes

Figure 5: Black Redstarts

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FOREWORD

While carbon reduction has rightly been given the highest priority in recent years, other environmental imperatives must also be addressed urgently including the reduction in water usage and treatment. This is a requirement in The Code for Sustainable Homes, and will also be affected by further legislation such as Article 6 of the Groundwater Directive and The Floods and Water Management Act.

Developers are encouraged to look at the dispersal of any unwanted surface water via various sustainable drainage (SUDS) options either at, or close to, the development. These water management measures all work towards achieving sustainable development as well as much needed points to gain the required Code rating.

This pragmatic guide to sustainable drainage systems is aimed at introducing the concept of SUDS and increasing the awareness of government policies and regulation in this area. Technical guidance is included for the differing options, their selection parameters, construction requirements and maintenance issues. The guide also covers relevant social and environmental issues, together with the health and safety considerations for incorporating these systems in housing developments.

While providing information that will be useful to all those concerned with SUDS and the management of surface water in housing developments, particularly for the first time, it is aimed specifically at individuals and organisations involved in small developments and in-fill projects to give an insight into the options available at site control level.

The NHBC Foundation exists to promote good practice within the house-building industry. Whether you are involved in designing, building or managing SUDS in housing developments, I hope this guide contributes to your understanding of the key issues involved and the important factors for safe implementation.

Rt. Hon. Nick Raynsford MP

Chairman, NHBC Foundation

ABOUT THE NHBC FOUNDATION

The NHBC Foundation was established in 2006 by the NHBC in partnership with the BRE Trust. Its purpose is to deliver high-quality research and practical guidance to help the industry meet its considerable challenges.

Since its inception, the NHBC Foundation's work has focused primarily on the sustainability agenda and the challenges of the government's 2016 zero carbon homes target. Research has included a review of microgeneration and renewable energy techniques and the groundbreaking research on zero carbon and what it means to homeowners and housebuilders.

The NHBC Foundation is also involved in a programme of positive engagement with government, development agencies, academics and other key stakeholders, focusing on current and pressing issues relevant to the industry.

Further details on the latest output from the NHBC Foundation can be found at www.nhbcfoundation.org.

NHBC Foundation Advisory Board

The work of the NHBC Foundation is guided by the NHBC Foundation Advisory Board, which comprises:

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1 Summary and scope

This guide aims to provide general guidance on the concept and use of Sustainable Drainage Systems (SUDS) to aid the management of surface water in housing developments. It is to inform designers, developers and other stakeholders such as local authorities and property owners about the incorporation and use of SUDS in housing schemes. This guide is not intended to be a design guide to SUDS but to inform those involved in small developments and in-fill projects of the concept of SUDS, and to give insight into the options available at the site control level.

SUDS schemes need to cover three main aspects of surface water management: water quantity, quality and amenity. The aims for sustainable development for housing, including the provision of SUDS, are based on two main government policies: *Sustainable Construction*[1] and *Future Water*.[2] These policies require all developments to consider and provide adequate drainage and management of surface water. SUDS solutions must not cause an impact on the quality of the groundwater or the water catchments of the local water bodies which can subsequently impact on the water supply and increase the burden of further treatment costs for water companies (as required by the Water Framework Directive).[3] The incorporation of SUDS aims to balance environmental, social and economic requirements for a site development to provide a sustainable, healthy, pleasurable environment for the new housing community as well as adequate management of surface water drainage by attenuating excess stormwater flow to reduce risk of flooding which would have an impact on the social community.

The objectives of this guide are to:

- Introduce the concept of SUDS, regulatory drivers, requirements and best practice.
- Encourage and support the incorporation of SUDS in new and existing small housing developments and in-fill.
- Increase awareness of the government policies and the Water Framework Directive requirements related to surface water management and the impact housing development has on surface water drainage and water quality of local environments.

- Provide information regarding government regulations for England, Wales and Scotland.
- Give information concerning planning consent issues.
- Provide technical information relating to SUDS devices, the selection of techniques, and the considerations required for SUDS construction and maintenance.
- Provide information regarding land use, adoption and health and safety considerations in connection with the incorporation of SUDS for a housing development.
- Offer guidance relating to the advantages of incorporating SUDS by considering the social, economic and environmental issues.

If planning to implement SUDS on a project, it is important to review current legislation. SUDS has been growing apace recently; however, much of the promised legislation is still being delivered; this guide refers only to documents that are in the public domain. Two of the most important documents are:

- the transposition of Article 6 of the Groundwater Directive[4] into UK law, which could expose SUDS to four tiers of regulatory control, ie planning, the Building Regulations, environmental permitting, and the Code for Sustainable Homes Assessment
- the Flood and Water Management Act 2010.[5]

2 Introduction

SUDS are a sequence of management practices, control structures and strategies designed to efficiently and sustainably drain surface water, while minimising pollution and managing the impact on water quality of local water bodies.[6] SUDS are increasingly used to mitigate excessive flows from stormwater and reduce the potential for pollution from run-offs in urban areas. SUDS are often designed to replicate as closely as possible the natural drainage prior to any development. This may include infiltration devices to help reduce pollution contained in the surface water run-off. SUDS remove water quickly and efficiently in a sustainable manner and should be included in the masterplanning of housing developments wherever possible.[7] The adoption and success of SUDS will depend on the local ground conditions (primarily type of soil) and groundwater tables in the area.[8] A survey of the ground conditions will be necessary before deciding on a specific SUDS technique. The assessment should also include a study of the ecological status and sediment releases of the area, the possible impacts caused by flooding, and current drainage patterns in the area.

SUDS are considered a design and planning issue and consist of a number of management techniques[6] (Fig. 1). Strategies include prevention, source control, site control and regional control of stormwater, and reducing pollution entering watercourses.

There are a number of devices associated with SUDS and its site design, planning and management. Devices include stormwater design features, pervious paving, soakaways, swales, infiltration trenches, filter strips, sand filters, bioretention filters/areas, green roofs, water harvesting systems, infiltration basins, detention basins, ponds and stormwater wetlands, silt removal devices, pipes and conduits, and subterranean storage. Management incorporates maintenance procedures to keep paving areas and roads clear of debris as well as minimising the application of de-icing agents and run-off of pollutants, for example. Prevention and maintenance are an important aspect of managing SUDS. Prevention involves site management and design, and educating users. The amount of pollution contained in the first flush of a storm can be efficiently

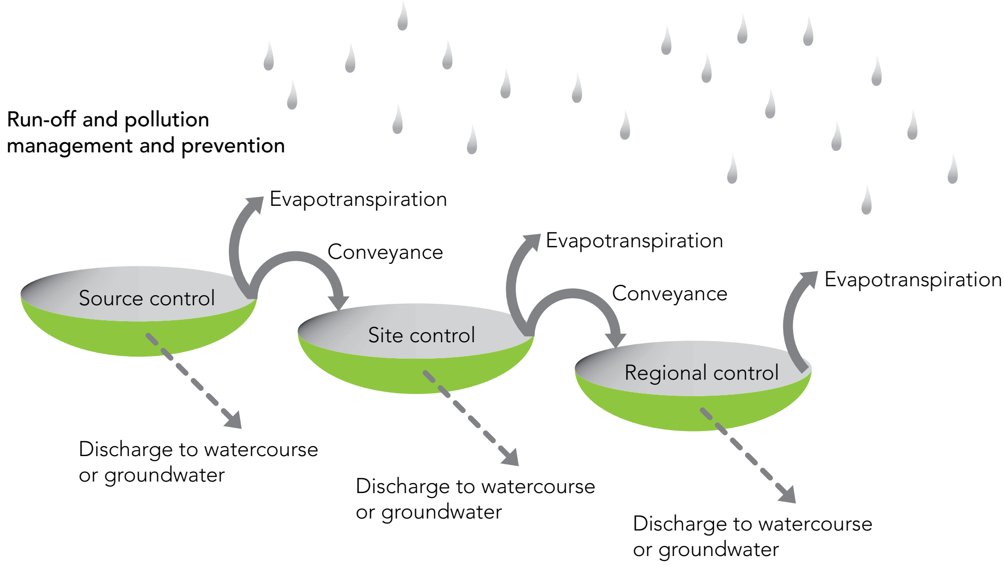


Figure 1 SUDS management train (adapted from an original illustration, courtesy of Construction Industry Research and Information Association – CIRIA).[6]

minimised by good maintenance procedures, keeping all paving surfaces clean, and preventing the accumulation of pollutants. All masterplanning[7] should include 'pollution prevention control', for example bunding of oil tanks, appropriate chemical storage, good workmanship regarding pipework, drainage, and sewage systems. A site management system must ensure that best practice guidance and standards are adhered to. Pollution prevention initiatives should be included in the masterplanning[7]; agreement early on and co-operation between the site developer, contractors, water quality consultants and the Environment Agency or local authorities is pivotal to successful delivery. The pollution prevention initiative should establish an action plan, examining actions required in order to comply with the Pollution Prevention Guidelines (PPGs)[9] and an audit system, for monitoring the effectiveness of the action plan. A system for inspection, maintenance, and regular cleaning of drains, traps, basins, and gully separators forms part of the maintenance strategy.

SUDS are included in Approved Document H: Drainage and Waste Disposal of the Building Regulations (England and Wales).[10] The drive for the increased consideration of SUDS in developments is emphasised throughout the UK:

- In England and Wales Planning Policy Statement 25 *Development and Flood Risk* (PPS25)[11] (Communities and Local Government) and Technical Advice Note 15 *Development and Flood Risk* (TAN15)[12] (Welsh Assembly) consider the use of SUDS wherever it is practical to mitigate the risk of flooding downstream and the impact on water catchments. In Scotland, consideration of SUDS is required by Planning Advice Note 61 *Planning and Sustainable Urban Drainage Systems* (PAN61).[13] A SUDS design manual has been published by the SUDS Scottish Working Party for masterplanning implementation by developers in Scotland and Northern Ireland (*Sustainable Urban Drainage Systems – Design Manual for Scotland and Northern Ireland*).[14] PPS25 outlines a tiered approach to SUDS not dissimilar to the SUDS management train referred to in Figure 1, and shown in Figure 2 as a flowchart.

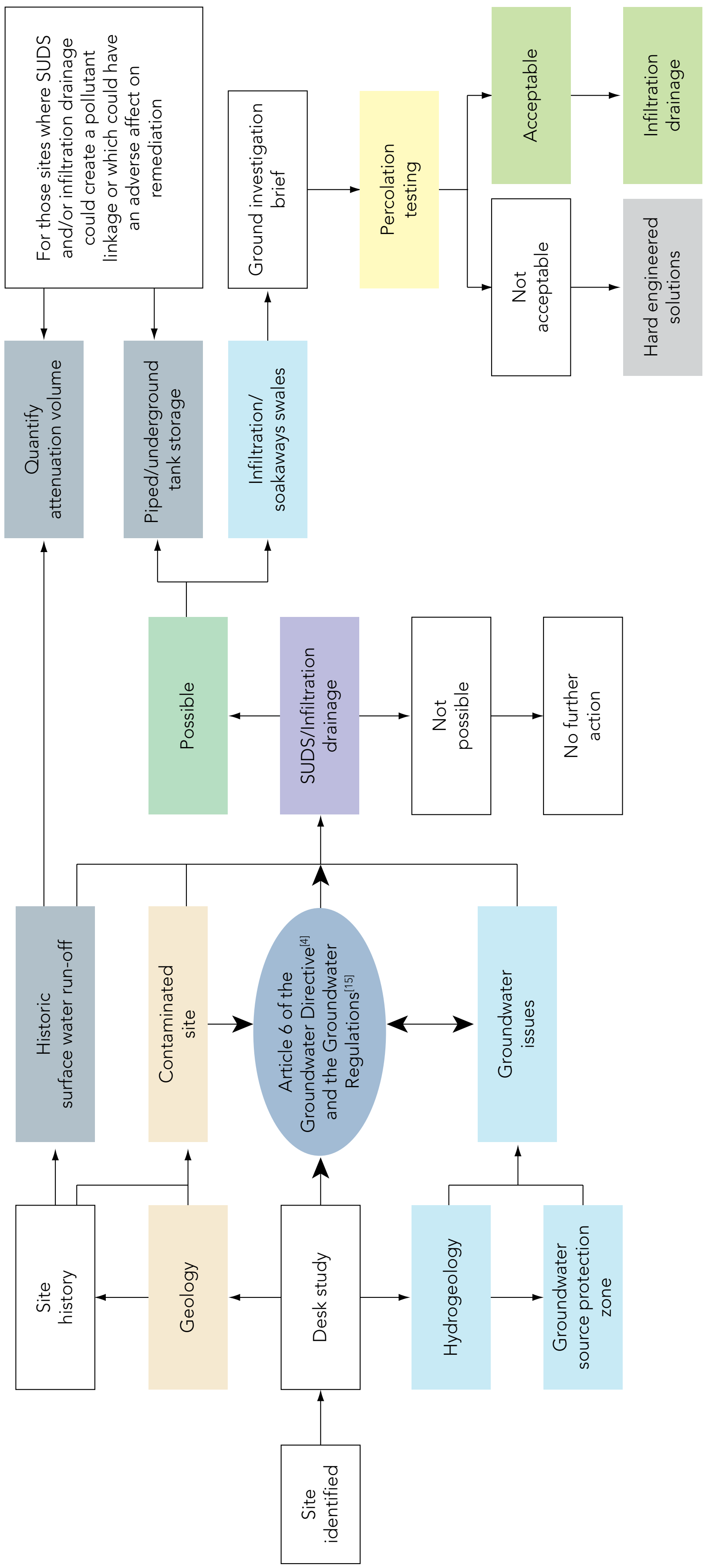


Figure 2 SUDS evaluation flowchart (courtesy of Stephen Wielebski, Miller Homes).

3 Water quality – environment, planning policies, and regulations

3.1 Water quality and the Water Framework Directive

The protection and restoration of water quality is required by the Water Framework Directive (Directive 2000/60/EC),[16] which provides common objectives, guidelines, strategies, and requirements for the member states of Europe to prevent deterioration and to improve water quality. The Water Environment (Water Framework Directive) (England and Wales) Regulations 2003[17] provide the framework to meet the Water Framework Directive objectives of protecting and enhancing the water bodies and groundwater of England and Wales by 2015. In addition, wetlands dependent on groundwater must be safeguarded and the water-related requirements of other community legislation taken into account. The Water Framework Directive has been implemented in Scots law by the Water Environment and Water Services (Scotland) Act 2003.[18] The overall objectives are to prevent deterioration of the water environment and to restore waters to good status by 2015.

The Water Framework Directive prohibits discharge of all polluting substances arising from human activities directly to groundwater and to the water table (the Groundwater Regulations 1998).[15] All discharges of List I and II substances to groundwater are subject to prior investigation and authorisation; this includes indirect discharges or disposals.[19]

Not all discharges from SUDS will require authorisation. A summary of the types of drainage and their requirement for authorisation are shown in the Appendix and Table 1.

Table 1

Related regulations which also provide a control for diffuse pollution
The Water Resources (Environmental Impact Assessment) Regulations 2003[20]
The Building Regulations (Amendment) 2002[21]
The Control of Pollution (Oil Storage) (England) Regulations 2001[22]
The Environmental Impact Assessment (Land Drainage Improvement Works) Regulations 1999[23]
The Groundwater Regulations 1998[15,19]
The Waste Management Licensing Regulations 1994[24]
The Water Resources Act 1991 (and subsequent amendments), Discharge Consents, Work Notices[25]
The Town and Country Planning Act 1990, Good Design Requirements[26]
The Control of Pesticides (Amendment) Regulations 1997[27]
Dangerous Substances Directive[28]
Environmental health legislation

The Water Framework Directive stresses the need to control surface water pollution and this requirement has led to government policy and Planning Policy Statements (called planning advice notes in Scotland) recommending SUDS as the practical way of dealing with the sources of diffuse pollution acceptable by the Environment Agency and Scottish Environment Protection Agency (SEPA). This policy is already being implemented in Scotland and by some local authorities in England and Wales to reduce the impact caused by stormwater and to reduce surface water pollution discharging into groundwater and watercourses.

Diffuse pollution[29] is defined as pollution arising from land use activities (rural and urban) that are dispersed across a catchment or sub-catchment and do not arise as a process effluent, municipal sewage, or effluent discharge from farm buildings. Diffuse pollution is closely related to land use and the majority of urban diffuse pollution is caused by run-off from areas of impermeable surface, such as industrial and commercial estates, construction sites, roads, and other urban areas. Development of land reduces the amount of natural ground surface available to rainwater by replacing green field areas with largely impermeable surfaces. Such development of land leads to an increase in surface water run-off as the amount of water infiltrating into the ground reduces.

3.2 Environment policies related to Sustainable Drainage Systems

Recent extensive flooding in the UK has illustrated the extent of damage caused by surface water flooding. The Environment Agency estimated that two-thirds of the 57 000 affected homes in the summer of 2007 were affected because of surface water run-off overloading existing drainage systems. The Pitt review *Learning Lessons from the 2007 Floods*[30] highlighted the risk of surface water flooding and puts forward recommendations to reduce the chance of homes, businesses and services being damaged by floods in the future and to prevent the loss of services such as water and power due to floods.

The Department of Trade and Industry (DTI) report *Key Information on Flood and Coastal Defence*[31] estimated over 80 000 properties being at very high risk from surface water flooding, potentially causing annual damage of approximately £270 million. These costs are believed to increase due to climate change.

The requirement to provide sustainable drainage provision is established by a number of regulators in the UK, such as the Environment Agency, SEPA, and local authorities.

The Environment Agency policy statement, *Sustainable Drainage Systems* issued in 2002[32] confirmed the government's commitment to promote SUDS as a viable technique to manage surface and groundwater regimes sustainably. The Environment Agency has the power under the Water and Resources Act 1991[25, 33] (complemented by the Environment Act 1995)[34] to regulate discharges and control pollution; its policy is to establish SUDS as the normal drainage practice where appropriate for all new developments in England and Wales, and to retrofit SUDS on the existing surface water drainage systems that are causing a negative environmental impact.

The water strategy set out by Department of Environment, Food and Rural Affairs in *Future Water* [2,35] provides a plan for more effective management of surface water in response to the environmental pressure caused by climate change and the requirement for housing development. It states:

> "By 2030, we will manage the surface water more sustainably, by allowing for the increased capture and reuse of water, slow absorption through the ground and more above-ground storage and routing of surface water separate from the foul water, where appropriate. Water will be increasingly managed on the surface, rather than relying on wholesale upgrade of the sewer system to higher design standards, which will be costly and a lengthy process."

The strategy also announced changes to PPS25[11] (June 2008) to allow householders to implement SUDS without the need for planning permission, including paving gardens and using porous materials.

In Scotland SUDS are now required in all new developments as a means of reducing pollutants entering water catchments and water bodies and to mitigate the risk of flooding due to urban developments. *Choosing Our Future: Scotland's Sustainable Development Strategy*[36] recognises the importance of securing a high quality of local environment as a key aspect of promoting health and well-being for the Scottish population. The Scottish Building Standards Agency is responsible for the Building (Scotland) Regulations 2004; housing development incorporating SUDS is an integral part of this strategy.

To enable the legislation relating to the Water Framework Directive,[3] the term 'sewer' has been redefined to include SUDS components in *Sewers for Scotland*,[37] which also includes the construction and design guide for SUDS for developers in Scotland to reflect the changing approach to surface water drainage. Scottish Water is responsible for the future management and maintenance of publicly shared SUDS devices according to the Water Environment and Water Services (Scotland) Act 2003.[38]

3.3 National planning guidance

In the construction industry, there is a particular issue with different levels of awareness of the Water Framework Directive and water environment regulations. The client/contractors/sub-contractor chains and operators of site work must be aware of environmental issues, and compliance with Water Framework Directive requirements of prevention control of diffuse pollution, at the planning stage of construction projects (Fig. 2).

The development plan will need to take water-related issues into account when identifying land for development and redevelopment. The development should co-ordinate the provision of sustainable water supplies, sewage treatment, and discharges in accordance with Planning Policy Statement 12 *Local Spatial Planning* (PPS12),[39] local development frameworks, and to avoid sites where water supply and/or drainage provision is unlikely to be sustainable. Wherever possible, SUDS should be used and, when applicable, sites chosen that can be remediated without damage to the water catchment ecosystem.

The Building Regulations Approved Document H[10] provides the regulatory framework for drainage of rainwater. There must be adequate provision to carry rainwater from the roof of the buildings; paved areas around the building must be adequately drained; and rainwater should be discharged, preferably to an adequate soakaway or some other adequate infiltration system. But where this is not practicable rainwater should be discharged to a watercourse or, if that is not reasonably practicable, a sewer. PPS25[11] provides guidance in relation to the impact of flooding on the water environment, SUDS, and the policy for prevention of pollution.

In industrial and commercial land development, there is a need to consider provision to control contaminated run-off to the drains. The run-off from a construction site could have an impact on the local water environment. Separate drainage systems should be provided where materials used or stored on site could cause pollution. There should be a separator or treatment system to intercept the flow, and the flow should be discharged into a system suitable for receiving the polluted effluent.

Planning Policy Statement 23 *Planning and Pollution Control* (PPS23)[40] explains the government's policy regarding the pollution control legislation, its interactions with the planning system, and how these interactions should be dealt with by planning. Regional planning bodies are responsible for producing regional spatial strategies (regional planning guidance [RPG]) setting out policies for the development and the use of land in the region. This should include guidelines to ensure that development plans can identify the general locations or specify the criteria for the location of particular major industries or facilities (eg petrochemical industry, research centres and petrol stations) including SUDS, which could have an impact on the local environment.

PPS23 requires developers to discuss planning proposals with the pollution control authorities and other authorities (eg Health and Safety Executive) in order to assess potential health and safety risks of pollution, to contribute to the design process and to minimise any likely impact. The environmental impact assessment (EIA) is an important procedure to ensure that potential environmental effects of a proposed development are fully evaluated prior to undertaking the development, see Town and Country Planning Regulations 1990.[26] The developer is required to produce an environmental statement describing the likely environmental effects (including impact on water environment and soil quality) of the project, mitigation measures and evaluation of alternatives. The Environment Agency provides a series of Pollution Prevention Guidelines (PPGs) to help business and individuals as well as developers with practical advice to avoid pollution and minimise waste, eg PPG3 *Use and Design of Oil Separators in Surface Water Drainage Systems*[41] and PPG4 *Treatment and Disposal of Sewage where No Foul Sewer is Available.*[42]

PPS25[10] (TAN15[12] in Wales) recommends the use of a spatial planning system to ensure that flood risk is considered and development is directed away from high-risk areas to ensure that the surface water drainage of the new development does not enhance the flood risk. PPS25 identifies how built development can affect flooding by increasing or decreasing run-offs. In most cases, built development tends to cover the area with impermeable ground, increasing total and peak water flows rather than allowing water to percolate into the ground, which could lead to flooding. By introducing vegetated areas in the development, water run-off would be attenuated. PPS25 encourages the incorporation of SUDS in new development and local planning authorities are encouraged to consult and have joint strategies with the Environment Agency sewerage undertakers regarding planning permission of new development. Appendix E of PPS25 provides guidance on SUDS and SUDS devices (features), outlining the benefits and restriction of such systems and issues relating to the implementation of SUDS.

PPS25 emphasises the need to include SUDS at both the conception and the planning stage of the development. The following issues should be considered:

- incorporating SUDS into the overall site concept and layout
- investigating the need and subsequently remediating contaminated land
- agreeing the adoption, maintenance, and operation of SUDS
- the need for monitoring long-term performance.

PPS25 encourages local planning authorities to use SUDS by incorporating favourable strategic policies within RPG and structure plans (eg for the south-east, see RPG9 Government Office for the South East)[43] and persuading developers to install SUDS wherever practicable as a part of all future development, if necessary by the use of appropriate planning conditions or agreements. The local plan should provide the policy to implement SUDS, and the Environment Agency recommends that the local plan should include policies to ensure that developers will incorporate SUDS in their proposal to prevent the water environment being adversely affected by:

- increasing surface water run-off
- increasing the risk of pollution in particular diffuse pollution
- reducing the recharge of groundwater
- causing physical damage to the beds and banks of watercourses.

Furthermore, there should be policy in the local plan to ensure that any SUDS implemented have adequate provision for their future maintenance.

In Scotland, the Scottish Executive requires the incorporation of SUDS in new building developments. According to the Scottish Building Standards:

> "Every building, and hard surface within the curtilage of a building, must be designed and constructed with a surface water drainage system that will: (a) ensure the disposal of surface water without threatening the building and the health and safety of the people in and around the building; and (b) have facilities for the separation and removal of silt, grit and pollutants."[44]

PAN61[13] provides the guidance for planners and industrial developers to implement SUDS using *Sustainable Urban Drainage Systems – Design Manual for Scotland and Northern Ireland* developed by the SUDS Scottish Working Party.[14] Planning Advice Note 60 *Planning for Natural Heritage* (PAN60),[45] describes the application of ecological principles in the design of new developments. A *Habitat Enhancement Initiative*[46] has been developed by SEPA to further promote the issues relating to managing and creating small water bodies including SUDS.

New development, including drainage, will require the approval of planning authorities: roads and water authorities, and SEPA, are all statutory consultees to the planning process and co-ordinate the provision of SUDS in new developments. The planning authority provides the structure and local plans which outline the expectations required in relation to the use of SUDS. The structure plan should give a general commitment to include SUDS in the development plan. There is also an emphasis for inclusion of SUDS as part of the river basin management plans as required by the Water Framework Directive.

Local plans should describe how SUDS will influence the overall design of a major development or regeneration project. A planning brief or masterplan will be required, taking into account:

- the land requirement needed for SUDS when specifying housing density
- the opportunity afforded by SUDS to satisfy the open space requirement.

After consultation, the developers need to provide a drainage strategy to be submitted as an integral part of the planning application. The drainage strategy should include:

- an indication of the types of measures to be used and included in the detailed design
- evidence of subsoil porosity and suitability for use of SUDS infiltration devices
- pre- and post-development run-off calculations to determine the scale of SUDS required
- assessment of flood risk where this is deemed appropriate
- proposals for integrating the drainage system into the landscape or required public open space
- demonstration of good ecological practice including habitat enhancement
- estimates of land use for different drainage options based on initial calculations carried out to size any significant drainage structures.

When submitting a full or reserved matters application, a detailed drainage design is required. The objective should be that, wherever feasible, the developer incorporates SUDS into the full and reserved matters application. This involves:

- Agreeing with the planning authority and the other regulating authorities the type of information required in the planning application.
- The developer and the drainage designer consulting the regulatory authorities agreeing on the appropriate criteria.
- The designer planning the drainage system according to the procedures of the relevant SUDS design manual and confirming with the regulatory authorities that the techniques or devices selected are appropriate.
- The designer, in accordance with the selected SUDS design manual, producing designs for planning, building warrant, drainage and road construction applications and complying with the requirements of prohibition notices where appropriate.

3.4 Strategy for sustainable construction – surface water management

Drainage of land is required to make it suitable for development, to protect existing and proposed development from the effects of flooding, and to manage pollution that could arise from the interaction of rainwater and development run-offs. Although guidance on surface water management has been available for some time for adoption by the construction industry, this remains an issue. The Environment Agency (SEPA in Scotland) has a duty to monitor discharge consents from construction sites to contribute to the management of risks of pollution to watercourses. The Environment Agency provides regulations and consultancy on surface water management and environmental infrastructures. Traditional drainage systems are often not designed with a prime consideration of sustainability and generally do not include sufficient control measures to manage flooding in catchment areas (to reduce any impact on water quality or water resources) or provide landscape features which could create habitats with enhanced biodiversity and green spaces. This also impacts on the amenity value for people living in and around the environment.

Another strategy has been developed by the DTI (now the Department for Business Innovation & Skills – BERR): The *Sustainable Construction Review*[47] includes management of surface water and water resources as one of the requirements for sustainable construction. The review provides a target for flood risk management; the peak run-off rates and annual volumes of run-off should be no worse than the existing conditions for the site and consistent with PPS25[11] and the *Code for Sustainable Homes Technical Guide*.[48] Some industrial organisations however, would like the run-off rate to be reduced to the pre-development (greenfield) rate or better, and that sustainable drainage rather than rainwater harvesting should be implemented. The government's target also includes implementation of SUDS, that surface water is managed on sites using the SUDS approach to drainage and to cause no adverse impacts due to surface water discharges from developments. The government strategy *Making Space for Water*[49] promotes the integrated approach to urban drainage and a joint approach to the development of surface water management plans for developments.

Further guidance is also available from:

- CIRIA guidance on SUDS: *The SUDS Manual* (C697),[6] and the *Site Handbook for Construction of SUDS* (C698)[50]
- The Highways Agency design manual *Building Better Roads: Towards Sustainable Construction*[51] for roads and bridges for the transport industry
- Pollution guidance leaflets and videos from the Environment Agency[52]
- *Code of Practice for Using Plant Protection Products*[53] for the use of approved pesticides in amenity and industrial areas.

Highway authorities are responsible for the construction, management, and maintenance of drainage infrastructures, including the authority to drain run-offs to, and via, private land or land owned by other authorities or landowners. The drainage run-offs can also be directed to watercourses not owned by the highway authorities. The highway authorities can also consent to run-offs from private properties to public highways and into sewers. Local authorities are important stakeholders for planning, drainage, and housing development consent. They are responsible for implementing SUDS to control diffuse pollution and to manage stormwater drainage.

The capacity of conventional drainage systems can be a constraint on development. All proposals for development should therefore take account of the effects of potentially increased surface water run-off. This can increase the flow downstream and so increase the risk of flooding, particularly so for greenfield sites and where the existing drainage could not cope with the extra flow; the downstream impact on brownfield development could also be significant. For brownfield development, SUDS can also contribute to more efficient management of the surface water discharges. In Scotland, SUDS are the preferred solution to drainage of surface water run-off, including run-off from roofs for all proposed development, greenfield and brownfield. SUDS are included in Part M of the *Technical Handbook for Compliance with the Building Standards (Scotland) Regulations, 2004*.[54] Surface water run-off from building is also included.

Surface water from rainstorms can pose a significant and variable burden on wastewater treatment works, leading to flooding of the sewerage systems. Assessments by the Environment Agency of the new growth points for housing developments in England highlighted that in 80% of cases there has been an increase in flood risk, lack of sewage capacity in 72%, and breaches of water quality standards in 62%. These developments have placed significant environmental constraints in the region and additional environmental infrastructure is required to cope with the growth in demand. Of particular concern is the development of houses in flood plains and flood risk areas and where water quality and water resources are stressed. For flood risk management, location and long-term planning are key issues according to the *Environment Agency Policy Brief: Environmental Infrastructure*.[55]

Planning and design for housing and environmental infrastructures must adapt to climate change, according to the Environment Agency.[55] This includes planning for the long term (a timeframe of 100 years for flood risk management), choosing locations for development, and supporting the infrastructure and services wisely by incorporating resistant and resilient design features. Local authorities need to prepare infrastructure delivery plans for large developments (3000 to 5000 homes). If flood risk management has been identified as an issue by regional or strategic flood risk assessments, local planning authorities need to produce surface water management plans. According to PPS25[11] surface water management plans should be developed as supplementary planning documents within the local development frameworks and contain policy statements on management of flood as well as local surface water management. Policies should:

- include strategic use of SUDS including clear guidance on who should be responsible for the adoption and maintenance of SUDS
- encourage source control within the curtilage of the building and manage surface water before it enters the drainage system
- protect watercourses, avoid culverting, and promote the reopening of culverted watercourses
- deliver multiple benefits such as the use of open spaces for recreation in addition to surface water drainage, attenuation, and flood storage
- include maps and information on watercourses, corridors, aquifers, boreholes, and other features
- include flood routes, flood risk areas, and flood plains
- include soil types

- include the type and locations of the SUDS infrastructure to service new development and to improve the environmental performance of drainage of existing urbanised areas.

Surface water management plans should be integrated into local future development planning policies and form part of the river basin management plan to meet the requirements of the Water Framework Directive.[3] Surface water drainage is mandated in the building regulations to control the adverse impacts of flash flooding caused by heavy rains.

3.5 Code for Sustainable Homes – surface water run-off

The aim of the Code for Sustainable Homes relating to surface water run-off, is to reduce and delay water run-off from the hard surfaces of a housing development to public sewers and watercourses, thus reducing the risk of localised flooding, pollution, and other environmental damage. On many sites, it should be possible to include holding facilities to delay the release of stormwater from the site, and statutory authorities may require this in certain sensitive areas, usually where natural watercourses are affected. The main intention is to reduce the overall surface run-off to rainwater from hard landscape surfaces and roofs within the development. In housing developments, this can be done either by specifying permeable paving for all hard surfaces in the development, or by the adoption of soakaways or other systems, including green roofs, which reduce run-off loads. Run-off from roofs to water butts does not automatically comply with the requirements, as water use is dependent on the occupier and excess water is normally discharged directly to drainage systems. The following criteria are included:

- Ensuring that run-off rates and annual volumes of run-off post development will be no greater than the previous conditions for the site.
- Where rainwater holding facilities and SUDS are used to provide attenuation of water run-off to either natural watercourses or surface water drainage systems, percentage time attenuation should be provided to meet the mandatory requirement or the following, whichever is greater:
  - 50% in low flooding risk areas
  - 75% in moderate flooding risk areas
  - 100% in significant flooding risk areas.
- Where the local authority (or other statutory body) requires greater attenuation than the percentage given above, and/or a more onerous design flooding frequency than that recommended in BS EN 752-4,[56] then the higher requirement must be met in order to achieve credits for this issue.
- Credit is given for run-off attenuation from hard surfaces and from roofs.
- The requirements for water run-off attenuation in a flood zone defined as having a high annual probability of flooding can be reduced to 75% where the site was previously occupied by buildings or hard surfaces. The easing of the requirements in such cases is to recognise the benefit of not locating the development on an undeveloped site in a zone with high annual probability of flooding, and therefore not contributing further to the flooding risk in such zones.
- When the drainage system designed to discharge all surface run-off to a properly designed soakaway system, including permeable paving or other SUDS devices for the appropriate design storms, then the credit may be awarded without the need to specify additional attenuation measures. Confirmation that the system is designed to cope with the required water run-off is required.
- If all run-off is discharged directly from the site to either the sea, or estuaries covered by a shoreline management plan, or designated wildlife areas as part of habitat management, then the credit may be awarded without the need to specify additional attenuation measures where such run-off has been approved by the appropriate statutory or management bodies.

To ensure effective operation of the water run-off attenuation measures, the facilities must discharge half their volume within 24 to 48 hours of the storm event in readiness for any subsequent storm inflow, unless advised otherwise by a statutory body. Most soakaways are designed to have discharged at least half the storage volume over 24 hours. The following are required to demonstrate compliance:

- Confirmation of appointment of an appropriate consultant to carry out the design of rainwater attenuation according to the above criteria.
- During the design stage, confirmation from an appropriate consultant that the capacity of the specified rainwater run-off attenuation device complies with the requirements.
- Post-construction manufacturers' data providing details of any rainwater run-off attenuation devices on the site where applicable.
- Confirmation of the probability of flooding given by national flood risk assessment.

3.6 Code of Practice for Sustainable Drainage Systems

An *Interim Code of Practice for Sustainable Drainage Systems*[57] has been produced by the National SUDS Working Group to facilitate the implementation of sustainable drainage in developments in England and Wales by providing model maintenance agreements and advice on their use. The specific objectives of the document are to:

- encourage the implementation of SUDS in new and existing developments
- provide basic guidance for practitioners on the implementation of SUDS in a new development
- make the adoption and allocation of maintenance for SUDS more straightforward.

The interim code of practice aims to provide a set of agreements between those public organisations with statutory or regulatory responsibilities relating to SUDS. Production of the interim code of practice is part of a wider range of actions being pursued to ensure that the potential of SUDS to offer cost-effective solutions is fully exploited. It has been developed by the National SUDS Working Group, which includes Communities and Local Government, the Department of Environment, Food and Rural Affairs, the Department for Trade and Industry, the Environment Agency, the Welsh Assembly, the Office of Water Services, Water UK, the House Builders Federation, the Local Government Association, Natural England, the Planning Officers' Society, Construction Industry Research and Information Association (CIRIA) and the County Surveyors' Society.

Membership of the SUDS Scottish Working Party includes East of Scotland Water, West of Scotland Water, North of Scotland Water Authority, CIRIA, The Scottish Office: Scottish Environment Protection Agency, the Scottish Housebuilders Association, the Convention of Scottish Local Authorities, the Society of Chief Officers of Transportation in Scotland, and the Scottish Society of Directors of Planning.

Model agreements[58, 59] have been introduced for agreement and guidance on implementation and incorporation of SUDS in new and existing developments and to establish standard approaches for allocation of responsibilities for the maintenance and operation for clients of the construction industry. Developers will need a clear definition of responsibilities to incorporate SUDS into buildings. The interim code of practice and model agreements are developed to ensure that all involved are aware of their responsibilities, costs are distributed equitably, and that activities are co-ordinated.

The main guidance documents are:

- CIRIA publications:
  - C582: *Source Control Using Constructed Pervious Surfaces*[60]
  - C625: *Model Agreements for Sustainable Water Management Systems. Model Agreements for SUDS*[58]
  - C626: *Model Agreements for Sustainable Water Management Systems. Model Agreement for Rainwater and Greywater Use Systems*[59]
  - C630: *Sustainable Water Use in Land Use Planning*[61]
  - C697: *The SUDS Manual*[6]
  - C698: *Site Handbook for the Construction of SUDS*[50]
  - RP664: *Model Agreements for Sustainable Water Management – Review of Existing Legislation*[62]
  - RP697: *SUDS updated Guidance on Technical Design and Construction*[63]
- *Interim Code of Practice for Sustainable Drainage Systems*[57]
- *Funding and Charging Arrangements for Sustainable Urban Drainage Systems.*[64]

4 Concept, devices and accessories, and benefits

4.1 Concept

Drainage of surface water is one of the key issues for land developers; it has to be resolved by designers and engineers and must be acceptable to government regulators. It must minimise the risk of flooding, reduce adverse effects of urban pollution on water catchments, and enhance environmental quality of the developments, thus providing a more pleasant amenity for people as well as increased biodiversity in the area. The growing demand for housing and commercial development as well as the increasing environmental pressure caused by climate change has increased the focus on sustainable construction and SUDS.

Traditional surface water drainage used underground piping systems to convey run-off from built-up areas as quickly as possible without consideration of the effects downstream. Conventionally, surface water would combine with wastewater (sewage) and drain through combined sewers. This method of drainage could become overloaded during rainstorm surcharge and would cause an intolerable burden on the wastewater treatment works. Separate piping systems of surface water to watercourses and wastewater to sewers can deal with quantity of water run-offs but are not able to provide the means to manage the risk of flooding and cannot control the poor quality of surface run-offs to minimise the impact on the water environment. These systems were generally not designed with the objective of sustainable development in mind and cannot contribute to the management of water resources, amenity, and landscaping potential, or enhance biodiversity.

Sustainable drainage is a concept that includes long-term environmental and social factors. It takes account of the quantity and quality of run-off, and the amenity value of surface water in the urban environment. SUDS provide an integrated approach to surface water design problems and consider quality, quantity, and amenity aspects equally in an integrated approach unlike that conventionally adopted (see the SUDS triangle Fig. 3). SUDS are more sustainable than conventional drainage systems

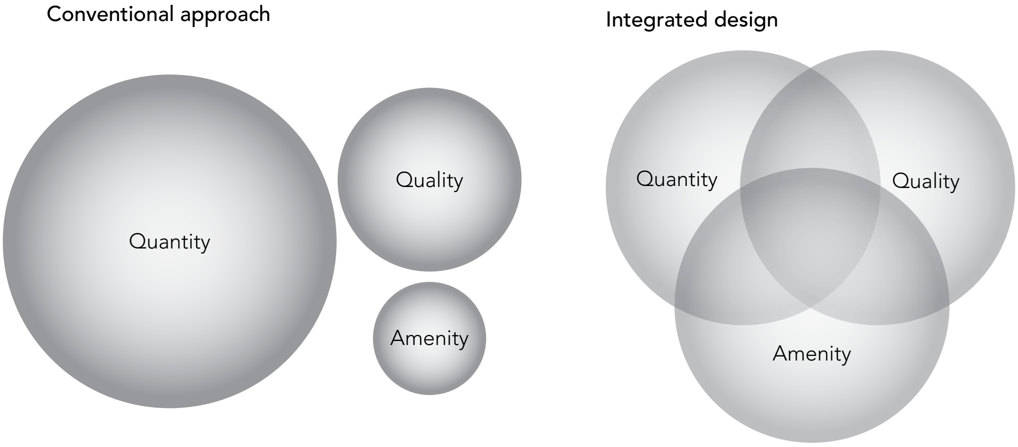


Figure 3 The SUDS triangle.

because they are designed to manage flow rates, protect or enhance the water quality and are sympathetic to the environment and the needs of the local community by controlling rainwater at source (source control), attenuating flows, and regulating discharges to greenfield run-off. It is now widely accepted that the drainage of developed areas by conventional piped systems is not sustainable. In dry periods when flows are low, these systems can often silt up, causing a problem when the next storm arrives, contributing to flooding and pollution of watercourses. Also, by diverting rainfall to piped systems, the amount of water infiltrating the ground is reduced, depleting groundwater and reducing flows in watercourses in dry weather. As a result, many urban watercourses have become lifeless and are often hidden underground in culverts.

The treatment train (Fig. 4) has been developed to give a rationale for the development of SUDS on a variety of scales, to be tailored to suit the size and the complexity of the area being drained. The full hierarchy has principally been adopted for larger developments by major developers with independent site supervision. A major site will have a range of integrated surface water drainage components. Retention ponds and wetlands are the major regional treatment facilities, whereas detention basins, treatment swales, and infiltration systems are the principal forms of site control. Source controls (eg pervious paving, green roofs, and rainwater harvesting) may or may not be encouraged within each sub-site of a development and depending on local conditions.

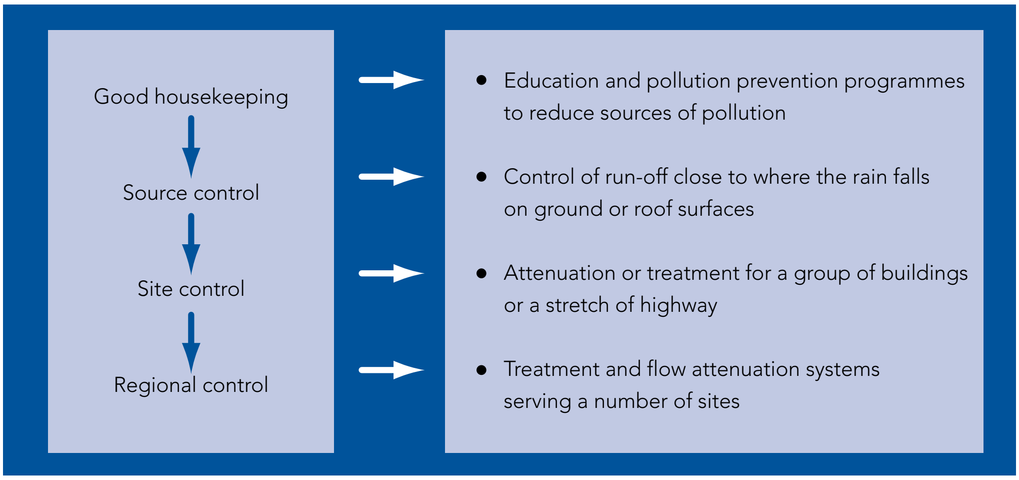


Figure 4 SUDS philosophy – the treatment train.

Many developers will not wish to follow the management hierarchy to such detail, which might not be appropriate in some cases. The design of SUDS is mainly influenced by flow attenuation, most of which is provided by site controls with regional ponds providing surface water treatment where needed. Good housekeeping, in the form of pollution prevention and good maintenance practice, is always required.

- Residential sites are the least likely to cause severe pollution, and the developer can select from the full range of SUDS, although some devices would be over elaborate for small sites. Residential sites require only the first level of treatment.
- Non-residential sites include shopping areas and their car parks, and larger housing estates that have access roads and bus stops, etc. These require the first and second levels of treatment.
- Industrial sites are where manufacturing processes are carried out and there is the potential for spillage of chemicals. This category also applies to trunk roads and to locations such as bus garages. Containment of pollutants is also needed for industrial sites.

It is not possible to apply rigid rules for the number of houses or the area of the development since the level of treatment is much more likely to depend on the potential for the production of pollution and the sensitivity of the receiving water. For example, a small housing development by the sea would require a different level of treatment from one draining to a small eutrophic water body.

4.2 Devices and accessories

The term SUDS covers a wide range of urban drainage facilities:

- end of pipe facilities eg wetlands or retention ponds
- source control systems eg pervious paving
- storm control devices eg soakaways
- site controls eg infiltration trenches and basins and swales.

The most common techniques for management of surface water are shown in Table 2, summarising the SUDS devices and accessories. There is no single correct technique specific for a site and in most cases a combination of techniques is required. Prevention is an important part of SUDS management and requires careful consideration of paving surface, eg gravel surface for a car park or for disposal of roof water onto a lawn. For a full description of the SUDS techniques, see *The SUDS Manual* (C697).[6] A schematic presentation of some SUDS devices are shown in Figures 5 to 11.

Table 2

SUDS devices and accessories

SUDS device	Description	Practical considerations
Management plan, prevention and good housekeeping	The first SUDS approach is to prevent and reduce pollution and to attenuate run-off quantities. The design management plan of a site would include the reduction of impermeable surface areas, encouraging rainwater reuse/harvesting and good housekeeping, preventing spills and leaks, storage of rainwater run-offs in water butts, and the incorporation of green roofs and brown roofs.	Requires consideration of site design and practices that occur within the site to minimise run-off and diffuse pollution, eg storage and disposal of oil, fuel and chemical; the use of herbicides and pesticides and discharges of detergent and soap water wastes. Also good housekeeping practices, keeping the surfaces free from debris (eg fallen leaves, litters or rubbish).
Green roofs and brown roofs[65]	A roof of a building that is partially or completely covered with vegetation and soil or a growing medium, planted over a waterproofing membrane. It may also include additional layers such as a root barrier and drainage and irrigation systems. Container gardens on roofs, where plants are maintained in pots, are not generally considered to be true green roofs. Rooftop ponds are another form of green roofs which are used to treat greywater. Green roofs are also referred to as eco-roofs, vegetated roofs and living roofs. Intensive green roofs have a deep growing medium, which allows the use of trees and shrubs. The term brown roof or eco-roof is often used in conservation circles to refer to the mitigation for the loss of brownfield land. Brown roofs use a substrate material, laid down on a flat roof and allowed to colonise naturally. Often, crushed bricks and recycled aggregates from the previous construction of the building are generally left to colonise naturally and seeded with annual wildflowers or local seed source. Green roofs store rainwater in the plants and growing mediums and evaporate water into the atmosphere. Green roofs reduce and delay run-off during heavy and prolonged rainfall and therefore contribute to minimise stormwater flooding. Green roofs have also been known to provide a system for harvesting rainwater and recycling greywater.[66] Rainwater harvesting involves the collection and storage of rainwater on site for watering of garden, flushing toilets and washing cars.	Green roofs can improve water quality and reduce the peak flow and the total volume discharged from a roof. Vegetated roofs provide an extra protection to waterproofing systems from Ultra-Violet light, frost, erosion and other forms of weathering. They can enhance the insulation properties and increase the lifespan of the roofs. In Germany, The German Landscape Research, Development and Construction Society (FLL) provides guidelines and standards for design, planning, construction and maintenance of green roofs. No such guidelines are available in the UK. Intensive green roofs require extra loading requirements within the supporting structure and require a complex irrigation system for maintenance. These are generally costly and require extra structural design to the building. Extensive green roofs have a thin growing medium and require minimal maintenance and irrigation although some require irrigation initially. They are generally less costly to install than intensive green roofs. The amount of water that is stored on a green roof and evaporated back is dependent on the growing medium, its depth and the type of plants used. In summer, green roofs can retain 70 to 80% of rainfall and in winter they retain between 25 to 40%.

Table 2

SUDS devices and accessories (contd.)

SUDS device	Description	Practical considerations
Pervious surfaces/paving	Permeable hard-standing surfaces that allow passage of rainwater into the underlying construction or soil or storage layer. They are effective to provide attenuation of water flow treatment. Pervious paving would ameliorate the need for surface water drains, allowing run-offs to permeate through porous pavements, such as permeable concrete surfaces, crushed stones or porous asphalts. Pollutants are removed by filtration occurring within the surfacing or sub-base material itself, or by the filtering action of the reservoir or subsoil. Some biological breakdown of organic pollutants can also occur. Permeable surfaces can be designed to fit in with a variety of environmental settings, eg hard surfaces of a car park, town centre or gravel surfaces for light traffic. They can be grasscrete or soft landscape surfaces for rural areas. Infiltration devices can be incorporated into open space areas, eg playing fields or car parks as part of a flood management scheme.	Surfaces should be regularly checked to prevent clogging and water pooling, and be regularly cleaned and maintained. Depending on the ground conditions, the water may infiltrate directly into the subsoil and be stored in an underground reservoir, eg a crushed stone layer, before slowly soaking into the ground. If infiltration is not possible, or appropriate, eg due to contaminated land, an impermeable membrane can be used with an overflow to keep the pavement free from water in all conditions.
Filter strips	Gently sloping areas of vegetated land where run-off is directed. Filter strips, usually lie between hard surface areas and a receiving stream, and can be planted with grass or shrubs. The filter strips are designed to drain water evenly from impermeable areas and to filter out silt and other particulates. The vegetation is required to trap/remove pollutants. They work by filtering out pollutants in the surface run-offs and attenuate water flows.	The vegetation will need cultivation and care. The grass will need to be mowed and worn and bared areas will need to be replanted with seeds.
Swales	Swales are shallow vegetated open channels (usually grassed) that convey run-offs from surface to provide source control by infiltration and sometimes to storage and to drain discharge. Swales receive rainwater where it falls or via run-offs over the edge and sides or from kerbside offlets. Swales work by attenuating and slowing down flow to allow sedimentation and infiltration of pollutants. The vegetation removes the particulate matters and other pollutants. Organic pollutants could also be broken down biologically by microbes and plants. Typically, swales are incorporated in a development using the sloping green space areas and roadside margins.	As filter strips. Swales may replace roadside kerbs, saving construction and maintenance costs.

Table 2

SUDS devices and accessories (contd.)

SUDS device	Description	Practical considerations
Filter drains/ trenches	Linear drains consisting of trenches filled with permeable materials, to store and convey water and provide infiltration. Often a perforated pipe in the base of the trench is incorporated to assist drainage. Filter drains are often used by highway authorities for draining roads, and receive rainwater where it falls and from flow over the edge, from the immediate surrounding areas. Pollutants are removed by absorption, filtering and microbial decomposition in the surrounding soil. Systems can be designed to successfully incorporate both infiltration and filter systems.	Surfaces should be kept clean to prevent the voids being blocked up.
Infiltration devices: soakaways, infiltration trenches and swales	These are sub-surface structures excavated and filled with stones or other granular materials to provide a transient reservoir, to allow the infiltration of surface water run-offs to the ground. They can be trenches, basins (eg swales) or soakaways where surface water run-offs can be temporarily stored, percolate to the ground. Stormwater flows into the trench and gradually infiltrates into the ground. The stormwater could be pre-treated using a filter strip, gully or sump pit to remove excessive solids. Infiltration devices, such as soakaways, would provide considerable storage of water. The infiltration would improve the water quality of the run-offs before discharge to waters. Some biological breakdown of organic pollutants can occur.	Care should be taken to prevent the ground becoming compacted or the device becoming blocked with silt. An initial survey of the area would be needed to ensure that the ground soil and conditions are suitable to receive the quantity and quality of the surface water run-offs.
Infiltration basins: swales and ponds	Basins are temporary water features to hold back stormwater run-offs, to reduce peak flows to receiving waters. These can provide infiltration of pollutants which can be deposited and absorbed into the soil substrate and allow microbial decomposition as well as allowing water infiltration directly into the ground. Swales are usually dry during dry periods. Ponds could be permanently covered with shallow water designed to contain stormwater.	Sometimes, basins and ponds can include vegetation (eg reeds), providing further treatment of pollutants in the surface water run-offs. Swales and ponds can provide pleasant green and water features in the local development and could support ecological habitats of small animals and in some cases recreational activities (eg play areas) for children.
Bio-retention areas	Vegetated areas that are designed to collect and treat water before discharging via a pipe system or by infiltration to the ground.	Maintenance and cultivation care are necessary to ensure long term service of the vegetation (eg reed bed).

Table 2

SUDS devices and accessories (contd.)

SUDS device	Description	Practical considerations
Basins, ponds and wetlands	Basins, ponds and wetlands collect surface water run-offs from large drainage catchments via pipe network or from other SUDS upstream. Ponds and wetlands are designed to provide surface water run-off storage and allow storage of various levels of water during storms, enhancing flood-storage capacity and attenuating flow. Surface water can be conveyed via swales, filter drains or piped systems. Basins are planted with grass and are usually dry except during and after raining, they allow sedimentation of pollutants. Ponds and wetlands can be permanent water bodies, planted with aquatic species and would enhance the amenity and biodiversity, providing habitats for wildlife in the urban areas. Ponds would allow sufficient detention time for the particulates and solids to settle and not discharge to the watercourses. Pollutants can be filtered and broken down biologically. Algae and plants in the wetlands would provide a good level of nutrient removal and filtration for pollutants. Large ponds (lakes) and wetlands can provide recreational activities in the local environment.	The vegetation will need to be cared for and cultivated. The use of inlet and outlet sumps will enhance performance by trapping silt and preventing clogging of the outlet. Regular maintenance and removal of the collected sediment from the outlet sump may be needed, typically this may be about once in every seven years.
Pipes and accessories	A series of conduits and their accessories – these are normally laid underground and designed to convey surface water to a suitable location for treatment and or disposal.	Care to ensure regular maintenance to prevent blockages or to impede water flow.
Inlets	Deliver water into the drainage component, these can be from open structure or pervious surfaces or closed structure such as pipes.	Maintenance of the system to ensure it is free from blockages.
Outlets	These usually provide the control mechanism for discharging water to drainage, and may include pipes, weirs and storage structures.	Maintenance of the system to ensure it is free from blockages.
Filters and silt traps	Engineered sand filters, and in some circumstances other types of filters, designed to remove pollutants from surface water run-offs. Silt traps can be open structures such as filter strips and swales, others such as catchpits which are small in-line chambers designed to remove silt from the flow and protect drainage systems.	Wherever possible silt should be managed by the open traps to allow monitoring. Regular maintenance involving on-site inspections and removal of clogged up silt in the systems.
Flow control devices	The control of flow through a drainage system should be passive and not involved complicated devices.	Simple solutions such as orifice plates, slot weirs and sluice controls offer robust solutions to flow control and can easily be managed. Devices should be accessible and easy to maintain without risk or requiring skilled operators.

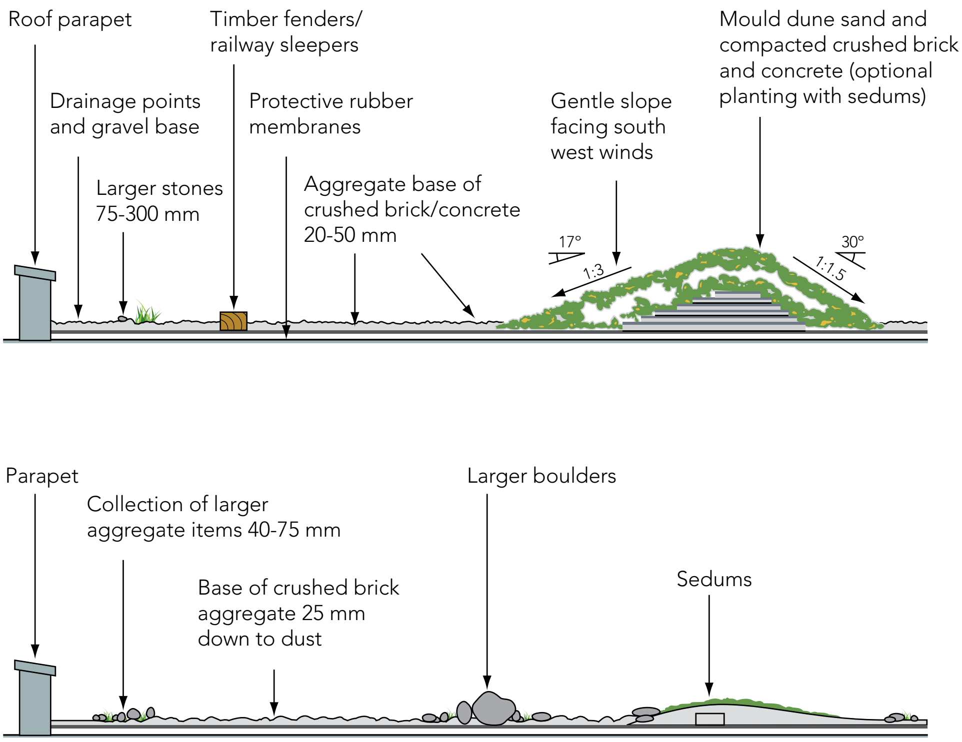


Figure 5 Cross section views of green and brown roof designs (adapted from an original illustration, courtesy of Black Redstarts).[67]

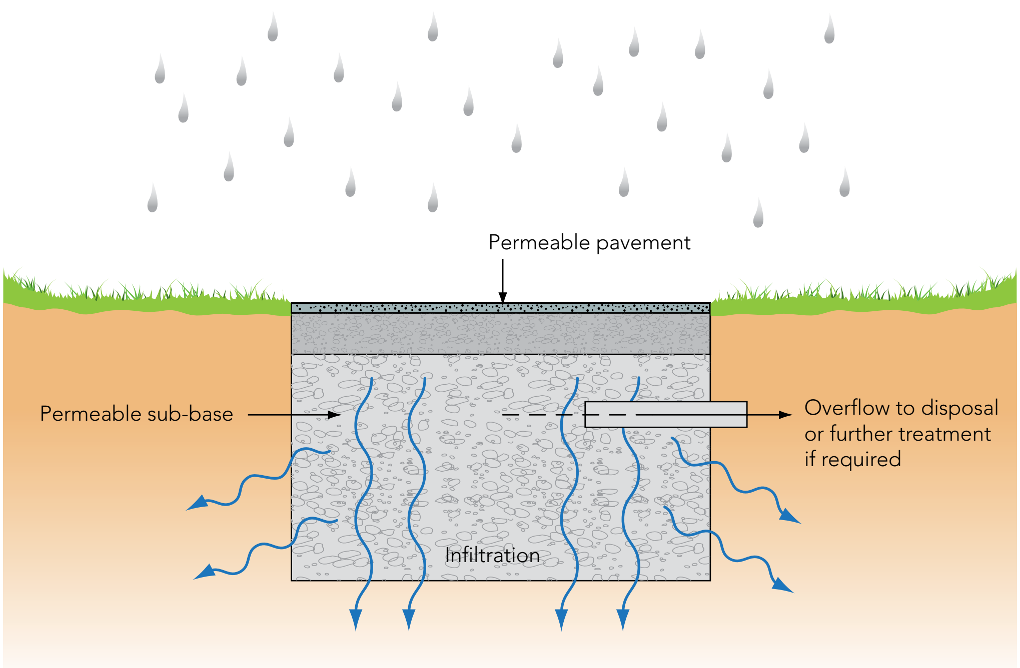


Figure 6 Cross section of a pervious paving (adapted from an original illustration, courtesy of the Environment Agency).

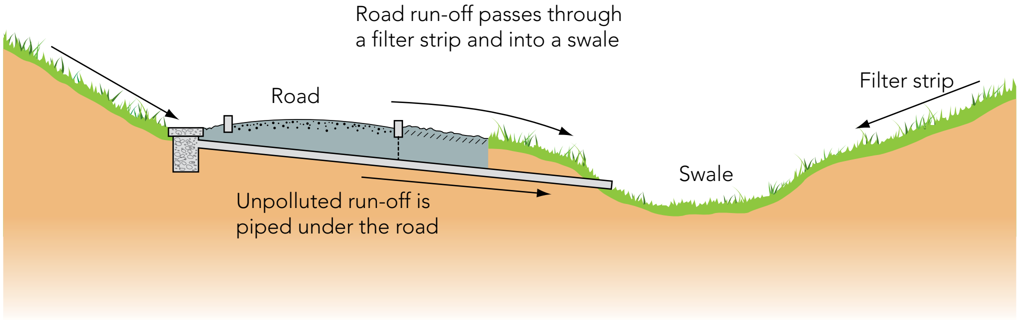


Figure 7 Cross section view of a filter strip (adapted from an original illustration, courtesy of the Environment Agency).

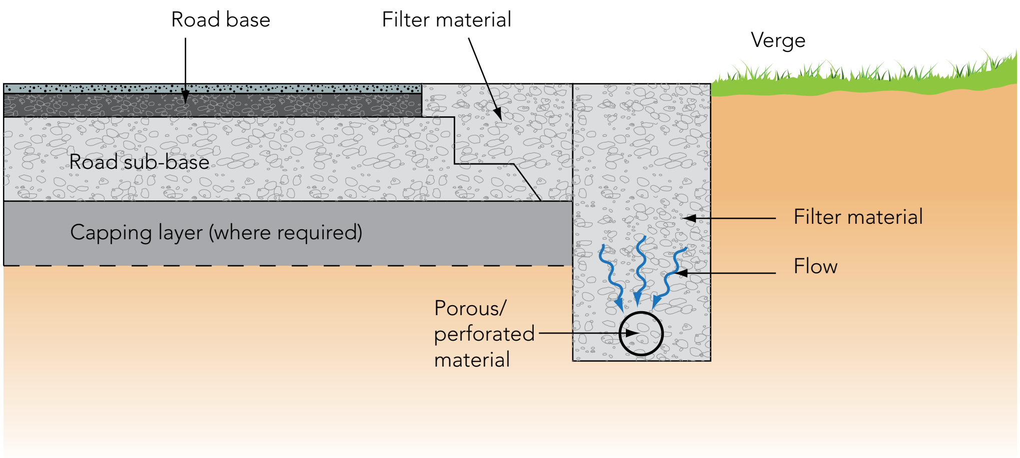


Figure 8 Cross section view of a filter drain (adapted from an original illustration, courtesy of the Environment Agency).

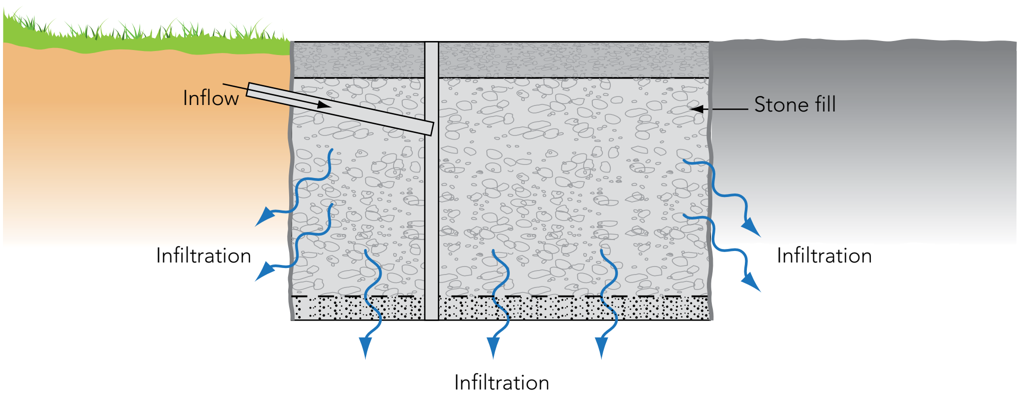


Figure 9 Cross section of an infiltration trench (adapted from an original illustration, courtesy of the Environment Agency).

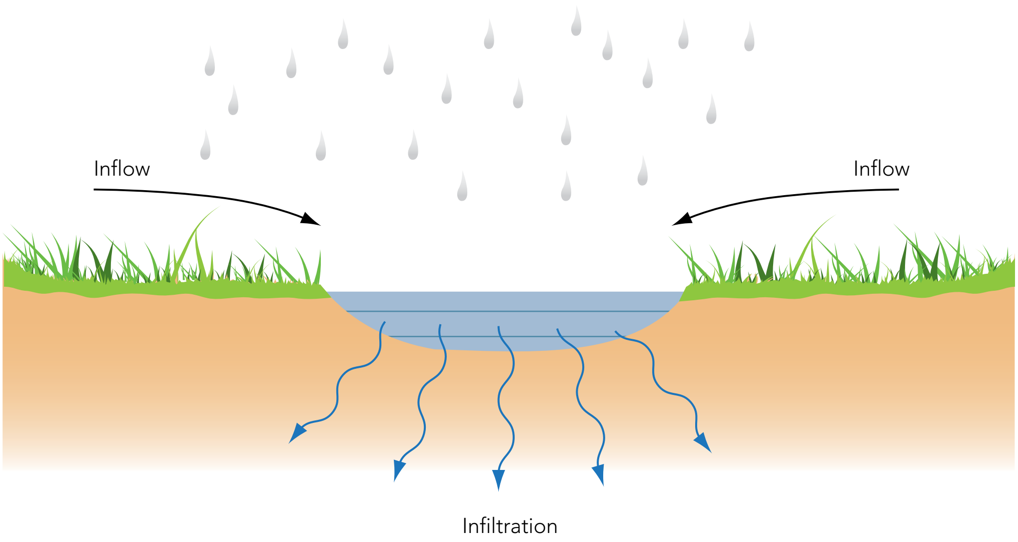


Figure 10 Cross section of an infiltration basin (adapted from an original illustration, courtesy of the Environment Agency).

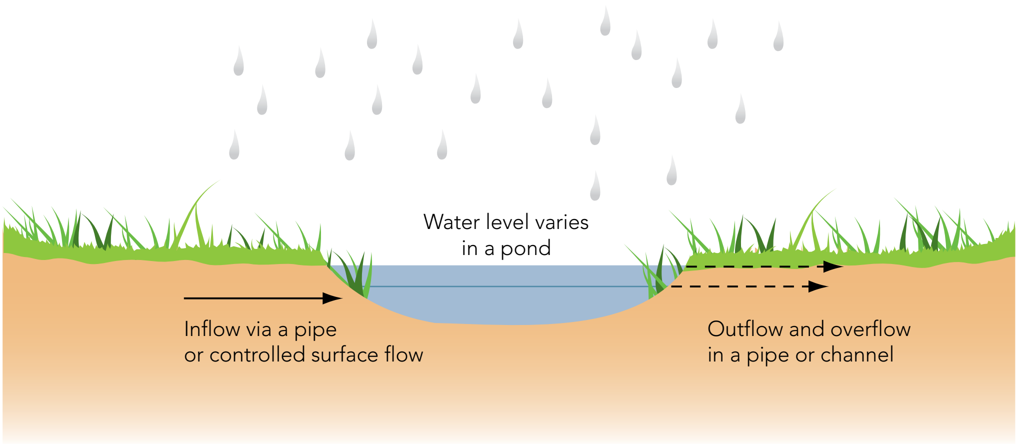


Figure 11 Cross section of a retention pond (adapted from an original illustration, courtesy of the Environment Agency).

4.3 Benefits

The benefits of SUDS are characterised by their key multifunctional facilities, addressing three important issues related to surface water drainage:

- quality of surface water run-offs
- quantity of run-offs
- amenity, including biodiversity.

Appropriately designed, constructed, and maintained, SUDS may improve the surface water management of an area and may mitigate many of the adverse effects of stormwater run-offs in urban environments and other environments. The benefits are:

- reduced peak flow discharge to watercourses or sewers, thus reducing the risk of flooding downstream
- reduced volumes and frequency of water flowing directly from developed land to watercourses or sewers to mimic natural drainage and reduce flood risk
- improved water quality by removing pollutants by filtration, sedimentation, and biodecomposition from diffuse pollution sources

- harvesting rainwater to reduce demand on potable water and abstraction of water
- improved amenity by provision of more public open green spaces and water features
- enhanced habitats for wildlife, thus improving the biodiversity value of the development
- reduced surcharges and overflowing sewers and minimising the flow of sewage pollutants to watercourses
- natural drainage of surface water, allowing recharging of groundwater so that base flow is maintained and reduced drying up of ground soil that causes problem for the environment and on building foundations.

SUDS can be incorporated into any development, even in urban areas where land space is an issue. This will need a multifunctional approach, involving stakeholders to agree design and requirements during the early stage of development. The added water features, the 'pond effect' could add premium value and desirability for a site development for housing and office accommodations overlooking a well-designed and well-maintained pond and wetland. The reduced use of underground piping systems and impermeable paving also reduces construction and maintenance costs for a development.

5 Guidance on selection techniques

5.1 Scoping studies

As discussed in the earlier sections, incorporation of SUDS is required for developments in Scotland and is encouraged by the governments in England and Wales. The national planning guidance as well as the surface water management issues of the Building Regulations (Approved Document H),[10] Building Standards (Scotland) Regulations (2004) and the *Sewers for Scotland*,[37] Code for Sustainable Homes, and the *Interim Code of Practice for SUDS*[57] have already been discussed in sections 3.3 to 3.6.

The design and planning of SUDS requires the involvement of stakeholders, and a survey of the history of the site and ground (soil types and groundwater tables) conditions will be necessary before deciding on a SUDS technique for development of the site. The assessment should also include a study of the ecological status, sediment release, and the possible impact that could be caused by flooding. The survey will also involve an environmental assessment of the ground, land use, and surface water quality based on the requirements of the Water Framework Directive to minimise the sources of pollution. The monitoring will also include analysis of any pollution of the surface water by priority substances under the Dangerous Substances Directive (76/464/EEC).[28] The development plan will need to take water-related issues into account when identifying land for development and redevelopment in accordance with PPS12[39] and PPS25[11] (PAN61[13] in Scotland and TAN15[12] in Wales) in relation to flooding and SUDS.

At the local level, the multifunctional benefits of SUDS will require involvement of the developers, the design and construction engineers, environmental consultants, and local authorities to develop a masterplan for the site development, and to design and select the locations of SUDS devices. As discussed in sections 3.3 and 3.4, the Environment Agency (SEPA in Scotland) and the sewerage undertakers who provide the regulations and environmental infrastructures for SUDS should be the principal consultees and if drainage to roads is involved then the Highway Agency should also be included in the design and planning processes.

A scoping study should be undertaken to look at the feasibility of incorporating SUDS in a site development; this would contribute to the surface water quality management as required by the Water Framework Directive, and the planning consent issues required by the local planning authorities. The scoping study should focus on the following:

- environmental assessment of the areas, their geological conditions (soil permeability and hydrology characteristics of the site), surface water run-off characteristics and wastewater drainage, ecological status, and sediment releases
- assessment of the impact of the land development (urban, domestic, commercial, industrial, mining, power generation, forestry, and agricultural), the density of the development, the community and services required for that development, including the impact caused by waste discharges, contamination, landfill, and abstraction on local water catchments and river water quality
- assessment of the impact caused by climate change and flooding scenarios
- assessment of the cost and benefits (flood management, diffuse pollution, amenity, and biodiversity)
- appraisal of the implementation issues and opportunities for a set of SUDS mechanisms identified, suitable for the site development.

The assessment could also involve a study of environmental issues such as contaminated land, pollution load and chemical discharges, surface water discharges, water supply and utilisation, drainage and water treatment, industries, product manufacture, urban and built environments, resource efficiency and waste management, farming, land development, and communities that could have an important contribution to the local river water catchment quality. The drainage area should be down slope of any groundwater sources. It is important that the subsoil has percolation characteristics suitable for drainage. Examples of poorly drained or saturated soils are sandy clay, silty clay, and clay. Examples of subsoils with good percolation characteristics are sand, gravel, chalk, sandy, and clay loam. Reed bed treatment or other constructed wetland treatment systems can also be used to provide secondary or tertiary treatment, see BRE Good Building Guide 42 *Reed Beds: Part 1 – Application and Specification; Part 2 – Design. Construction and Maintenance* (GBG42).[68]

5.2 Design objectives

The design criteria when selecting SUDS for incorporation in a site development should include all three elements of the SUDS principles: quality, quantity, and amenity (including biodiversity). Selection and design of SUDS devices and techniques will depend on several processes, including planning issues, water quality, water resources, architectural and landscape requirements as well as ecology and amenity issues, and the need to meet the requirements for that particular development (eg housing, schools, hospitals, and commercial parks, etc). A scoping study will be needed to decide on the SUDS techniques for the development.

The selection tool should be based on the surface water management train principles (described in section 4.1) and should include the following objectives:

- Drainage techniques should be used in series to provide a multifunctional approach to meet the design criteria of attenuating flow, reducing risk of flooding, improving water quality by filtration and absorption, preventing drying of soil, and recharging of groundwater.
- Surface water should be allowed to flow naturally to the watercourses by infiltration and to allow the natural functioning of the hydrological cycles. Artificial treatment of water should not be needed if the water is not contaminated.
- Wherever possible, the design and planning should give preference to the prevention and source control at the top of the management train rather than regional control techniques downstream.

- Selection may involve several factors and SUDS devices (techniques) to provide drainage and treatment solutions for that site development.
- Minimise the use of impermeable surfaces in the development, except where needed. There should be a maintenance plan and all surfaces should be kept clean and all SUDS devices cultivated where needed.
- The design should be sympathetic to the local needs and environment; this will require consultation of all stakeholder groups, eg play areas for children or car parking for residents or for hospital visitors. The design should not just be a technical consideration but also take into account the value of the development; in some cases, water features (eg a pond or a swale) included to enhance environmental value could also increase the desirability of the development and the property value of the housing.
- Source control is preferred, as this would provide a natural drainage of surface water, prevent problems arising rather than having to mitigate later, and prevent mixing of the pollutants passing downstream. Source control would also provide a clear management structure to the people/organisation responsible for the run-offs.

5.3 Land use, locations, and adoption

As discussed in section 3.3, PPS25[11] encourages local authorities to include favourable strategic policies within their regional spatial-planning strategies (RSS) to influence developers, to incorporate SUDS as one of the conditions for the site development. The provision of SUDS should be included in the development briefs or master plans which integrate SUDS in the overall layout of the development. The developers should engage the relevant stakeholders and, most importantly, the local planning authorities and the principal consultees (Environment Agency, sewerage undertakers, and highway authorities) to consider SUDS over a wide area and across a number of sites, eg the location for an attenuation pond or a swale in a playing field or community amenity area. The selection of the types and locations of SUDS should also include consideration of the run-off characteristics of the development, the local and the regional areas, and whether the areas are prone to flooding where a series of SUDS features, retention pond or wetland, with alternative routing of flood water could be needed to cope with heavy rainfall.

The density and layout of the development could affect the surface water run-off characteristics, and these are important factors to determine the scale and types of SUDS to be included, and these could have an impact on land use. At the planning stage, the sizing and siting of SUDS should be part of the feasibility study. Land use is part of the RSS that controls the development of land in public space. Land use has an important social, economic, and environmental impact on a development and on the subsequent developed housing community. Planning Policy Statement 1 *Delivering Sustainable Development* (PPS1)[69] identifies sustainable development as the core principle underpinning planning. Planning permission is needed for all development as required by the Town and Planning Act 1990.[26] Guidance on the adoption, responsibility, and funding for maintenance of SUDS has been provided by C625.[58] There are a number of issues to be considered for local authorities to adopt SUDS features:

- The use of open space for nature conservation, recreational activities and for improving the aesthetic value of the housing development should not be in conflict with the effectiveness of SUDS for management of surface water drainage.
- Health and safety issues relating to public hygiene and safety of people living and working in the areas.
- Long-term responsibility and maintenance of SUDS.

Land use and adoption are important issues for the developers, these are summarised in Table 3.

Table 3

SUDS devices and level of space requirement and responsibility				
SUDS device		Space	Adoption	Comment
Above ground	Green roofs	L	✓	The adoption of green roofs would be by the owner-occupier of the properties.
	Pervious surfaces	L	✓	Public pavements and car parks would be adopted by local authorities and roads by highway authorities. Driveway of private properties would be by the property owners.
	Filter strips	L/M	✓	Ownership by the local authority as determined by the Town and Planning Act 1990. Highway authority would adopt if part of the highway drainage system.
	Bio-retention areas	L/M	✓	As filter strips.
	Swales	M	✓	As filter strips. Also swales could be considered for adoption by the sewerage undertaker if it is connected to a proper 'outfall'.
	Basins, ponds, and wetlands	M/H	✓	As swales.
Below ground	Filter drains and trenches	L	✓	As swales.
	Soakaways	L	✓	As swales.
	Infiltration trenches	L	✓	As swales.
	Pipes	L	✓	As swales, for adoption by the sewerage undertaker, requirements of *Sewers for Adoption*, 2006[70] must be satisfied.

L, M, H (low, medium and high) space requirement
✓ adoption of SUDS by authorities (property owners, local authority, highway authority and sewerage undertaker).

The adoption authorities (eg property owners, local authorities, highway authorities, and sewer undertakers) will require independent assurance that SUDS have been constructed according to good design and practice as advised by *The SUDS Manual* (C697)[6] and that the conditions for handover are acceptable by inspection to the responsible authorities. The developer will need to provide a maintenance plan, including remedial work (eg dredging and cleaning) during the development phase any required in the future, and advice regarding any accumulation of materials (eg silt) that will need periodic clearing for the maintenance of the SUDS.

5.4 Hydrology, ground, and geotechnical considerations

This section briefly considers hydrology (water delivery), hydrogeology (water flow within the ground), and geotechnics (the potential impact of water disposal on the behaviour of the ground).

The site hydrology, geohydrology, and ground conditions will have a significant influence on the applicability of a site for a SUDS scheme and selection of the various SUDS options.

When planning a development at any scale it is important to start by considering:

- What is the natural situation?
- Where will the water go?
- What possible hazards are there?

These can be related to hydrology, hydrogeology, and geotechnics.

The rainfall landing on a site can be transported by three routes (Figs 1 and 12):

- evaporation back to the atmosphere
- run-off over the surface
- infiltration into the ground.

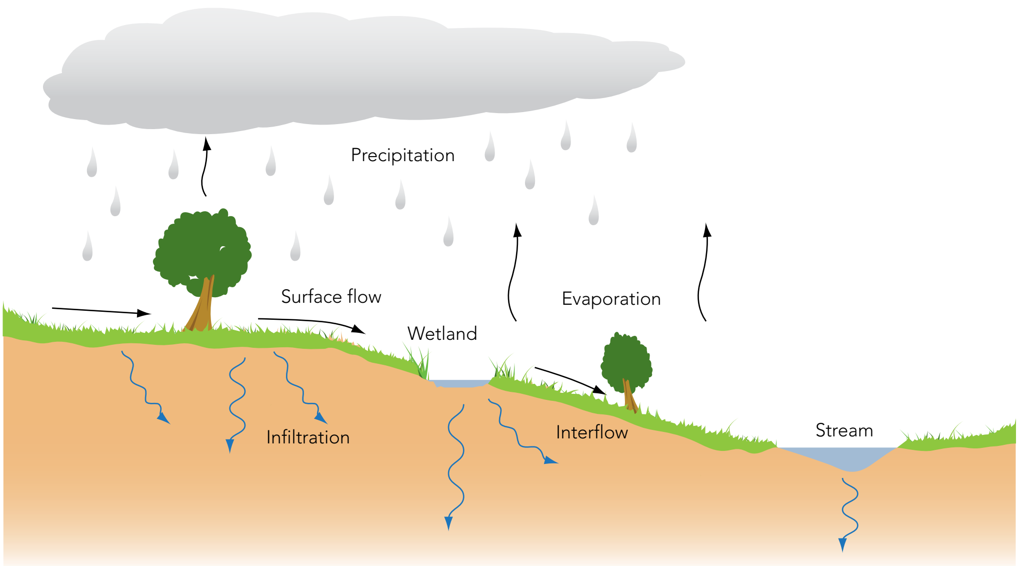
The relative proportions carried by each of these routes will depend on a number of conditions such as:

- weather – temperatures
- amount of rainfall – the storm event
- the site conditions, including relative percentages of natural vegetation, impermeable surfacing, infiltration opportunities, ground slopes, etc
- soil/ground types.

The topography of the site will determine the likely direction and concentration of run-off. The surrounding developments may impact on the hydrogeology of a particular site.

At an early stage it is important to visit the site and undertake a walk-over survey or review (*Site Investigation for Low-rise Building: The Walk-over Survey* BRE Digest 348).[71] A visit of this type is always undertaken as part of a geotechnical investigation of any site of size for foundation design, but in this case the idea is to gather additional information for potential drainage and SUDS schemes. The general topography of the site should be recorded along with evidence of previous use and all relevant information about features relating to groundwater and drainage (ditches, ponding, evidence of existing drainage systems, vegetation type – reeds might indicate poor drainage). Information from any trial pits about soil types, groundwater, etc, will aid the planning process for further drainage-related investigations. Information should also be available from a desk study (*Site Investigation for Low-Rise Building: Desk Studies* BRE Digest 318)[72] on likely ground types and previous use; this can all feed into the planning process.

The amount of impermeable surfacing will determine the volumes of direct run-off, and minimising these areas will reduce the required capacity of the various components of the SUDS. It is generally the changes/increases in impermeable areas that have the greatest impact on the relative percentages of water removed by evaporation, run-off, and infiltration. It is the changes to run-off that most affect the required capacities of the SUDS elements, be it infiltration or attenuation. In general, in all but the smallest of developments, it will not be possible to solve the situation by infiltration alone and some storage/attenuation will be required (this could simply be the storage capacity of a soakaway for instance).



The hydrological cycle is a complex system of water flows

Figure 12 The hydrological cycle.

In the *Code for Sustainable Homes Technical Guide*[48] (see section 3.5) assessment methodologies, it is the change to infiltration, or ideally lack of, that is assessed. For the development of a greenfield site, then, maintaining the status quo in terms of run-off is the most desirable target and, at worst, minimising additional run-off by the development (Fig. 13). However, in the case of redevelopment or brownfield development, it may be possible to improve the situation with regards to stormwater run-off by increasing infiltration or attenuation.

Once rainfall is on an impermeable surface rather than natural ground/vegetation there will be the potential for contamination of the water in various forms. If this water is directed to infiltration devices and/or retention devices, then the potential for contamination of the ground and groundwater is introduced. As discussed in section 3 the requirements for contamination control and the effects on hydrogeology need to be considered.

In terms of SUDS control and design, infiltration from any SUDS device will be more concentrated than in the greenfield situation. In the case of a naturally vegetated area, rainfall will infiltrate the ground with little run-off, even in steeply sloping terrain, except possibly in the most severe storms. Vegetation can hold rainfall and allow both evaporation and infiltration to take place, even when the ground beneath is clay. If the vegetation is stripped from a sandy soil, it is likely that the rainfall will still infiltrate; on a clay soil water will probably immediately collect on the surface and, if the ground is sloping, run off. It can be seen that the ground type and topography are very important when considering infiltration systems. Large volumes of water can be introduced in concentrated locations, and ground that absorbs rainfall under natural conditions may be totally unsuitable when presented with large concentrated volumes. With all SUDS devices it is important that they perform in their required/expected way. Infiltration devices must allow water to permeate the ground and storage or attenuation devices must hold water and then allow controlled release either into the ground or to a watercourse or drain. The system may also be required to attenuate water flow to allow filtration of pollutants eg reed beds in swales, natural filtration by the soil, or even base gravel layers beneath permeable pavements. Therefore, for the systems to work, due consideration must be given to the ground in terms of its properties (geotechnical) and groundwater (hydrogeology). The ideal is to mimic the greenfield situation.

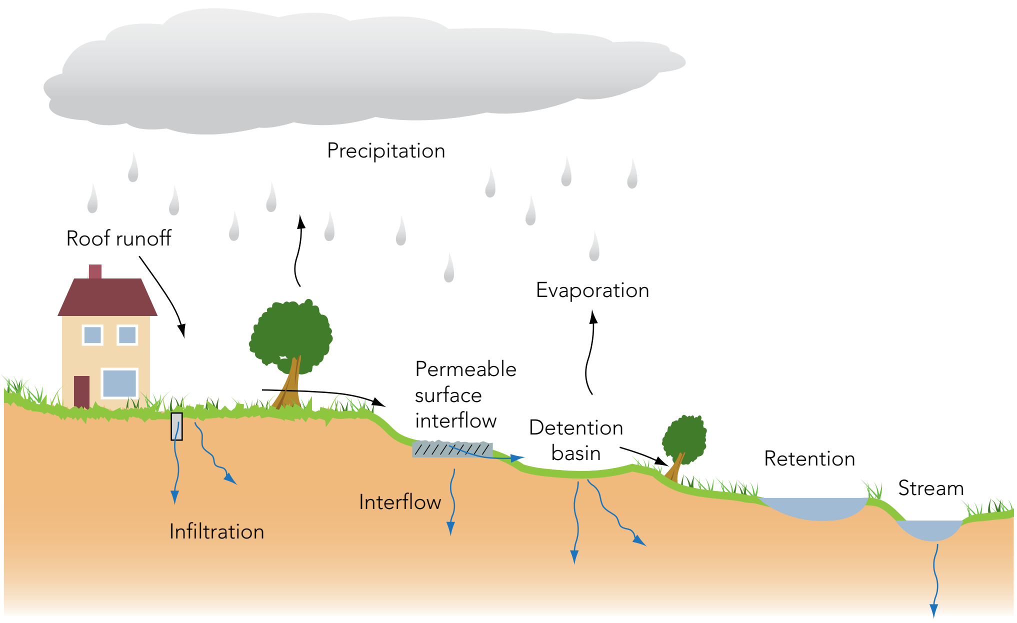


Figure 13 SUDS techniques.

For surface attenuation systems the ground required should have a low permeability (water infiltrates slowly), so that the water is held for a period before evaporating naturally, slowly infiltrating leaving pollutants behind, or flowing into watercourses at a controlled discharge rate.

In terms of hydrogeology the designer must ensure that the water can enter the ground but that there is no likelihood of polluting the groundwater (section 3.1). All systems that are expected to infiltrate must be above the groundwater table; if they are not, then they will contain standing water at some time and thereby limit the device's performance. However, for ponds the device can be within the groundwater table (as a natural pond would be) or if not then it will have to be lined to ensure containment of some water or within a saturated clayey soil.

With infiltration systems the primary geotechnical property is the ground's permeability: the rate at which water can flow into and through the ground. The ground has to accept water at a rate so that the system will not overflow and can also continue to accept water within a given timescale. For an infiltration system two main issues must be considered: the ground must be permeable and the device must be above the water table, otherwise flow will be restricted.

Water entering an infiltration system is temporarily stored. Eventually it soaks through the infiltration surface and percolates through the soil, and flows sideways and downwards through the partially saturated zone in the ground. Around a working infiltration system, a 'bulb' of saturation develops and the water flows through the soil under the influence of the hydraulic pressure gradient, moving generally outward and downward. As water seeps away from the infiltration surface, the flow area expands outwards and saturated conditions can no longer be maintained. The water continues to percolate through the soil as unsaturated flow (Fig. 14).

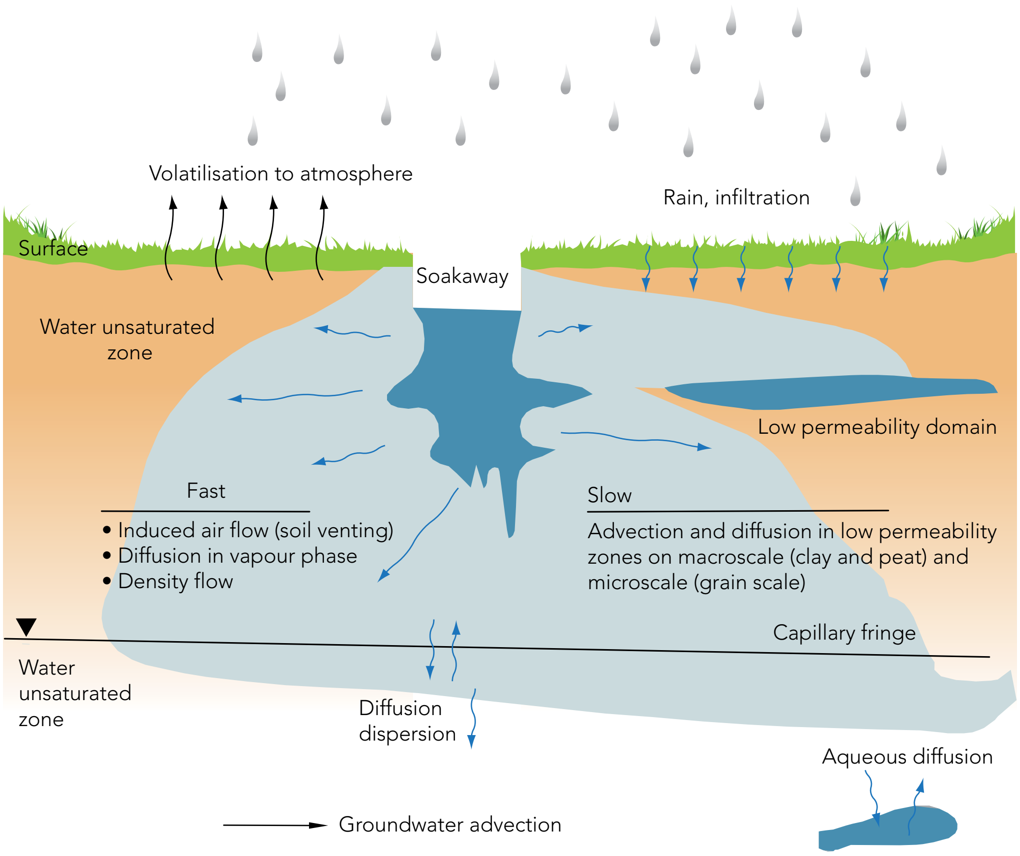


Figure 14 Water infiltrating into the ground.

Once the infiltration system is empty, the bulb of saturation will dissipate and the soil moisture will return towards ambient conditions.

When designing infiltration devices the extent of the 'wetted' zone around the device must be considered for both its impact on surrounding structures and the ground performance. This is the case when several devices are to be built near each other; their zones of influence must not overlap. Most design procedures cannot allow for this situation.

For all infiltration systems an assessment of the ground's ability to take water and at what rate should be verified by an infiltration test (see section 6). In most situations it is unlikely that clay soils, competent rocks, and some silts will be suitable for infiltration systems; the more suitable being the more porous materials such as sands, gravels, fractured rocks, and soil mixtures. However, the ground can be very variable and this is why it is so important to verify the local situation with infiltration tests. The size and frequency/spacing of tests is discussed in section 6.

It should not be forgotten that any infiltration device may attract water flow into it from the surrounding soil. It acts as a drain as water permeates through the soil from the ground surface. This will of course only happen when the water level in the infiltration device is low. The water flow into the device can cause the migration of finer particles from the ground into it, which can have the effect of both weakening the surrounding soils, resulting in collapse around the device, and clogging of the voids within the granular material of the soakaway, which can reduce its effectiveness for storage. For these reasons all infiltration devices should have a geotextile barrier (a fabric) at the interface between the ground and the device. This acts as filter to the movement of soil particles into and out of it. Any fines actually entering the system (either from the ground or carried in by the run-off) will tend to collect at the base of the device and will reduce the ability of infiltration to take place via the base. This will be discussed further in section 6 when the design is considered.

The above discussions have considered the ground in terms of suitability for SUDS; however, due consideration must also be given to the potential impact of SUDS devices, particularly the effect of infiltration, on the ground and its behaviour. An infiltration system will, in general, direct the inflow of water in a more concentrated way than in the greenfield situation, and therefore consideration must be given to the likely impact this might have of the surrounding ground.

As mentioned earlier, data relating to the potential geotechnical issues for the site should be gathered at an early stage in the design process. The available data should give information on:

- the history of the site
- information on groundwater levels
- the way in which the ground might react to water entry
- the location of adjacent foundations, slopes, and services, including their robustness to movement
- any obstructions to natural water movement in the ground caused by local geology or nearby structures
- local experience, both bad and good.

Examples of potential impact are:

- Locating infiltration systems on or at the top of sloping ground may result in:
    - creating springs in the slope if the water entering finds it easier to flow laterally rather than vertically, resulting in localised flooding lower down the slope
    - causing slope instability by introducing water at critical levels within the slope.

In these situations, geotechnical guidance should be sought:

- Locating infiltration systems too close to structures can result in softening or weakening of the foundation soils, resulting in the potential for foundation movements and building distress. General guidance is to locate soakaways 5 m (*Soakaway Design* BRE Digest 365[73]) or 6 m (*Infiltration Drainage – Manual of Good Practice* C156)[74] away from foundations, but this should be taken as a minimum and local ground conditions must always be considered.
- Infiltration systems installed in fill or non-natural ground should be avoided unless geotechnical guidance is sought. In non-engineered fills, ingress of water can result in collapse compression of the ground with resultant effects on foundations and services.
- As with fills above, some natural soils can have a structure that when wetted can weaken and collapse. Soils of this type include residual soils and loose sands. If in doubt then geotechnical advice must be sought. In ground such as chalk large volumes of water can cause softening or dissolving of the material with the potential for collapse and, as above, adverse impact on foundations and services as well as landscaping.
- Infiltration systems should not cause preferential drainage paths or water flow that can cause erosion of the surrounding soils. This can lead to weakening of the soil structure and potential collapse.
- In general, highly swelling/shrinkable soils (those that give rise to subsidence and heave problems with foundations) are unsuitable for infiltration systems, but there may be situations where all the indicators show that infiltration might be an option. Great care must be taken in these situations, as introducing water once construction has taken place could cause significant movement of structures and foundations.

It should be evident from the above examples that geotechnical advice should always be sought when planning infiltration/SUDS, as their impact can be significant on the surrounding ground and structures.

5.5 Construction

The purpose of SUDS is to mimic natural drainage from an undeveloped situation where rainfall soaks into the ground and saturates soil and vegetation before significant run-off occurs. The systems are designed to manage the environmental risks resulting from urban run-off and to contribute wherever possible to enhancing the environment. SUDS elements are generally small scale and relatively shallow and will require simple civil engineering construction and landscaping, such as excavation, filling, grading, top-soiling, seeding, and planting. Guidance for these operations can be found in the *Civil Engineering Specification for the Water Industry*[75] and *Site Handbook for the Construction of SUDS* (C698).[50]

The performance and operation of SUDS depend largely on the planning and implementation of the specific design requirements during the construction phase. The construction contractor will need to pay particular attention to requirements that are not normally included in conventional construction practices. SUDS require compatibility with the environment and specific plants, eg reeds are important for water treatment and environmental enhancement. The use of inappropriate plants could inadvertently affect functioning of the SUDS device and not meeting the purpose of the SUDS. Protecting the systems from construction run-off and build up of particulates, dead leaves, and organic matters mixed in soil must also be considered. The landscape needs to be integrated with the construction to enhance the performance of SUDS. The following must be considered during the construction of SUDS:

- Planning and phasing of construction to ensure that the performance of the facility is not compromised by over-compaction or clogging with construction debris.

- Conservation planning taking account of programming and erosion, sediment, and pollution control measures together with the need for method statements and inspections by the designer.
- Erosion will reduce the effectiveness of SUDS and cause a build-up of silt load, which can cause problem to run-offs and drainage downstream.
- Sediment entrapment should be included to reduce sediment discharge to the effluent flow and receiving waters.

The planning of temporary drainage during the construction phase is important to avoid polluting the surface water and to reduce the build-up of silt. Run-off from the construction site must not be allowed to enter SUDS unless it is allowed for in the design. Construction run-off is often laden with silt, which can clog up infiltration systems, retention ponds, and basins, and pollute the subsequent receiving waters. Conventionally, drainage is an early part of the construction. For SUDS, the early earthworks will include making the formwork for SUDS but the final construction of SUDS should be undertaken near the end of the site development; this is to avoid the build-up of silt.

The construction of inlets should take account of the design details and spread the flows and avoid scouring of soil or other SUDS surface materials. Outlets will tend to be smaller than inlets to encourage water to be attenuated within the drainage systems. Grass filter strips and swales should be lower than the impermeable surfaces that they drain from. There should be careful levelling and grading of earthwork to ensure water flow through the systems without ponding, resulting in unattractive mudding areas; careful planting of vegetation can alleviate this problem. Planting erosion control features should be in place before run-off is allowed to flow through the SUDS devices.

If pervious surfaces are included in the development, construction of pavements and car parks should be scheduled at the end of the construction programme to avoid clogging of the permeable surfaces. This practice may be a deviation from the conventional operation where car parking and other footpaths and driveways are constructed or partially constructed during the early stage of development to allow access, delivery, and storage of materials on site. The storage or preparation of soil, concreting materials, and mortar should not be undertaken on permeable surfaces or pervious pavements or in filter drain areas.

The construction programme should include inspection by the SUDS designer to agree the acceptability of the construction processes and for a review of the performance of SUDS and to allow for readjustment to mitigate problems that might arise during construction; a plan for future maintenance of the SUDS devices after development for adoption by the responsible authority should also be developed. The construction plan should identify and specify protection areas (eg buffer zones, filter stripes, and trees), establish construction access areas, routes, equipment parking zones, and stabilising vegetation and tree roots in the boundary areas. Principal basins should be installed after construction access is completed and traps and barriers set up during grading. Control measures should be installed to prevent sediment run-off to build up and stabilise stream banks, storm drains, and channels. Prevention control includes diversions, silt fences, and ditches. Landscaping is the final construction operation of SUDS construction and site development.

5.6 Health and safety considerations

Well-designed and integrated SUDS can alleviate some of the safety risks that are associated with conventional drainage systems. Advantages include:

- No need for manhole covers and road drains, which sometimes cause accidents particularly to cyclists, motorcyclists, and pedestrians.
- Pervious surfaces reduce the risk of local flooding or puddle formation, which could lead to accidents as a result of the wet and excess water on surfaces.

The Occupiers' Liability Act 1984[76] requires SUDS owners to have a duty of care to people visiting and living in the environment and to ensure that the SUDS devices incorporated are reasonably safe for the community to live and operate in. The possible risks to safety of people visiting SUDS or children playing in SUDS ponds, wetlands, or basins after heavy rain are:

- drowning due to open access and thin ice
- health risks due to the proliferation of blue green algae, mosquitoes, flies, and pathogens in the SUDS.

The following facts sheets produced by the Royal Society for the Prevention of Accidents[77] should be made available to those near SUDS schemes by SUDS' owners:

- water safety
- ice safety
- children swimming
- pond dipping
- pond and garden water safety
- water safety for children and young people.

The pond and wetland areas could be made safe by planting barriers and erecting notices on low-level fencing. Planting of brush borders or the use of shallow planted margins discourages access. Risks can be minimised by regular community engagement, information, and careful design.

Ponds can be designed with shallow side slopes and shelving edges, and strategically planted shrubs and/or other suitable vegetation to reduce safety risk. Swales can be designed with a side slope of less than 1:3 (generally shallow) to pose any risk to drivers alongside the roads.

Mosquitoes can be deterred from breeding by moving water in ponds and wetlands with a residence time of less than a few days; the water should be drained quickly and should not be stagnant. In ponds and wetlands, emergent plants that have minimum submerged growth can reduce the space for mosquito larvae to grow and develop.[78] Mosquito larvae favour growth in shallow, anaerobic water. Some water weeds oxygenate water, creating poor breeding conditions for mosquitoes. These water weeds will also compete with algae for nutrients and reduce the growth of algae (Fig. 15). Some water surface plants, eg water lilies, can reduce algal growth by reducing the space for available sunlight for algae to proliferate.

Figure 15 An example of a pond in the residential area of Caldecotte, Milton Keynes.

6 Stormwater and soakaway design

All SUDS designs require a prediction of likely run-off from the catchment they are serving. This run-off will be a function of the type of surface the rain is falling on, eg vegetated, hardstand, roofs, greenroofs, or ground slope; each will have a different percentage of the rain falling on it being delivered as run-off to the SUDS. It is also a function of where in the country the site is located, as the duration and intensity of storms vary around the country. In one part of the country short-duration, high-intensity storms may be more critical; elsewhere a longer duration less intense event may be most critical. The calculation of this run-off will also be related to the relative percentages of each type of surface and varying these percentages forms a major part of SUDS design. Many methods are available to calculate/estimate the catchment run-off, the natural attenuations likely to occur, and the delivery rate of the run-off to various parts of the catchment. Normally these calculations are done at the much larger scale for river flooding. This should not be undertaken by the lay person; further information can be found in *Sustainable Drainage Systems – Hydraulic, Structural and Water Quality Advice* (C609)[8] and *Design for Exceedance in Urban Drainage – Good Practice* (C635),[79] which review the options available.

However, the design of soakaways is often required, even for small developments. For this reason some procedures for their design are given in this section.

Soakaways are probably the most common infiltration system used in general developments for stormwater run-off when connection to main drainage is not possible or is to be avoided. Soakaways have been used within urban, fully sewered areas to limit the impact on discharge of new upstream building works and to avoid costs of sewer upgrading outside a development. Soakaways are increasingly seen as an important part of SUDS schemes as a means of stormwater control and disposal.

As discussed in section 4.5, ground conditions must be such that infiltration occurs at suitable rates; soakaways must not have the potential to pollute the groundwater. In suitable ground they can be used for any application, from small single storey extensions through complete buildings to estates, although in this last case they should be part of a full SUDS scheme. They can take roof and hardstand stormwater or complete road drainage; they can be in the form of traditional pits or rings, or as shallow linear trenches; they can be isolated or linked but in all cases they need to be designed properly in order to perform effectively.

Soakaways for areas less than 100 m^2 have traditionally been built as square or circular pits, either filled with rubble or lined with dry jointed brickwork or precast perforated concrete ring units surrounded by suitable granular backfill (Fig. 16). BS 8301 *Code of Practice for Building Drainage*[80] and DG365 *Soakaway Design*[73] suggest that soakaways may take the form of trenches that follow convenient ground contours: compared with square or circular shapes, they have larger internal surface areas for infiltration of stormwater for a given stored volume. The designer must consider the merits of the more compact square or circular forms against the better rate of discharge from the trench in the particular conditions of soil type, available space, site layout, and topography.

For drained areas over 100 m^2, soakaways can be precast ring or trench type and not substantially deeper than soakaways that serve small areas: 3 to 4 m is adequate if ground conditions allow. Although limiting the depth does mean the length must be increased, trench soakaways are cheaper to dig using readily available excavating equipment.

Trench and pit soakaways can be linked if this produces a more effective design.

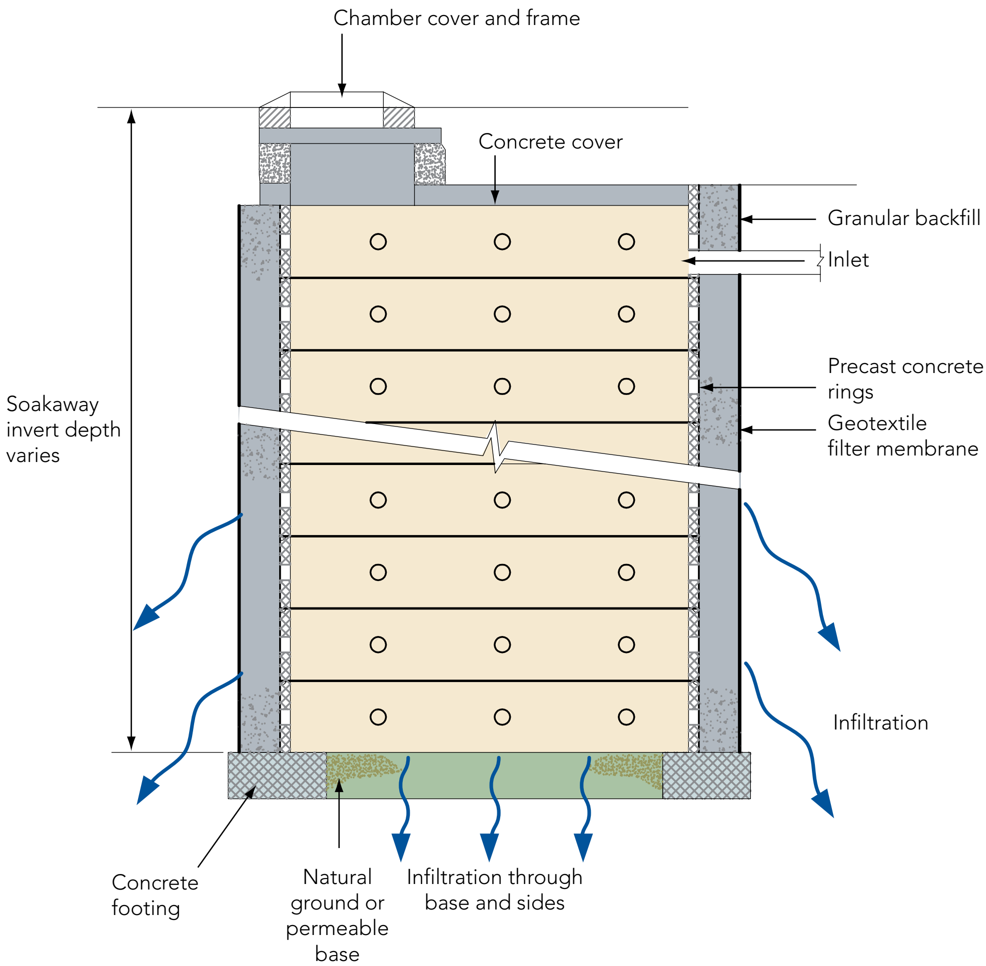


Figure 16 Typical ring soakaway section.

Main drainage is assumed to have an indefinite life, but soakaways in general do not. Historically, 25 years has been a realistic design lifespan for a soakaway that has not been maintained. In most instances when soakaways were built for general housing, they were built and then covered over with no record of location or means of maintenance; in many cases, this meant that they tended to silt-up with time or lost functionality. The source of the siltation could be derived either from soil inflow into the soakaway or general silt carried into the soakaway with the stormwater from roofs or hardstands. Collection of fines around the soakaway could also reduce performance. Current design procedures, as discussed below, include an element of control and monitoring for maintenance. Without this aspect, soakaways should not be expected to have an indefinite life and an element of reduced performance and increased frequency of overflowing has to be accepted. If, with time, a soakaway in a garden creates a soggy patch once or twice a winter then this may be acceptable without replacement, but if a soakaway overflows on to neighbouring property or floods a road with reasonable frequency then this is far more likely to be considered unacceptable. Equally, if the soakaway is part of a larger system, either a SUDS or linked soakaway scheme, then increased frequency of 'failure' would have implications for the rest of the system. *Design for Exceedance in Urban Drainage – Good Practice* (C635)[79] considers the design of various SUDS components and how to cope with exceeding the design values.

6.1 Design

As with any stormwater system, soakaways are designed to accept water and control it in a known way. The general philosophy for soakaways is to accept known amounts of water over a given period and to infiltrate it into the ground over an acceptable, often longer, period (this delay aspect is attenuation). The principles are the same whether designing ring, pit, or trench-type soakaways. Two generally accepted design procedures for soakaways are used in the UK: namely DG365 *Soakaway Design*[73] and *Infiltration Drainage – Manual of Good Practice* (C156).[74]

The purpose of the hydraulic design is to select the dimensions of the infiltration system which are sufficient to dispose of the run-off from storms of any duration with a selected return period. It is well understood that rainfall events tend to occur with 'a certain frequency', and when flooding occurs it is often said that this was caused by a 'one in x years' event.

*Soakaway Design (*DG365) and *Infiltration Drainage – Manual of Good Practice* (C156) chose 10 years as a suitable return period, as this was considered to give a similar level of protection as that provided by positive sewerage. However, it appears increasingly common now for longer return periods to be requested by various authorities, often up to 100 years or more; this is discussed in section 6.1.1.

Note: There is a method in the NHBC Standards that is based on the withdrawn BRE151 *Soakaway Design* (now superseded by DG365). Clause 5.3 S9c of the NHBC Standards suggests that large soakaways should be designed to either Appendix 5.3F or DG365. These two methods give very different results; Appendix 5.3E is the method based on BRE Digest DG151 and this method will generally undersize the soakaway compared with DG365, in some cases very significantly. DG151 was a very simple approach established many years ago with limited background and even then intended for small extensions, etc. Because of its weaknesses it was withdrawn in 1991.

The principles of the two design procedures, DG365 and C156, are very similar, but there are slight differences in the modelling adopted and the application of 'safety factors'. DG365 is potentially simpler to use than C156. Given the differences in assumptions it should not be expected that the two procedures will result in the same sizing.

The design method for sizing a soakaway is based upon the equation of volumes:

$$I - O = S \qquad [1]$$

where:

I = the inflow from the impermeable area drained to the soakaway
O = the outflow infiltrating into the soil during rainfall period
S = the required storage in the soakaway to balance, temporarily, inflow and outflow

Inflow to the soakaway

$$I = A \times R \qquad [2]$$

where:

A = the impermeable area drained to the soakaway
R = the total rainfall in a design storm (a 10-year return period is used) (see section 6.1.1)

Outflow from the soakaway

$$O = a_{s50} \times f \times D \qquad [3]$$

where:

a_{s50} = the internal surface area of the soakaway to 50% effective depth: this excludes the base area which is assumed to clog with fine particles and becomes ineffective in the long term (in C156 allowance for the base area is included)

f = the soil infiltration rate determined in a trial pit at the site of the soakaway (note that slightly different units are used in DG365 and C156 but as long as consistent units are used throughout there should be no problems)

D = the storm duration

Required storage volume in the soakaway

Storage must equal or be greater than inflow minus outflow, defined above, and is the required effective volume available between the base of the soakaway and the invert of the drain discharging to the soakaway.

There are four steps in the design procedure for a soakaway:

- Carry out a site investigation to determine the soil infiltration rate.
- Decide on a construction type (eg filled pit in square, circular or trench form, or concrete ring units with granular surround).
- Calculate required storage volume, S, from inflow minus outflow for a range of durations of 10-year design storms to determine the maximum storage predicted for the type of soakaway.
- Review the design to ensure its overall suitability considering space requirements, site layout, and time for emptying.

This design method for sizing soakaways using DG365 contains assumptions which generally combine to increase the factor of safety against surface flooding of the design:

- The percentage run-off is taken as 100% from the drained area, ie no reduction is made to the design run-off volume discharged to the soakaway for losses due to surface wetting or the filling of puddles during the storm.
- No allowance is made for the time taken for run-off to discharge to the soakaway: the required storage volume is calculated on the basis of instantaneous discharge to the soakaway.

- The outflow from the soakaway is underestimated; higher infiltration rates occur at greater depths of storage in practice than are adopted in design and because the outflow is calculated on the basis of the rainfall duration rather than the run-off duration. The latter may be considerably longer, depending on the length of drains.

C156 also assumes 100% run-off but uses factors of safety that are applied to the observed infiltration rate to give an effective rate which is then used in the design. The factor of safety is based on the acceptability of flooding and the area being drained (Table 4).

6.1.1 Inflow

At a particular location, for a specified return period, the rainfall depth varies with the duration of the storm event. This relationship between depth and duration varies throughout the country and so attention must be paid to the geographic location of the system.

The Institute of Hydrology has carried out an extensive analysis on rainfall statistics and has provided a method to determine the relationship between depth, duration, and return period. This has formed the basis for the method described in C156 and DG365:

- The notation MT-D is used to identify a storm, where M is the depth of rain in mm; T is the return period in years; D is the storm duration.
- Thus M10-15 is the depth of rainfall of a 10-year return period storm event lasting 15 minutes.
- A design storm is assumed to be a rainfall event of duration D with a 10-year return period, ie M10-D.

C156 and DG365 use slightly different derivations to arrive at the M10-D values; a brief explanation is given here. The base data available for rainfall events are the M5-D records from around the UK for two minute and two day duration events. A map of the ratio of these two events from around the UK is available (see DG365 and C156) and is designated 'r' and varies between 0 and 0.45.

The starting point is the M5-60 rainfall, which can be taken as 20 mm throughout the country. Tables are available, eg from C156 and DG365, giving a factor Z to convert the M5-60 to other durations M5-D; Z varies with the r and D. So M5-D = M5-60 × Z = 20 × Z.

To convert M5-D to M10-D a 'growth factor' is applied. The growth factor varies with depth of rainfall in M5-D and whether the site is in England and Wales, or in Scotland and Northern Ireland.

In the case of C156, a simplification has been applied, two constant values of growth factor are used, one for England and Wales, and one for Scotland and these are combined with the r vs. D values to give a single table (they use the highest value of growth factor in each case, thereby overpredicting the rainfall but are on the safe side).

Therefore values of total rainfall depths for various storm events are derived along with total volume inflows when incorporated in equation 2.

To extend these calculations to longer return periods, new growth factors are required and there appears to be a number of studies available, all of which use different theories to establish growth curves for longer durations. It is suggested that until further guidance is available the values contained in Table 4 (based on Table 2 in DG365) could be used to calculate rainfalls for 20- and 50-year return periods.

Table 4

Growth factors for different return periods

	Growth factor Z2		
	Return period (years)		
M5 rainfall (mm)	10	20	50
5	1.19	–	–
10	1.22	1.40	1.64
15	1.24	1.43	1.69
20	1.24	1.45	1.71
25	1.24	1.44	1.71
30	1.22	1.42	1.69
40	1.19	1.39	1.67
50	1.17	1.38	1.64
75	1.14	1.38	1.64
100	1.13	1.38	1.64

6.1.2 Outflow

Throughout this guide frequent mention has been made to permeability, infiltration values, etc, of the ground. Both publications DG365 and C156 determine a value for the infiltration characteristics of the soil in the same way, the only differences being the size of the infiltration test. The test is simulating water flowing out of the soakaway and into the ground using a test pit. It has to be remembered that the ground can be very variable and testing in one location may not be representative of another; location and size are important factors.

The method of determination must give representative results for the proposed site of the soakaway:

- The test pit should be of sufficient size to be representative of the soakaway.
- When the soakaway is working the surrounding ground may already be wet, so repeat filling of the test pit should be undertaken.
- The geology of the test pit should be examined to ensure it is typical of the surrounding ground.

6.1.3 The infiltration test

DG365 suggests excavating trial pit to the same depth as anticipated in the full-size soakaway (for run-off from 100 m^2 this will be 1 to 1.5 m below the invert level of the drain discharging to the soakaway). Overall depths of excavation will be typically 1.5 to 2.5 m for permeable areas up to 100 m^2 draining to the soakaway. The trial pit should be 0.3 to 1 m wide and 1 to 3 m long. It should have near vertical sides trimmed square and, if necessary for stability, should be filled with granular material. When granular fill is used, a full-height, perforated, vertical observation tube should be positioned in the pit so that water levels can be monitored with a dip tape. It should be possible to construct a suitably dimensioned pit with a backhoe loader or mini-excavator. Narrow, short pits use less water for the soakage tests but may be more difficult to trim and clean prior to testing. Measure the pit carefully before trials (safety of personnel should always be paramount). C156 suggests slightly different pit sizes, but the underlying point is that the size should be known and of sufficient depth to represent the final soakaway.

Once completed the pit should be filled quickly with water to the effective depth (up to the likely invert level) and changes in water level recorded with time until the pit is near empty (readings should be sufficiently frequent to define a curve as shown in Figure 17; this operation should be repeated for at least three fillings; this simulates the soakaway functioning under repeat storm events).

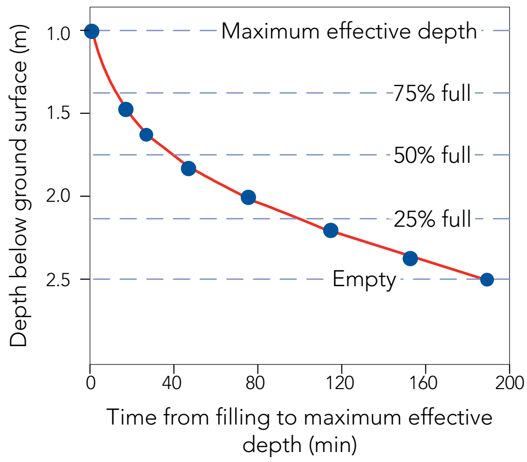


Figure 17 Infiltration test result.[73]

For each of the three fillings (ideally on the same or consecutive days) the infiltration rate is calculated from the time taken for the water level to fall from 75% to 25% effective storage depth in the pit as:

$$f = \frac{V_{p75-25}}{a_{p50} \times t_{p75-25}} \qquad [4]$$

where:

V_{p75-25} = the effective storage volume of water in the trial pit between 75% and 25% effective depth

a_{p50} = the internal surface area of the trial pit up to 50% effective depth and including the base area

t_{p75-25} = the time for the water level to fall from 75% to 25% effective depth.

The lowest value from the three tests is used in the design.

If it is impossible to carry out a full-depth soakage test, soil infiltration rate calculations should be based on the time for a drop in the water level from 75% to 25% of the actual maximum water depth achieved in the test. The effective area of loss from the soakage pit is then calculated as the internal surface area of the pit to 50% maximum depth achieved plus the base area of the pit. Fuller details can be found in DG365 and C156.

For trench-type soakaways it is important to carry out a number of infiltration tests at different locations along the proposed trench if the trench exceeds 25 m or if the ground conditions are particularly variable.

The infiltration rate thus determined is used in equation 3. Note DG365 and C156 use different units but within any one method consistency is always maintained.

Using equation 3 and taking a known depth for the soakaway, then an equation can be established for the outflow from a soakaway for a known storm duration in terms of the unknown dimensions (width, length, etc) for the soakaway.

Note: The infiltration rate of the soils must be tested using large-scale tests at the location and depth of the proposed infiltration device. Small-scale tests using small (eg 300 mm × 300 mm × 300 mm pits and small volumes of water are not representative and will not give a reliable estimation of the infiltration capacity of the ground. The results of the test should be accompanied by detailed soil descriptions made in accordance with British Standard BS 5930.[81] Tests should be undertaken until water levels drop below the level equivalent to 25% of the starting volume remaining in the pit and extrapolation should not be used to determine the infiltration rate.

6.1.4 Storage

If the type of soakaway is known, then the available storage capacity can be estimated. In the case of a gravel-filled soakaway this would be the void space in the gravel fill between the invert level and the base. Using the general dimension from above and the porosity of the fill, the storage volume is determined.

6.1.5 Sizing

Based on the information gathered from section 6.1.1 to 6.1.4, and inserting it into equation 1, the unknown dimensions of the soakaway can be calculated.

Repeat the calculation for a range of M10-D storms and determine the maximum dimensions required; the storm with this maximum is the critical storm (DG365 and C156 show examples [73, 74].

Having sized the soakaway, it must be ensured that the device does not remain full of water for an unacceptable time, so the time for emptying has to be checked.

Time of emptying of soakaway

The soakaway should discharge from full to half-volume within 24 hours in readiness for subsequent storm inflow. This is done using equation 5:

$$t_{50} = \frac{S \times 0.5}{f \times a_{50}} \qquad [5]$$

Providing t_{50} is less than 24 hours the design is acceptable.

6.2 Construction

Having sized the soakaways they should be constructed to deliver a soakaway to the required design. Too often soakaways are seen on site being backfilled with any rubble to hand; this is unacceptable and can lead to early failure. Soakaways can be constructed as shown in Figures 9 and 16 and generally comprise excavated pits or trenches filled with granular backfill or precast rings surrounded by granular backfill. As explained in the design stages, the porosity of the backfill needs to be known and should be established. C156 gives some general ranges for porosity for different types of fill but this should always be verified for each particular case.

Perforated, precast concrete ring unit soakaways should be installed within a square pit, with sides about twice the selected ring unit diameter. The need to oversize the soakaway pit for constructing the ring unit chamber may be used to advantage by incorporating the total excavation volume below the discharge drain invert in the design storage volume.

Granular material must be separated from the surrounding soil by a suitable geotextile to prevent migration of fines into the soakaway. If migration from surrounding soil occurs, it can cause ground settlement around the soakaway sufficient to affect the stability of adjacent buildings. The top surface of the granular fill should also be covered with geotextile to prevent the ingress of backfill material during and after surface reinstatement. Geotextile should not be wrapped around the outside of the ring units as it cannot be cleaned satisfactorily or removed once it has become blocked.

Many proprietary systems are now available to the market not just for soakaways but for other infiltration systems. Figure 18 shows a system using cellular modules that can be connected together to form the soakaway. These systems have the advantage of maximising storage volume (as would be the case of a ring soakaway over a gravel-filled one) but can also be adapted to various shapes.

As discussed elsewhere it is important to be able to inspect and maintain the soakaways in order to monitor their performance and to ensure that their life is not shortened by siltation.

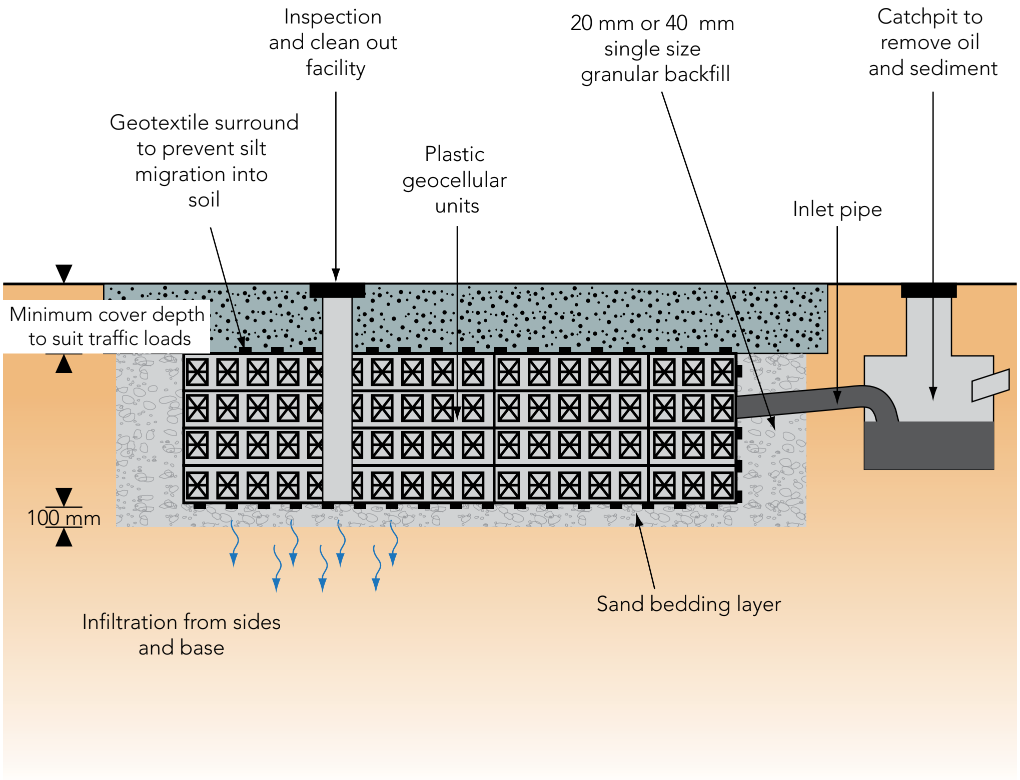


Figure 18 Infiltration device details (adapted from an original illustration, courtesy of the Environment Agency).

Current guidance (eg DG365 and C156) suggests that inspection systems should always be installed in infiltration systems.

Long-term maintenance and inspection must be considered during the design and construction process. With wet well soakaways, vehicle-mounted suction emptying and jetting equipment can be used (Fig. 19). Given correct construction the main source of siltation will be from fines running off roofs and hardstands. If this material can be prevented from entering the soakaways, then this will help to extend their life, especially if access for cleaning and maintenance is difficult. Systems such as silt traps on rainwater pipes should be considered as a suitable addition to systems for houses and buildings.

It should always be remembered that care must be taken to ensure that SUDS in general, and soakaways in particular, are not contaminated or compromised by material being washed into them during general site construction works. They should be either constructed after main activities are completed or isolated in some way during the construction activities.

If infiltration systems are likely to receive any contaminated waters, suitable traps or filtration systems should be included in the design (see Fig. 18).

A qualified geotechnical specialist should advise on the suitability of soil and groundwater conditions to accept infiltration drainage. The most important aspect of design is that the soil has sufficient capacity to accept infiltration of stormwater run-off (Table 5).

Infiltration cannot normally be used in clay soils, and soils used to accept infiltration of run-off should have a clay content of less than 20% and a clay/silt content of less than 40%.

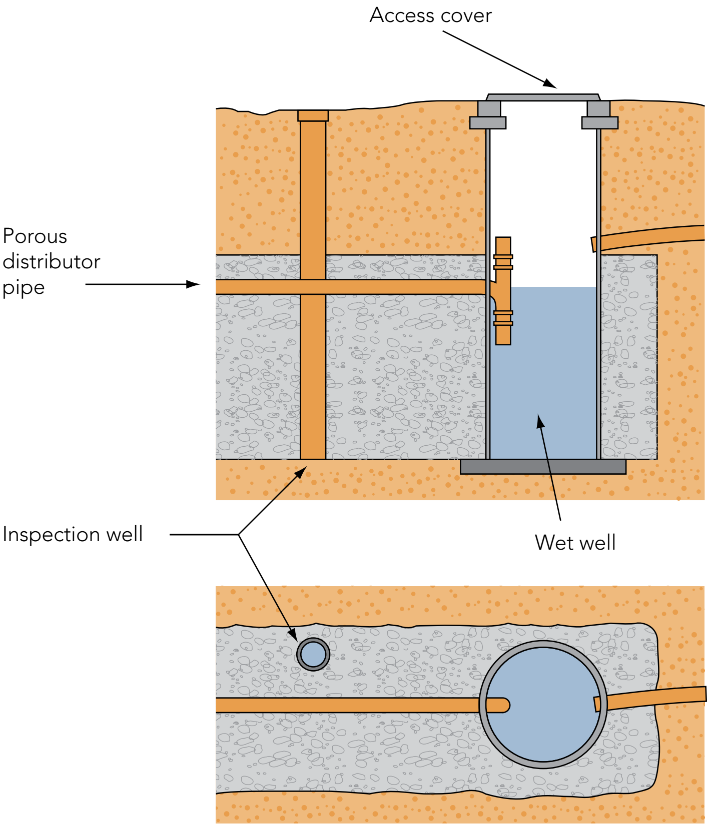


Figure 19 Trench-type soakaway with large wet well equipped with T-piece overflow to porous distributor pipe and separate inspection well.[73]

Table 5

Factors of safety for infiltration design[74]

Catchment area	No damage or inconvenience	Consequences of failure	
		Minor inconvenience, eg surface water on car park	Damage to buildings or structures or major inconvenience
<100 m^2	1.5	2	10
100–1000 m^2	1.5	3	10
>1000 m^2	1.5	5	10

7 Pervious paving and infiltration systems for surface water treatment

7.1 Pervious paving

The use of pervious paving is a key techniques in SUDS for surface water management and source control of the quantity and quality of run-off. Surface water is infiltrated through the surface and into the underlying construction layers where water is stored prior to infiltration to the ground, reuse, or release to the watercourse or other surface water drainage system. Pervious surfaces are often used for pavements, walk paths, driveways, car parks, cycle routes, and sports grounds. Pervious surfaces can be either porous or permeable involving the following materials and techniques:

- Porous surfacing infiltrates water across the entire surface of the material forming the paving/car parking areas, eg grass and gravel surfaces, porous asphalt and porous concrete.
- Permeable surfacing consists of impervious material to water. However, voids are built-in to these materials that allow infiltration of water through the minute void channels, eg concrete paving blocks.

These materials in various forms are available commercially. Impermeable membranes can also be installed to the sides and base of the pavement if storage is required, or infiltration to the ground is to be prevented, eg in water harvesting situations.

Pervious surfaces can be applied on a wide variety of developments, eg housing, commercial and retail parks, industrial estates, etc, and these can provide infiltration and attenuation of surface water, including rainwater on the surface, and also provide a drainage path for run-off from adjacent areas, such as from roofs or driveways. The use of pervious paving satisfies the requirements of Planning Policy Statement 3 *Housing* (PPS3)[82] for high-density housing developments and a high percentage of hard surfacing in industrial/commercial developments. An example of pervious paving in a housing development area is shown in Figure 20.

Figure 20 Pervious paving.

The pervious paving will require regular routine maintenance to ensure the surface is free from clogging due to high silt content in the surface water run-off. The incorporation of a debris trap helps to protect the surface and it is advisable to include an oil interceptor device in situations where there could be spillage of oil, eg in industrial estates, to allow retention and treatment of organic pollutants.

Properly constructed pervious paving installations treat the surface water using the following mechanisms:

- filtration
- biodegradation of organic pollutants such as fuels from motor vehicles
- adsorption (this will depend on the materials of the pervious paving)
- retention and settlement of solids
- impermeable bases provide a means to control the direct flow to groundwater
- adsorption of the subsoil within the pervious paving system can be further enhanced by adding an adsorbent substrate material, eg sawdust, peat, clay, granular activated carbon
- biodegradation of organic pollutants and other hydrocarbons.

The inclusion of geomembrane in the construction of pervious paving further enhances the retention of oil. The incorporation of geotextile within the pervious paving system increases adsorption of heavy metals, nitrates, nitrites, and ammonia. Comparatively, much lower concentrations of suspended solids, total solids, chromium, aluminium, copper, zinc, and lead can be expected in the drainage water of the pervious paving system than from effluents collected from impermeable surfaces. For guidance on the design criteria for source control, see *Source Control Using Constructed Pervious Surfaces. Hydraulic, Structural and Water Quality Performance Issues* (C582).[60]

Pervious paving can be constructed in all soil types. If infiltration is required, groundwater must be at least 1 m below the base of the construction and must comply with regulations (Water Resources Act, 1991[25] and Groundwater Regulations, 1998).[15] The Environment Agency should be consulted at an early stage of development to agree the nature and scope of risk assessments. If the SUDS discharge is uncontaminated surface water, then discharge consent will not be required. However, if the run-off into the SUDS might contain high concentrations of pollutants and/or the SUDS run-off requires treatment before discharge to watercourses, discharge consent is required by the Environment Agency. Where discharge is to a sewer, then discharge consent from the sewerage undertaker will be required. If infiltration is not required, the highest groundwater level should be below the base of the pavement structure.

Unlined pavements should not be used in locations where water infiltration may cause slope instability or foundation problems (eg landslide situation). Assessment by a chartered geotechnical engineer is required to advise on the situation. The effects of the storage water on the structural integrity of the underlying soil must be assessed. Unlined pavements should not be used in contaminated land situations, unless sufficient evidence suggests that leaching of the contaminants is minimal.

The design surface water infiltration rate should be greater than the design rainfall intensity, including allowance for run-off from adjacent impermeable areas. The infiltration rate must be much higher than the rainfall intensity so that the infiltration rate of the unmaintained paving area is sufficient to cope with the designed rainfall events. A reduction in the design infiltration rates of 90% should be allowed in the design to take account of the possibility of clogging by debris or silt. The storage volume of the surface water of the underlying layer should take 24 to 48 hours to empty. For outflow via piped systems, the storage below the pavement should be designed as a tank system with limiting discharge rate. Where the surface slopes, the water storage would be wedged at the lowest point; this can be prevented by including intermediate dams within the pavement structure.

The design of the pervious paving structure will be determined by the possible loading imposed by traffic and by its required operational life. Conventional pavement design can be applied to pervious paving. It should be noted that pervious paving has different density and porosity in the material than conventional paving materials, and porous asphalt has a poorer durability due to losses in adhesion and may become brittle when air has been passed through the voids. Porous concrete paving is made using single size aggregates to create the high void ratio for the paving to be permeable, the material tends to be less stiff than the normal concrete block paving. Geotextile must be carefully specified to minimise friction between layers. For guidance on the design criteria, see *The SUDS Manual*.[6]

Water permeability can affect the durability of materials and the structural performance of pavements or driveways. However, if the pavement structure is designed according to *The SUDS Manual*, then less water would be trapped within the sub-base structure and foundation subsoil. The CBR (California bearing ratio) value used in the design of pervious paving should be measured[83] or estimated for the saturated foundation soil.[84] The design of the paving should take into account the material conversion factor[85] for guidance on replacing DBM (dense bitumen macadam) with porous asphalt and sub-base. If aggregates are used as the sub-base material instead of plastic geocellular units, these tend to be in contact with water, which could have an impact on the durability and strength of the aggregates when saturated. To maximise the strength of the aggregate particles, the soil used should be rough and angular; crushed rock or concrete that have >90% fracture faces or blast furnace slag would be suitable. Sand and gravel with rounded particles should not be used. Aggregates for use in the sub-base layer below the pervious paving should comply with values given by the following tests: 10% fine test,[86] flakiness index[87] and plate bearing tests[88] and Los Angeles abrasion.[89] For guidance on pavement design see C582,[60] *Design Principles: Pervious Paving*[90] and the *Standard for Pervious Paving Systems*.[91]

To prevent clogging of the pervious paving, the landscaping area adjacent to the paving should not slope towards the pavement where run-off carrying the soil could cover the surface. The lawn or other landscaping areas should be at least 50 mm below the pavement edge of the kerb. A permanent air space in the pavement is recommended to allow for a 30% increase in volume for water storage, and to prevent water freezes and ice to expand. The airspace also provides an insulation layer for the pavement.

Examples of pervious paving systems are shown in Figures 21 to 23 and Figure 24, a housing development in Milton Keynes.

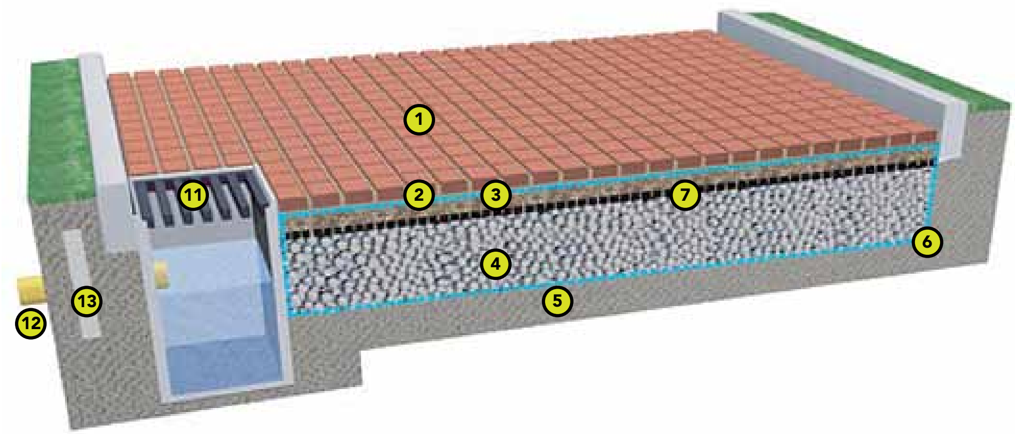


Figure 21 Full infiltration pervious paving system, for sites with subsoil permeability >15 mm/hour; rainfall is intended to infiltrate the underlying subsoil (adapted from an original illustration, courtesy of Metro Vancouver).

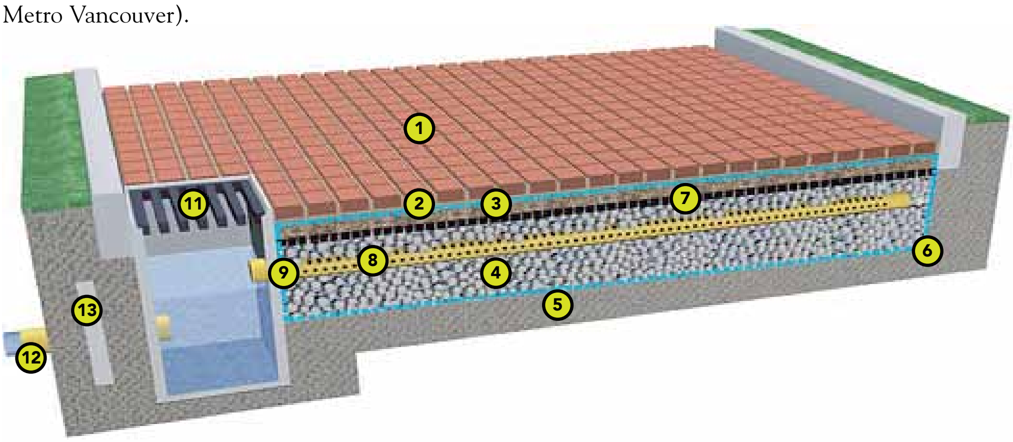


Figure 22 Partial infiltration, suitable for subsoil permeability >1 and <15 mm/hour, and designed so that most water infiltrates the underlying soil while the surplus overflow is drained by perforated pipes that are placed near the top of the drain rock reservoir (adapted from an original illustration, courtesy of Metro Vancouver)

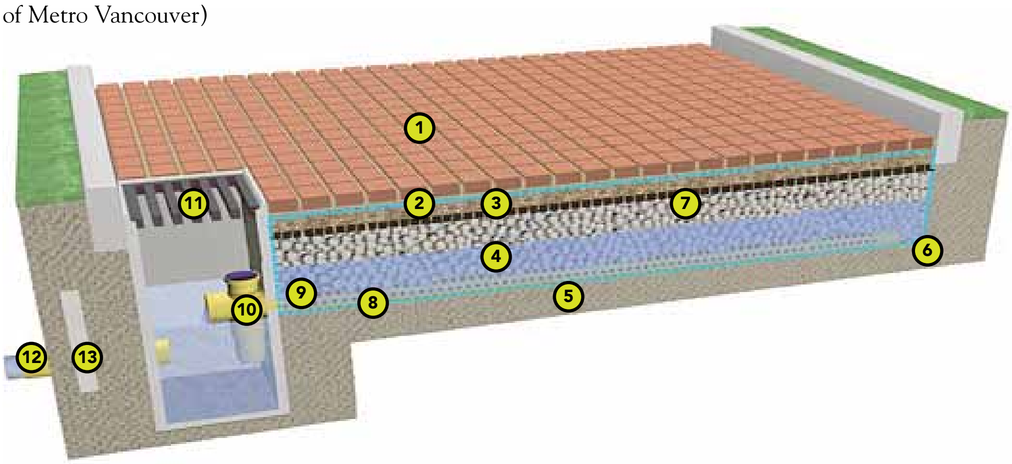


Figure 23 Partial infiltration with flow restrictor. Where subsoil permeability is <1 mm/hour, water is removed at a controlled rate through a bottom pipe system and flow restrictor assembly. Systems are essentially underground detention systems, used where the underlying soil has very low permeability or in areas with high water table. It also provides water quality benefits (adapted from an original illustration, courtesy of Metro Vancouver)

Notes to Figures 21, 22 and 23

1. Permeable paving (min. 80 mm thickness)
2. Aggregate bedding course – not sand (50 mm depth)
3. Open graded base (depth varies by design application)
4. Open graded sub-base (depth varies by design application)
5. Subsoil – flat and scarified in infiltration designs
6. Geotextile on all sides of reservoir
7. Optional reinforcing grid for heavy loads
8. Perforated drain pipe 150 mm diameter minimum
9. Geotextile adhered to drain at opening
10. Flow restrictor assembly
11. Secondary overflow inlet at catch basin
12. Outlet pipe to storm drain or swale system. Locate crown of pipe below open graded base to prevent heaving during freeze/thaw cycle
13. Trench dams at all utility crossings.

Figure 24 Pervious pavement used in a housing development in Milton Keynes.

7.2 Infiltration systems

In general, 'infiltration systems' include soakaways, infiltration trenches (Fig. 25), and infiltration basins. Infiltration systems take run-off from a development and allow the surface wastewater to percolate into the ground, thereby recharging the groundwater, maintaining the water levels in local watercourses, and reducing the volume of water to be disposed of through sewers. The systems have a storage capacity to allow run-off to drain into the ground over a period of time, usually a maximum of 24 hours to half empty. Infiltration devices can also be used to receive and release water from other SUDS techniques (eg pervious paving, swales, or basins – Fig. 26 shows an example of a dry swale). Infiltration basins are generally open, grass depression areas of land that are designed to store run-off and allow the surface water to infiltrate the ground. Infiltration basins require a large coverage area, which could have an effect on application in urban areas. The system should be limited to a maximum catchment area of 4 ha, and ideally 1 ha, to reduce the risk of clogging by sediments. Infiltration trenches and soakaways are generally underground and do not take up surface space. Infiltration systems have the following capacity to treat surface water:[92]

- A wide range of organic and inorganic pollutants from the water column can be removed.
- Sorption of a range of pollutants can limit the pollutants from entering the groundwater.
- Effective performance over an extensive period of time.

Adsorption, precipitation, microbial degradation, and filtration are the main processes for treatment of surface wastewater for removing pollutants in infiltration systems. Sedimentation of suspended solids and particulates is important in infiltration basins. The pollutants in the detained surface water above ground can be degraded by volatilisation and photolysis. In soakaways and infiltration trenches, the water is detained underground within permeable structures, where the surface water infiltrates into the surrounding soil and the pollutants are retained by the soil. Nitrates and phosphates are primarily removed by precipitation or by adsorption. Nitrates being soluble can travel through the soil, and depending on soil and catchments these could be leached into groundwater.

Figure 25 An infiltration trench by the side of a road.

Phosphates could be retained by the soil and transformed into minerals. Microbial action can remove organic compounds and trap heavy metals by their metabolic processes.[93] Oil and bituminous tar oil from road surfaces contained in the run-off in the infiltration systems can also be degraded by microbial action.[94] Some polyaromatic compounds from bitumen oil detained by the infiltration basin can be degraded by photolysis.[95]

Figure 26 A dry swale alongside Brickhill Street in Milton Keynes.

Infiltration systems are most suited to areas where run-off is relatively unpolluted and have low sediment loads (eg from roofs) and should be designed to take small incremental run-offs from small catchments. The run-offs should be treated by another system (eg a sediment or oil trap) prior to flowing into the infiltration system if contamination is likely. Usually, a geotextile or other filter layer is used around the perimeter and should be located at 150 to 300 mm depth to trap sediment and hydrocarbons. A sediment trap in the upstream pipework treats 25% of water. Erosion of fine particles from the soil near the infiltration system should be prevented. The pre-treatment can be by other SUDS such as pervious paving. The removal efficiency of pollutants by infiltration systems is shown in Table 6.

Table 6

Pollutant removal efficiency of infiltration systems[8]

Pollutants	Infiltration trenches (%)	Infiltration basins (%)
Total suspended solids	70–80	45–75
Nitrates	25–60	55–60
Total phosphates	60–80	60–70
Lead	60–90	85–90

The Building Regulations Approved Document H (2002)[10] requires drainage of rainwater from the roof of buildings and paved areas to an adequate soakaway or other infiltration system. Infiltration systems can be applied in urban developments, providing the infiltrating water does not affect the building foundations and other infrastructures. The infiltration system should be sited at least 5 m away from any building or structure and should not be used in flood-prone areas unless the run-off has been pre-treated to acceptable levels. On sloping sites, infiltration systems should not contribute to further rises in groundwater or cause problems to surface water downstream.

Groundwater condition and soil types can limit the infiltration systems, especially in high groundwater level and clay soil areas. Infiltration cannot be used in clay soils and should be used where the clay/silt content is less than 40% and the clay content is less than 20%. The soil must have an infiltration rate greater than 1×10^{-11} m/s. The permeable layer must be sufficiently thick and allow later dispersion of water. The base of the infiltration system must have at least 1 m above the seasonally high groundwater table so that the storage capacity is not reduced during times of high groundwater levels and to prevent direct discharge to groundwater. If an aquifer is particularly sensitive, the Environment Agency may require 3 m clearance. For an infiltration system to work effectively, it must have sufficient surface area to infiltrate water. The infiltration rate should be lower than the rainfall rate and sufficient volume must be provided to store excessive water from a design storm than infiltration during the storm. The size of the infiltration system depends on the following factors:

- the hydraulic properties of the ground (see section 5.4)
- the catchment area
- the rainfall characteristics.

The base of an infiltration system should have sufficient unsaturated soil beneath it so that filtration of the stormwater occurs prior to reaching the groundwater. Normally a minimum depth of 1 m is adequate but more might be required depending on the situation. The soils around the sides and base of the infiltration system must not become smeared or compacted, which would reduce the permeability and infiltration efficiency of the system. The use of plastic geocellular units can reduce the volume of excavation and disposal of surplus soils from the infiltration systems. These units have up to 85% porosity compared with 30% for aggregates, enabling more efficient infiltration while allowing greater storage for the same volume. Plastic geocellular units are often used in infiltration trenches, although aggregate openly packed with a large void space (30%) is more usual. Infiltration systems could adversely affect the structural load capacity of the ground due to water release to the soil. Care should be taken and the following taken into consideration:

- Infiltration trenches not located close to the top of a slope.
- Location not close to buildings.
- Infiltration not deposited into the ground, as this may cause inundation settlement.
- Ground conditions monitored to ensure minimum loss of fine soil particles.
- Infiltration not used if dissolution of the ground soil occurs.
- Ground slope should be less than 1:5 downstream of the infiltration system.

Infiltration systems are designed to cope with storms up to a 1 in 200 year return period. In the exceptional event of flooding, the stormwater should be routed over the site surface and an overflow weir or spillway should be provided if flood is considered a risk in the area.

Figure 27 shows examples of inclusion of landscaped SUDS in Campbell Park, Milton Keynes.

Figure 27 Examples of SUDS in Campbell Park in Milton Keynes.

7.3 Swales

Swales are shallow channels for conveyance of surface water run-off and can be used as infiltration devices for removal of pollutants. Channels are usually grown with plants and grass that enhance their pollutant removal efficiency. Swales can be a part of a series of SUDS devices and provide pre-treatment for run-off and then drain into the next system such as a retention pond or an infiltration basin. They are typically located as long, shallow channels alongside a major road or motorway (eg M11 near Stansted Airport); however, they can also be incorporated in landscaped residential areas and car parks.

There are three types of swales: swale, enhanced dry swale, and wet swale. Examples of swales used in residential areas are shown in Figures 28 and 29. Swales are not engineered to provide the same pollutant capacity as enhanced dry swales, which have a filter medium, or wet swales, which function as an infiltration basin. For frequent small storms, swales generally remove pollutants. For larger storms of 10 to 50% annual probability, they provide storage and a conveyance device for drainage. They are generally used for sub-catchments with small impermeable areas. The maximum impermeable catchment for which swales are useful is 2 to 4 ha. The soil (not coarse or sandy) should provide a stable vegetated bed and the groundwater must be more than 1 m below the base of the swales. Like infiltration basins, swales only accept slow flow of water over a maximum 10% slope for infiltration and pollutant removal.

Figure 28 Swales at BRE, Watford.

Figure 29 Swales in a new housing development in Milton Keynes.

8 Green roofs and water harvesting systems

8.1 Green roofs

Green roofs are roofs that are intentionally planted with vegetation as part of the building design. This can be anything from a rooftop garden planted with flowers, shrubs, or grassy swards to patches of mosses and lichens. Green roofs are also referred to as eco-roofs or roof gardens. A green roof consists of a multilayer system that includes vegetation top layer, soil or a suitable substrate, drainage, protection, waterproofing, and insulation layers. There are two types of green roofs, extensive and intensive, although some buildings have a combination of both in the roofing system.

8.1.1 Extensive

Extensive green roofs cover the entire roof area with low growing, low maintenance plants. They typically comprise 25 to 125 mm thick soil layer supporting a variety of drought-tolerant, low and hardy plants. Examples of extensive green roofs are shown in Figures 30 to 33.

Figure 30 An extensive green roof on a factory near Zug, Switzerland (courtesy of livingroofs.org).

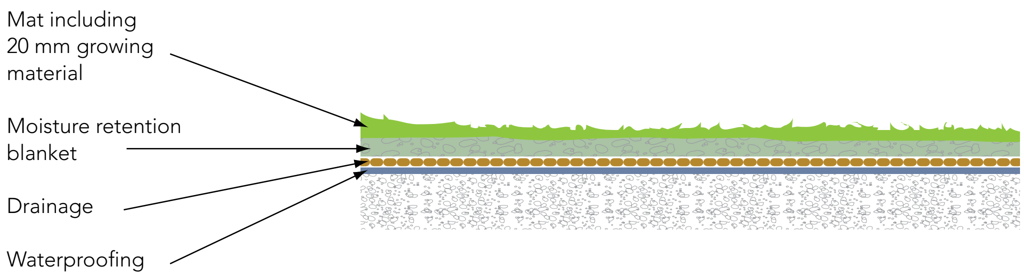


Figure 31 Sedum mat roofing system. Ultra-lightweight system incorporating sedum mat base layer (polyester, hessian or porous polythene) laid on a growing medium (20 mm thick). The sedum carpet is then applied to a 50 to 70 mm growing medium (soil) or a water retention medium.

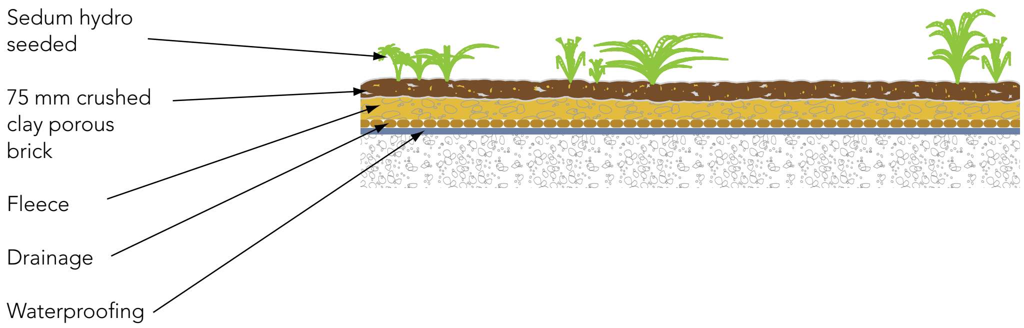


Figure 32 Extensive hydro-seeded roofing system. Substrate-based roof created by planting on to crushed (about 70 mm) used clay bricks placed on sedums.

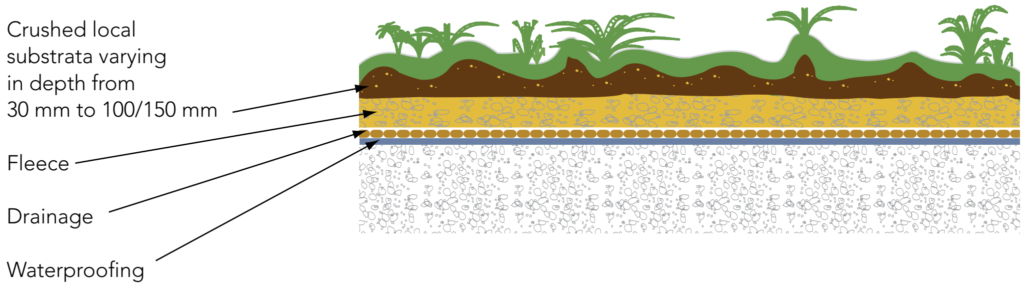


Figure 33 Green system for biodiversity. Crushed concrete or left over aggregates left on a growing medium on a roofing system planted with wildflowers and/or other seedlings.

8.1.2 Intensive

Intensive green roofs include landscaped gardens that have soil deep enough to support trees, plantains, and shrubs. Sometimes water features and rainwater storage or water harvesting systems are included. Intensive roofs impose heavy loading on the roofing structure and require ongoing maintenance of the plants and water system. Figures 34 and 35 show examples of intensive roofs in urban city centres.

Figure 34 Example of intensive green roofs in a roof garden in London.

Figure 35 Example of intensive green roofs in a roof garden in Milton Keynes.

Green roofs can be used on most roofs, including pitched roofs, but are more commonly applied on flat roofs or slightly sloping roofs in commercial buildings, schools, sports centres, hotels, holiday homes, and apartment buildings. Green roofs can be easily retrofitted providing there is sufficient structural support in the existing building. There are many lightweight drainage systems and geosynthetic layers available to enable retrofitting. The services of a structural engineer should be engaged.

Green roofs contribute to a company's corporate social responsibility by providing habitats to encourage and enhance biodiversity. The desired habitats can be planned to attract particular species of birds or wildlife. Green roofs provide green spaces in densely populated urban city centres or in housing developments where space for gardens and landscaped greenery for communal amenity is limited. The successful design of green roofs requires contributions from structural engineers, landscape architects, horticulturalists, and SUDS drainage experts. Green roofs can reduce run-off rates and volumes from roofs to reduce pressure on the surface water management and loading on other drainage systems, such as sewerage surcharging or requirement for retention ponds or larger swales. The maintenance required will depend on the type of green roof and the planting, water features, drainage/water harvesting required for the building. The benefits of green roofs are longer life expectancy of the roofing systems, water attenuation/retention, enabling rainwater harvesting, thermal insulation of buildings, and more efficient long-term maintenance cost compared with conventional flat roofs, as well as providing a pleasant green space in urban environments and contributing positively to reduce CO_2 emissions to the atmosphere.

A variety of green roofs exist in Europe and worldwide. General criteria for different types of green roof are shown in Table 7.[96]

Table 7

General criteria requirement for different types of green roofs

	Extensive green roof	Semi-intensive green roof	Intensive green roof
Costs	Low	Middle	High
Irrigation	No	Periodically	Regularly
Maintenance	Low	Periodically	High
Plant	Moss, sedum, herbs and grasses	Grass, herbs, and shrubs	Lawn or perennials, shrubs and trees
System build-up height	0.06–0.2 m	0.12–0.250 m	0.15–0.4 m Underground garages >1 m
Use	Ecological protection layer	Designed green roof	Park-like garden
Weight	60–150 kg/m^2	120–200 kg/m^2	180–500 kg/m^2

Modern green roof systems are highly durable and provide a number of sustainable and environmental benefits. The vegetation layer of green roofs protects the roofing system from ageing by environmental exposure to temperature stresses during summer and winter, the degradation caused by UV radiation of the sunlight, and varying ozone intensity of urban environments. The waterproofing layer also provides protection from direct mechanical stresses caused by hail, rain, wind, and wear and tear of general walking traffic on roofs. The incorporation of a green roof extends the life expectancy of an ordinary flat roof system (which has a life expectancy of about 15 to 25 years) because of the protection provided by the vegetation and soil (or growing medium) layer.

The hydraulic design of green roofs should comply with BS EN 12056-3.[97] The code of practice for flat roofs with continuously supported coverings (BS 6229: 1982)[98] also provides useful information for roofing. Guidelines for the planning, execution, and upkeep of green roofs developed by the Landscaping and Landscape Development Research Society (FLL)[99] in Germany have provided the industry with useful standards for construction of green roofs in Europe. The standards provide guidelines for building techniques, loading capacity, wind uplift protection, fire protection, thermal

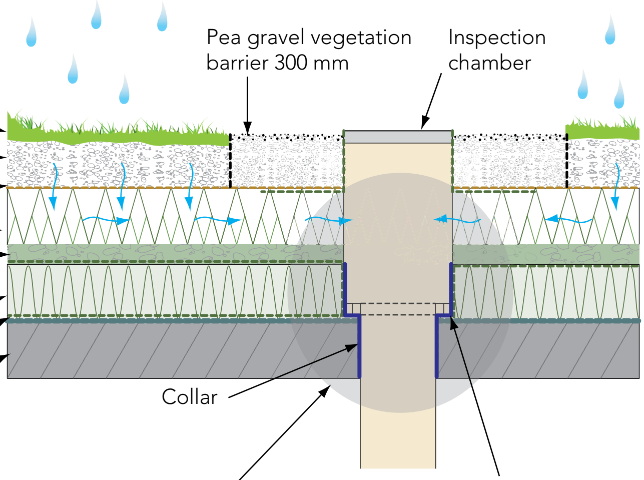


Figure 36 An example of a green roof construction (adapted from an original illustration, courtesy of CIRIA).[104]

and acoustic insulation, waterproofing material and installation, up-stands, slope and drainage as well as planting and landscape architecture requirements. Other regulations regarding roofing and landscape architecture should also be observed, see, for example, Cleaner Air for Cities;[100] US Green Building Council;[101] The City of Excelsior;[102] and Stanford University.[103]

An example of green roof construction is shown in Figure 36. On inverted roofs, thermal insulation is fitted on top of the waterproofing; this provides a variable moisture risk and the build-up system should not prevent vapour diffusion from the insulation.

When constructing green roofs, damage of water membranes by root growth in the structures should be considered. This can be determined using the FLL procedure for investigating resistance to root penetration at green roof sites. If the waterproofing membrane does not meet the root resistance requirement, then an additional barrier may need to be fitted. Other structures such as roof surfaces, upstands, perimeter parapets, joints, and roof edges will also need protection from root damages. The following upstand and parapet heights will need to be considered:

- a minimum upstand height of 150 mm for adjacent building parts and penetrations
- a minimum roof edge height of 100 mm.

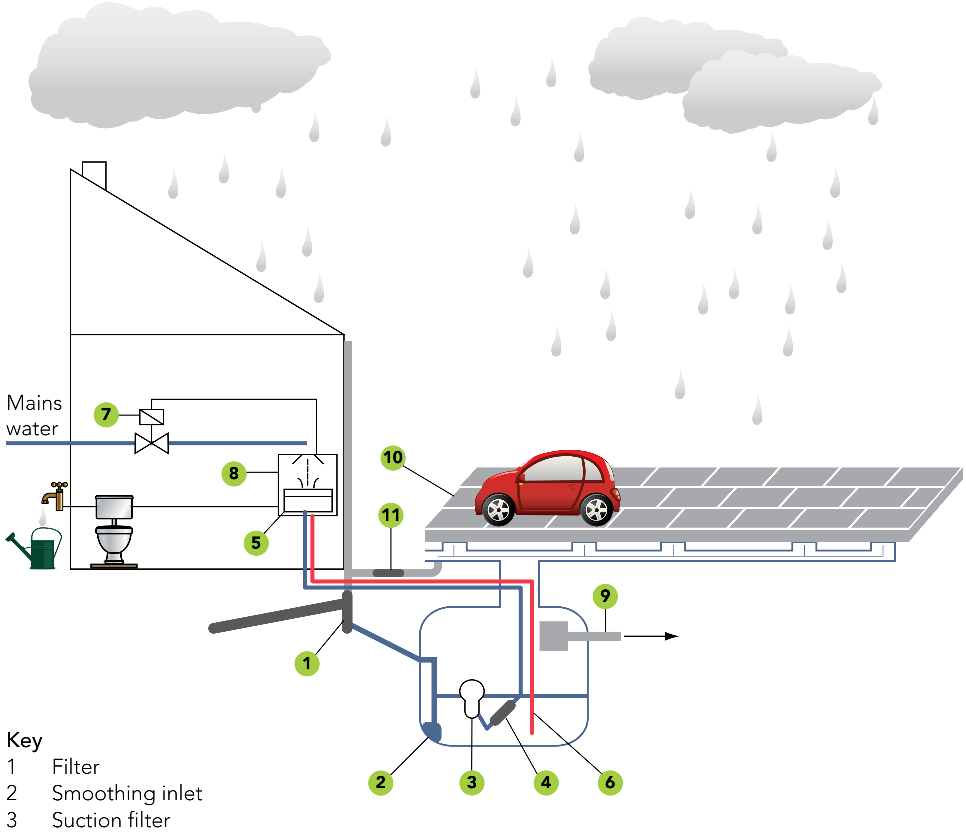
The upstand height is measured from the upper surface of the green roof system build-up. Clamping profiles guarantee reliable protection and a tight connection of the upstand areas.

For more guidance on green roofs, plant selection, and planting, see *Building Greener. Guidance on the Use of Green Roofs, Green Walls and Complementary Features on Buildings* (C644),[104] *Green Roofs*,[105] the International Green Roof Association website,[106] Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau,[99] the Green Roofs website[107] and Europäische Föderation der Bauwerksbegrünungsverbände (EFB).[108]

8.2 Water harvesting systems

The benefits of harvesting rainwater are increasingly being recognised due to the increasing pressure on the natural resources.[2] Large surfaces such as roofs or ground (pervious paving) are ideal for rainwater harvesting and can provide up to 100 m^3 (100 000 litres) of water per year from a medium-sized area. Rainwater harvesting systems can be installed in new and existing buildings and for purposes other than drinking; therefore water of drinking quality is not required. Rainwater for daily household activities can reduce demand of potable water from the water supply by approximately 33%.

The primary driver for rainwater harvesting systems in the UK is economic. There is an economic benefit for users of such systems because of a reduction in metered water charges; this will become widespread over time as the number of properties with water meters increases, especially in new housing developments. If rainwater is appropriately collected, the water can be used for flushing toilets, washing clothes, washing cars, and watering gardens without further treatment. The garden butt system of collecting rainwater from a roof downpipe is the simplest form of rainwater harvesting. The type of rainwater harvest system used in a housing development will depend on cost, maintenance, and requirement. A typical rainwater harvesting system is shown in Figure 37. The storage tank for household water use should have a capacity of about 5% of the rainwater that can be collected in a year or the volume of the annual household demand for water. Stored water is not suitable for drinking. Additional treatment (eg UV system) can also be incorporated if higher quality water is needed.



Key
1 Filter
2 Smoothing inlet
3 Suction filter
4 Pump
5 Control unit with intermediate storage
6 Water level monitor
7 Automatic change over
8 Type AA air gap
9 Overflow trap
10 Permeable pavement
11 Oil trap

Figure 37 An example of a water harvesting system (adapted from an original illustration, courtesy of the Environment Agency).

Green roofs can retain a high amount of rainwater, and excess rainwater is of sufficient quality for many purposes, eg toilet systems, irrigation, and cleaning. A reservoir (dam-up system) for a green roof can be installed on a flat roof above the roof outlets with the appropriate drainage layer. During heavy rainfall, the reservoir fills up and the excess is collected in the cistern; it is pumped and used for irrigating the roof during dry periods. The harvested water can also be used for other purposes.

The Environment Agency provides guidance on collection and amount of rainwater that can be harvested based on different roof areas and expected rainfall, assuming that 60% of the rain falling on the roof is collected and used.[109] The amount collected depends on drainage outlets on the roof. Table 8 shows the relative drainage factors for the different types of roofs. A factor of 1 indicates all water falling on the roof is drained via the gutter; a factor of 0.5 indicates only half of the rainfall is collected. Table 9 provides a guide of approximate amounts of rainfall that can be harvested per year for a number of roof sizes.

Table 8

Drainage factors for different types of roofs

Roof type	Drainage factor
Pitched roof tiles	0.75–0.9
Flat roof smooth tiles	0.5
Flat roof with gravel layer	0.4–0.5

Table 9

Approximate annual yield of rainwater (m^3/year) for a range of roof sizes and rainfall

Rainfall (mm/year)	Planned roof area (m^2)				
	50	75	100	125	150
500	15	22.5	30	37.5	45
1000	30	45	60	75	90
1500	45	67.5	90	112.5	135
2000	60	90	120	150	180

The Environment Agency also provides guidance for calculating the optimum tank size for storing the harvested rainwater. The tank size will need to store at least 18 days' worth of water or 5% of the annual yield. The formula for calculating the optimum tank size for a rainfall harvesting system is roof area (m^2) × drainage factor × filter efficiency × annual rainfall (mm/yr) × 0.05. For further guidance on rainwater harvesting, see *Rainwater and Greywater Use in Buildings. Best Practice Guidance* (C539)[110] and *Model Agreements for Sustainable Water Management – Review of Existing Legislation* (RP664).[62]

9 Selection of Sustainable Drainage Systems for brownfield sites

The Communities and Local Government's national planning policies as set out in PPS23[40] require local planning authorities to undertake strategic housing land availability assessments to identify suitable sites for housing development to meet the government's national target of at least 60% of new housing to be built on regenerated (brownfield) land. The assessment must take account of the environmental impact of housing development, including land contamination, flooding, and effects on biodiversity. Currently, about three-quarters of new developments are on brownfield land. PPS23 requires the planning system to identify and determine development sites that may give rise to pollution, either directly or indirectly, and to ensure that other uses and developments are, as far as possible, not affected by major existing or potential sources of pollution.

Recycling land helps to protect the environment and enhance quality of life, and reduces the demand for development on greenfield land. The regeneration of brownfield land brings with it important social and health issues. At the early stage of development, developers need to assess the environmental implications of the proposal in consultation with the Environment Agency and local authority. The development plan (PPS25)[11] should consider flood risk and provide in the development a mitigation to reduce the causes and impact of flooding. The provision of SUDS should be an important part of the plan for managing surface water to reduce flood risk downstream and to provide a pleasant environment to enhance the amenity and biodiversity for the new development.

A brownfield site is defined as a site that has been previously developed and this includes previous industrial and commercial sites, and contaminated land. The development of SUDS on brownfield sites is more or less the same as in other areas. However, the guidance provided in this section will supplement the general guidance for incorporation of SUDS. Brownfield sites could be contaminated and there is a need to include best practice related to assessment for its development and prevention of contamination of groundwater as a result of the development. Previously developed land may have been contaminated by a variety of land uses, such as fuel filling stations, gas works, and other industrial sites. Contamination could pose a risk to the health of current and future occupants of the housing development and to the environment. The risk must be identified early to establish the mitigation process or action to be taken. Annex 2 of PPS23[40] provides advice on handling contaminated land in the planning system, including submission of planning applications.

The incorporation of SUDS is commonplace in housing developments in Scotland, where more than 40% of sites that incorporated SUDS have been developed on brownfield lands.[111] SUDS offers a variety of techniques which can be selected to suit the particular requirements of a site, although selection of a SUDS technique will be based on the 'suitable for use' principle of redevelopment. Brownfield sites are often located in urban areas, where local watercourses are already polluted by urban and industrial drainage, which is exacerbated by flooding. Incorporating SUDS ameliorates some of the pollution load and flood risks; where the sites are served by an existing combined sewer the incorporation of SUDS and the reduced run-off of stormwater to sewers reduces the discharge of untreated sewage wastewater to downstream watercourses. Recycling land helps to regenerate the environmental quality of urban areas and enhances the biodiversity value of the new development. The scope for mitigating the ecological impact of previously developed and derelict land offered by SUDS features is an important part of assessment and masterplanning. The restoration strategy integrating SUDS should be based on the site characteristics.

In Scotland Planning Advice Note 33 *Development of contaminated land* (PAN33)[112] provides a framework for a structured approach to land remediation through the planning process; for a more detailed guide see *The SUDS Manual*.[6] In the case of possible land contamination by previous industrial and commercial applications, a 'source–pathway–receptor' assessment must be undertaken, whereby the sources of the hazard (eg heavy metals or industrial contamination), the receptor (eg public water supply borehole), and the pathway connecting the two (contaminated groundwater plume) are considered to identify risks and allow for suitable mitigation during the development process.

In Scotland, surface water discharges are regulated by a general binding rule or via a simple licence.[113] All proposals require initial assessment and screening to determine the type of authorisation applicable. Small-scale, low-risk developments (<25 houses and car parking spaces) are regulated by a general binding rule and large-scale, high-risk developments (>1000 houses and car parking spaces, industrial estates, retail parks, and motorways/major roads) are regulated by a simple licence. Risk assessment is required for all intermediate development proposals. Factors such as the nature of receiving water, dilution available, scale of proposed discharge, nature of land use, extent of existing pollution pressures, degree of urbanisation, and scale of any future anticipated development should all be taken into account. The following risk criteria should be in included:

- local water quality
- overall water body status
- designated conservation sites
- drinking water
- microbiological standards
- groundwater quality.

Low-risk developments involving SUDS need to consult SEPA. However, if the scale/location/nature of activity means that the proposed discharge poses a high risk to any of the above criteria, then the discharge should be licensed and may require ongoing monitoring and control. Incorporation of SUDS is required for all developments.

All efforts should be made to minimise the need for high-risk areas (fuel delivery/refuelling areas; vehicle loading or unloading bays and oil and chemical storage, handling and delivery areas) to discharge to the surface water drainage system (the sewer). A licence is required if there is no reasonable alternative other than to discharge to the surface water drainage system. The licence will specify controls including SUDS treatment and any additional treatment, eg oil interceptors required to protect the receiving waters. For activities that pose a risk of discharge of List I substances into the groundwater or a risk of groundwater pollution by other pollutants, a prior investigation must be undertaken before authorising such an activity. Development proposals that include a SUDS infiltration system require prior investigation for brownfield sites, industrial sites, petrol/fuel stations, and lorry parks. For other SUDS such as pervious paving and car park surfaces, roof water soakaways, and infiltration trenches serving housing and roads, no such prior investigation is required.

SUDS infiltration systems are not suitable for development in contaminated land, if the infiltration mobilises the contaminants into surface water or groundwater. The problem can be mitigated by using an impermeable layer separating the surface water drainage system from the contamination. The construction of the infiltration systems should be restricted to the areas that are not affected by contamination and therefore avoid contamination of surface water. The application of other SUDS techniques for attenuating and treating surface water are the same in brownfield land as in any other land. The design and construction of SUDS in contaminated land should take into account the likelihood of introducing a pathway where the aqueous and non-aqueous contaminants migrate, leading to contamination of ground and surface water. Therefore, the location of SUDS and other piped drainage systems should be carefully considered in the planning.

Selection of SUDS will depend on the requirement of the site development and land use. Table 10 provides a guide to the selection of SUDS for different development including development on brownfield sites.[113]

Table 10

SUDS selection for brownfield developments

Development	SUDS devices	Comments
Housing	Local control: pervious paving; filter drain; swales; soakaways; detention basins and ponds.	The SUDS will need to cope with dry weather contamination, absorb minor occasional contamination, as well as providing surface water treatment during rainy weather.
	Regional control: retention ponds and wetlands.	Source controls are the best practice and may in many situations be sufficient for small, low-risk housing developments. Generally, the source controls involve incorporation of gravel driveways, permeable paving, footpaths and driveways for individual houses; a swale alongside a road and alongside a back garden or in communal open space, a length of filter drain along other roads, water butts with overflows to soakaways or filter drain/swale.
Industrial estates	Local control: swales, detention basins. Regional control: retention ponds, stormwater wetlands.	Upstream oil interceptors may be required to protect SUDS from gross oil pollution. The incorporation of oil interceptors would generally not be adopted by local authorities and the owner should be responsible for the routine maintenance. Infiltration systems would not be appropriate due to the possible groundwater contamination and this should be assessed on a site-by-site basis.

(Table 10 contd.)

SUDS selection for brownfield developments		
Development	SUDS devices	Comments
Industrial estates and contaminated land	As industrial estates above, the use of infiltration systems would require careful consideration and may require impermeable layer to separate surface drainage water from contamination.	First level interception of pollutants and treatment by swales, then a retention pond and wetland system providing further treatment and flow attenuation. The retention capacity is achieved by two ponds in a series followed by wetland. Oil spillage retention and removal features are built into stage 1 pond. Key considerations: ▪ Measures to reduce risks of pollutants, removal of suspended particulates, local degradation of pollutants and attenuation of surface water ▪ Measures to reduce risk of contamination of surface and groundwater, detection of incidence and local controls ▪ Capping and containment remediation to prevent mobilisation of contaminants ▪ SUDS selection taking into account of soil types and water table, and requirement for risk management need, relevant for the development ▪ Cumulative impacts of development on combined sewers and spillage caused by combined sewage overflow ▪ Habitat enhancement to encourage biodiversity. Application of shallow grass swales and wetlands in contaminated land would provide beneficial treatment of pollutants and their incorporation would not increase the risk of groundwater contamination, although infiltration systems should not be used on sites that are not remediated. Appropriately designed pervious paving can offer advantage over traditional types of drainage systems. There would be no need to excavate deep trenches for drainage pipes, thus minimising the disposal cost of contaminated soil. The depth of excavation can be further reduced by using special high-strength geocellular boxes as sub-base.
Major roads	Local control: swales/filter drains and extended detention basins.	The requirement is to protect the water quality of the local environment from the contamination of hydrocarbon and oil spillage and particulate emissions from vehicles. Treatment can be provided by permanent wet ponds within detention basins. These will also encourage biodiversity by providing additional habitats.
	Regional control: larger ponds and wetlands for flood control.	Grassland, other vegetation, as well as filter strip can also provide additional treatment and degradation of pollution. Treatment can also be provided by detention of surface water in detention basins protected by filter drains and swales alongside roads.

10 Maintenance and management

The design, construction and incorporation of SUDS require a multifunctional approach to planning involving housing developers, landscape architects, building contractors, engineers, surface water consultants, environment consultants, sewerage undertakers, Environment Agency, local authorities, the Highways Agency, the Wildlife Trust, and other stakeholders. The success of SUDS depends largely on the adoption, maintenance, and management of SUDS and this requires effective transfer agreement of SUDS facilities from housing developers to the adoption authorities (the property owners, local authorities, highway authorities, and sewerage undertakers). *Model Agreements for Sustainable Water Management Systems. Model Agreements for SUDS* (C625).[58] provides the framework of a model agreement for the agreement processes for efficient transfer of SUDS to the adoption authorities who need to be involved at the outset of planning and during every stage of housing and SUDS development.

The planning and construction of SUDS have been described in section 5. There is a need for an agreement at the outset for independent validation and inspection, to ensure that proper construction of SUDS has been carried out in accordance with the design, planning, and good practice that is acceptable for the subsequent transfer. An owner's manual describing the SUDS concept and the specific requirements for the SUDS components must be provided at the outset of the construction to enable third-party inspection on behalf of the adoption authority. The manual includes specific maintenance plans for the SUDS facilities, including any dredging and cleaning during construction and development, and required at regular periods after development. The manual should also detail any material that might need replacing, recommendations for clearing silt, and requirements for planting to enable effective functioning of the SUDS components. The following should be included in the SUDS manual:

- Location of the SUDS.
- Description of the SUDS components, their functions and how these can be

damaged. The householder should be given a clear, simple guide for their understanding of SUDS, for example the householder should be informed that the surface water drainage is connected to the soakaways and any alteration or extension of the property will need to take this into account to avoid causing damage to the system.

- Explanation to the users that the surface water drainage is different from foul water sewers: sewerage systems should not be connected to the SUDS systems.
- Maintenance plan, and maintenance record, requirements.
- Explanation of detailing how the SUDS components can malfunction if maintenance is not carried out.
- Identification of areas where certain activities, eg storage of construction materials on SUDS surfaces, should not be allowed.
- Action plan for any accidental spillages of polluting substances.
- Advice about what can be altered or carried out if, for example, service companies need to excavate or undertake work at the location of the SUDS.

Most SUDS components can be maintained as part of the normal landscape site contract of the local authority or the relevant landowners; landscape maintenance can be adapted to include maintenance of SUDS surfaces, involving, for example, wetland vegetation maintenance, grass and landscape maintenance, and silt management. For SUDS components such as drainage systems in pervious paving, filter trenches, soakaways, and underground infiltration devices need regular maintenance by drainage engineers.

The risk of SUDS malfunctioning will depend mainly on the design, planning, and construction of SUDS and particularly the management of silt. The design of the SUDS takes into consideration the impact on water quality of surface water and catchments, stormwater flow rates, and run-off volumes; margin should be allowed to accommodate for events that could exceed these criteria to reduce risk of flooding or levels of pollution in the outflow effluent. Managing silt sedimentation is crucial for effective working of some SUDS components. The owner's manual should provide information about how silt accumulates and how to prevent this by trapping using filter strips, sediment forebays, and silt traps. The manual should recommend a schedule of regular silt maintenance, and removal should comply with waste management licensing requirements and wildlife considerations. Clean roof water discharging to a retention basin or pond where any pollutants contained in the run-off can degrade, requires a lower frequency for silt maintenance. However, run-offs collected from road, car and lorry parks contain a high sediment and pollution load, and these require higher frequency of maintenance. Some general examples of recommendations regarding maintenance for some types of SUDS are shown in Table 11.

The owner's manual should also contain guidance regarding conservation of wildlife habitats,[114] and should include the following considerations as recommended by CIRIA[6]:

- All wetland edges should have an uncut fringe at the margin of the lower bank.
- Careful planning to avoid maintenance work during breeding seasons and using machinery that could damage nesting birds or disturb birds' nests.
- Maintenance work in the area should not damage, destroy, or obstruct access of voles[115] (protected species) to their shelters or disturb them.
- Maintenance work should not be carried out from September to November within 1 mile (1.6 km) of wetland edges to protect banks and to avoid upsetting the breeding of sensitive animals.
- Maintenance of SUDS should consider the use of appropriate methods that cause the least damage to ecological habitats in the environment; if possible, maintenance work should be scheduled for September to November to protect species.

- Work to be carried out on ponds should be scheduled to avoid February to August. This is to protect great crested newt (protected species)[116] during their breeding season. The removal of silt and maintenance of pond plants (eg reeds) are compatible with newt conservation.
- There should be appropriate plans for dealing with plant waste generated from clearing of wetland banks, aquatic plant dredging, pruning and mowing of grasses.

Table 11

Operation and maintenance of some selected SUDS

SUDS	Maintenance requirements	Maintenance frequency
Pervious paving	Inspection for litters, clogging, weeds, and water puddles.	Immediately before handover to owner, then monthly and 48 hours after rainfall.
	Sweeping of dead leaves, vacuum cleaning of litters and weed removal.	Vacuum clean about twice a year and three surface sweeps per year (end of winter, mid-summer and after autumn leaf fall).
	Reconstruction (relaying).	As required and about every 15 to 25 years depending on use. Some materials would still be acceptable for reuse.
Swales and infiltration basins	Inspection of any areas not operating correctly, eg eroded areas, infiltration surfaces (soil and grass) have become compacted and silt-laden. Remove litters.	Monthly
	Record any areas of ponding for more than 48 hours.	Monthly
	Maintain grass height (50 mm above specified design water depth); do not cut during drought periods or when the soil and grass are wet.	As required and about twice a year.
	Remove plant cuttings from swales to dispose of pollutants absorbed by plants; accumulation of grass cutting can increase the nutrient load in swales and should be removed.	As required and about twice a year.
	Removal of thatch developed between zones of green plants and soil surfaces, during dry conditions and free from frost. To improve infiltration, break up silt deposits and prevent compaction.	As required
	Repair and reinstate design levels by returfing or reseeding.	As required
	Remove silt and dead/damaged vegetations.	As required
Infiltration/ filtration trenches, soakaways	Inspect silt traps and note rate of sediment accumulation.	Monthly during the first year and then half yearly.
	Inspect areas not operating correctly, infiltration surfaces that have become compacted and silt-laden.	Monthly
	Remove sediment from pre-treatment traps.	At least half yearly.
	Check observation well for clogging and to ensure emptying after dry weather.	Yearly
	Reconstruct, remove clogged filters and geotextiles and replace.	As necessary
Green roofs	Irrigation after planting and during initial establishment of plants.	As required during the first two years.
	Inspection for bare patches and replacement of plants.	Half yearly
	Removal of litters and debris.	Half yearly

11 Sustainability – social, economic, and environmental issues

Three aspects should be considered for SUDS to provide the basis for sustainable development for housing as required by the government policies for *Sustainable Construction*[1] and *Futures Water*[2]. These aspects are water quality, water quantity, and amenity. All development needs to provide drainage and management of surface water that will not affect the quality of groundwater or water catchments of the local water bodies, which can affect the water supply and increase the burden of further treatment cost for water companies. Management of water quality is required by the Water Framework Directive.[3]

One of the challenging issues for building and site designers and developers in the 21st century is providing adequate drainage of surface water. There is an increasing demand for new housing and commercial developments, which could cause increasing stress on the water supply. The government's Housing Green Paper (July 2007)[117] set a target to increase the rate of house-building in England to 240 000 homes per year: two million new homes by 2016 and three million by 2020. The changing environment as a result of global warming has further exacerbated the supply problem, as well as the increasing occurrence of flash flooding and heavy rain. Incorporating SUDS aims to balance environmental, social, and economic requirements for a site development to provide a sustainable, healthy, pleasurable environment for the new housing community as well as adequate management of surface water drainage by attenuating excess stormwater flow to reduce the risk of flooding having an impact on the social community. SUDS also reduce the impact on water quality by treating wastewater that could damage the water environment, affecting the ecological habitats of wildlife (invertebrates, birds and mammals), and by recharging the ground soil with an adequate flow of water, thereby reducing stress on water catchments. The provision of SUDS enhances the natural drainage of surface water and provides green space, which encourages further biodiversity, enhancing different species living and growing in the areas. The incorporation of SUDS can restore wetlands and habitats. The additional green space also provides amenity value for the residents in the housing development.

The benefits of green roofs have previously been discussed in this guide; these include a large reduction of rainwater run-off from the roof. The attenuation would reduce pressure on surface drainage systems, including sewage overflow, cleaning, and recycling of greywater and harvesting of rainwater; reduce air pollution and airborne particulates and dusts; reduce the urban island heat effect, screening for noise and electromagnetic radiation; reduce greenhouse gas emissions and cooling of the roofs by transpiration in the summer and insulation of the roofs against noise and thermal conduction, protecting roofs from damages caused by UV radiation and rooftop trafficking, as well as providing a pleasant environment in urban areas for people and enhancing biodiversity. Economics is an important factor for any housing developer to incorporate SUDS. Capital and maintenance costs are key factors that affect the profitability of a housing development. Although the capital cost of SUDS is somewhat lower than conventional drainage systems, there is a need to consider the maintenance cost, which can be significant in the long term for the adopting authorities. Economic considerations involve a whole life costing of the development, including estimation of future costs and present values.[118] The operation and maintenance costs incurred by SUDS have been compared with conventional systems for the benefits of property management companies, local authorities, and sewerage undertakers. Compared with conventional systems, SUDS have little risk of structural failure. Because SUDS do not require complicated structures and components (extensive ducts, piping, and sewerage network) for plumbing, labour and material costs for routine maintenance should be less than conventional drainage systems. Less excavation and disposal of soil than required for sewerage pipework could also result in cost savings. Conventional systems require discharge consents and enabling work to increase downstream sewers and large quantities of kerbs and gullies; further savings are therefore possible using SUDS.

There have been case studies showing the remedial saving by using SUDS and pervious paving for site developments[115, 116, 119] in place of conventional drainage discharge systems, where the sewerage undertaker objected to the discharge of stormwater from the site into surface water culverts at 30 m depth. The provision of a pervious paving system and SUDS attenuation ensured the discharge to a shallower drain did not exceed the limit required by the discharge consents, and also reduced the cost to a quarter of the original proposed drainage systems. Incorporating pervious paving and SUDS for a college car park also demonstrated a 50% saving by reducing the requirement for excavation, gully pots, and pipes but with additional benefits of flood and pollutant attenuation and groundwater recharge. Case studies of motorway services, schools, and commercial parks have also shown similar savings and benefits.

The construction industry is responsible for the greatest number of significant pollution incidences recorded by the Environment Agency in England and Wales. The construction industry must be informed of the value of good environmental practice and sustainable drainage to implement general environmental improvement and avoid fines or prosecution due to discharges of wastewater on construction sites. Incentives for using SUDS for draining surface water should be more than just regulatory, as in Scotland, or encouragement by the local authorities. The benefits of incorporating SUDS should be considered by designers and developers, with the reduced cost of construction being an additional encouragement. Flooding has been a regular issue in the UK in recent years; the cost of refurbishing flooded homes has been substantial. Although SUDS should not be considered as the only remedial flood prevention method, SUDS do reduce the flood. If SUDS have been included for the development in the region, their collective contributions would provide a suitable flood risk control for the area.

The restriction on land space should not be a barrier to incorporating SUDS; there is not a land space problem for incorporating pervious paving for driveways and car parks or incorporating green roofs to reduce run-off volume to surface drainage. Many urban pedestrianised areas can be laid using permeable tarmac or paviours, without having puddles forming in the roads or walkways. Swales, filter trenches, and soakaways along roadsides on major roads or in community areas do not generally use more space than that allocated for conventional roads, housing, and other developments.

Examples of the social, economic, and environmental benefits (Fig. 38) SUDS are demonstrated by case studies of SUDS incorporation in new school buildings.[120-123]

Figure 38 Caldecotte Lake in Milton Keynes.

APPENDIX

Source control

Source control should form part of surface water management.[123] Source control manages water using preventative measures, and these measures make a significant contribution minimisation surface water run-off. They include:

- Minimising paving areas, allowing surface water run-off to drain naturally through areas such as gardens and public green spaces.
- Using porous surfaces where possible.
- Capturing and recycling rainwater from roofs of buildings for use in flushing toilets, gardening and car washing.
- Minimising pollution by good practice, training, and information. Keeping paved areas clean, free of contamination from waste and litter, and informing the site managers how the site is drained.

Surface water management can be further supplemented by site control techniques, minimising the quantity of water discharged directly to a river. This includes:

- Infiltration devices to enhance the natural capacity of the ground to store and drain water. These consist of vegetated areas of land and grass verges (grass swales) which mimic the natural drainage systems and control discharges to ponds or wetlands or other discharge systems. These systems help to remove solid particles and pollutants before discharge into water effluent.
- Soakaways and trenches creating underground reservoirs, which allow surface water to gradually infiltrate subsoil or discharge to another structure at a controlled rate.
- Basins, ponds and wetlands to store surface water run-off infiltrated through the soil. These control temporary flooding, allowing settlement of solids and pollutants, or exist as a permanent water feature for the site.
- Where surface water cannot be stored on site, techniques should be employed to allow water to drain away to a point where it can be returned to the water cycle. These systems contribute to the flow and quality of run-off. They include filter drains, swales, and infiltration devices.
- Separate drainage systems should be provided when materials used or stored on site could cause pollution. There should be a separator or treatment system to intercept the flow and the flow should be discharged into a system suitable for receiving the polluted effluent, eg, in car parks and petrol filling stations.[10]

The outcome of masterplanning[7] should include a policy review of sustainability issues such as contaminated land, pollution load and chemical discharges, water efficiency and utilisation, drainage and water treatment, the use of sustainable products, resource efficiency and waste management, and impacts of urban and built environments, land development, and communities that could have an important contribution to the surface water quality. There should also be a review of codes of practice, including criteria and guidelines for different site operations, site history (eg mines, landfills, industrial discharges, oil depot, household and commercial waste dumps). If necessary, developing containment and defensive measures against flood; managing soil erosion, waste and industrial contamination; and avoiding future damage by pests, malpractice, discharge, and waste disposal should be considered.

SUDS provide a flexible approach to drainage and involve techniques ranging from soakaways to large-scale retention ponds and wetlands. These techniques are used in series in a management train as shown in Figure 1, appropriately designed for the requirement of a particular site development. Several management techniques or SUDS devices will be required to reduce the volume of run-off and to treat the polluted water. The management train for the drainage system should meet the criteria for water quality, quantity, and amenity, although one or two of the criteria will be the dominant factors in some site developments.

Pollution

The run-off may contain substances that can harm the water quality of nearby water catchments when wastewater flows into drains and watercourses, thus affecting the ecology of water catchment habitats, drinking water resources, and amenities. Misconnections of foul water to surface water either by flooding or poor plumbing work exacerbate surface water quality. Flooding also removes large quantities of surface water over a short period of time, leading to erosion of riverbeds, damaging watercourses and habitats. The following activities can cause diffuse pollution and should be included for environmental impact assessment, monitoring, and regulation:

- transport and use of heavy lifting and loading equipment (motor vehicles and trucks), leading to leaks/spillages of hazardous chemicals, oils, transmission fluid, lubricants, and hydrocarbon fuels
- storage and filling of fuels, power generation leading to discharges of petroleum gases and diesels
- supply of industrial and natural gases, leading to emissions of hydrocarbons
- detergent, bleach, and sanitation fluid, soap solution run-offs from cleaning/washing activities
- pesticides/herbicides/fungicides run-off from weed eradication, gardening and maintenance of grass areas, fungicide wash, insect and pest control and timber treatment
- coating, painting, and solvent cleaning of surfaces and irresponsible disposal of paints
- graffiti removal, leading to run-off of suspended substances
- de-icing of roads, giving off salts and de-icing chemicals
- food and drink waste
- effluent and sewage discharges, leaking sewer, blockages and misconnections, and flooding
- traffic-emitted dusts and particulates containing heavy metals from motor fuel combustion, brake linings, tyre and road surface wearing, eg Cu, Cr, Pb, Ni, Zn
- laying of roads with tarmac, leading to leaching of polyaromatics and bituminous substances
- roofing, sealing, and damp-proofing of buildings with bituminous emulsion and coating
- preparation of concrete and mortars on site, and constructing with concrete and mortars leading to discharges of cement particles, chemicals, and additives
- burning of wastes on site and fire-fighting leading to the use of foam chemicals, gases, and fluid, also emissions of fire residues to water
- sediment run-off and soil disturbance resulting from road work, land clearance and cutting of trees
- dredging of contaminated material and leaching of chemicals from contaminated land (eg former industrial sites, landfills and abandoned mines)
- excavations leading to discharge of suspended solids
- chemical waste and spillage from site activities
- waste disposal and disposal of unused liquid and paste materials from construction.

Table 12

Source and hazard assessment for authorisation for discharge into groundwater[8]

Source	Requirement for authorisation
Car park	Not normally required – if properly constructed, ie in accordance with *The SUDS Manual.*[6]
Industrial sites, major commercial sites	Required
Local roads	Not normally required – but if necessary to prevent listed substances entering or polluting groundwater or polluting surface waters, the Environment Agency will serve notice to control the discharge.
Lorry park, garage forecourt – outside canopy	Required
Major roads	Not normally required – but if necessary to prevent listed substances entering or polluting groundwater, the Environment Agency will serve notice to control the discharge.
Residential area, amenity	Not normally required – provided discharge is not direct to soakaway and in accordance with good practice.
Roof drainage	Not normally required – provided it is a sealed system.
Surface water sewer	Required

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Efficient design of pile foundations for low-rise housing This guide considers piled foundations for low-rise housing developments. It explores different design approaches and the associated environmental and economic advantages, which can save money and be more efficient by reducing the use of natural resources.
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Water efficiency in new homes This guide, specifically intended for the smaller builder, provides an introduction to water efficiency. It outlines the standards being encouraged by the Code for Sustainable Homes, the Building Regulations and the Water Efficiency Calculator for New Dwellings. The technologies used to achieve water efficiency – ranging from simple tap flow restrictors all the way through to greywater recycling systems – are described, together with some key issues associated with each. ***NF20*** October 2009

Open plan flat layouts – assessing life safety in the event of fire
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NHBC Foundation publications in preparation

- Homeowner expectations of new housing
- Zero carbon: Allowable solutions – energy efficient appliances and controls
- Building sustainable homes at speed: Risks and rewards
- Zero carbon homes: Low and zero carbon cooking appliances

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Housing research in partnership with BRE Trust
www.nhbcfoundation.org

A simple guide to Sustainable Drainage Systems for housing

As reduction in water usage and treatment is becoming more important, developers are encouraged to look at the dispersal of any unwanted surface water via various sustainable drainage options either at, or close to, the development. These water management measures all work towards achieving sustainable development to comply with the Code for Sustainable Homes and further legislation such as Article 6 of the Groundwater Directive and The Floods and Water Management Act.

This pragmatic guide to sustainable drainage systems is aimed at introducing the concept of SUDS and increasing the awareness of government policies and regulation in this area. Technical guidance is included for the differing options, their selection parameters, construction requirements and maintenance issues. The guide also covers relevant social and environmental issues, together with the health and safety considerations for incorporating these systems in housing developments.

NHBC FOUNDATION

Housing research in partnership with BRE Trust

The NHBC Foundation has been established by NHBC in partnership with the BRE Trust. It facilitates research and development, technology and knowledge sharing, and the capture of industry best practice. The NHBC Foundation promotes best practice to help builders, developers and the industry as it responds to the country's wider housing needs. The NHBC Foundation carries out practical, high quality research where it is needed most, particularly in areas such as building standards and processes. It also supports house builders in developing strong relationships with their customers.

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