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The SUDS manual

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The SUDS manual

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Summary

This guidance provides best practice guidance on the planning, design, construction, operation and maintenance of Sustainable Drainage Systems (SUDS) to facilitate their effective implementation within developments.

The guidance supersedes previous general guidance on SUDS and addresses landscaping, biodiversity issues, public perception and community integration as well as water quality treatment and sustainable flood risk management.

This book constitutes Environment Agency R&D Report SCO20114/2.

A handbook – *Site handbook for the construction of SUDS* (C698), has also been produced.

Acknowledgements

Research contractor

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Following CIRIA's usual practice, the research project was guided by a steering group, as listed below.

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	Paul Davies/David Bowen	Biwater
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- WSP Development

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Executive summary

Surface water drainage systems developed in line with the ideals of sustainable development are collectively referred to as Sustainable Drainage Systems (SUDS). Appropriately designed, constructed and maintained SUDS are more sustainable than conventional drainage methods because they can mitigate many of the adverse effects of urban stormwater runoff on the environment. They can achieve this through:

- reducing runoff rates, thus reducing the risk of downstream flooding
- reducing the additional runoff volumes and runoff frequencies that tend to be increased as a result of urbanisation, and which can exacerbate flood risk and damage receiving water quality
- encouraging natural groundwater recharge (where appropriate) to minimise the impacts on aquifers and river baseflows in the receiving catchment
- reducing pollutant concentrations in stormwater, thus protecting the quality of the receiving water body
- acting as a buffer for accidental spills by preventing direct discharge of high concentrations of contaminants to the receiving water body
- reducing the volume of surface water runoff discharging to combined sewer systems, thus reducing discharges of polluted water to watercourses via Combined Sewer Overflow (CSO) spills
- contributing to the enhanced amenity and aesthetic value of developed areas
- providing habitats for wildlife in urban areas and opportunities for biodiversity enhancement.

To mimic natural catchment processes as closely as possible, a “management train” is required. This concept is fundamental to designing a successful SUDS scheme – with drainage techniques in series incrementally reducing pollution, flow rates and volumes of runoff. Through effective control of runoff at source, the need for large flow attenuation and flow control structures is reduced. Effective sediment management and maintenance is vital to ensure the long-term effectiveness of all SUDS techniques. The passage of water between individual parts of the management train should be considered through the use of natural conveyance systems wherever possible. Overland flow routes will also need to be explicitly considered to ensure that floodwater is managed safely during extreme events

The variety of SUDS components and design options available allows designers and planners to consider local land use, land take, future management scenarios, and the needs of local people when undertaking the drainage design. Active decisions have to be made that balance the wishes of different stakeholders and the risks associated with each design option.

Like traditional drainage systems maintenance is a very necessary and important consideration of SUDS design, and sufficient thought should be given during feasibility and planning stages to long-term maintenance and its funding. Unlike conventional drainage systems, most SUDS features should be visible and their function should be easily understood by those responsible for maintenance. When problems occur, they are generally obvious and are remedied simply by using standard landscaping practice. If systems are properly monitored and maintained, any deterioration in performance can often be managed out.

Unlike conventional drainage, SUDS schemes often form part of public open space, with the potential to promote interaction between communities and their local environment, resulting in additional amenity benefits. With SUDS being championed within the UK, public understanding of the philosophy driving their implementation becomes increasingly important for the contribution to sustainable development and acceptance by local residents.

This guidance document is aimed at providing comprehensive advice on the implementation of SUDS in the UK. It provides information for all aspects of the life cycle of SUDS, from initial planning, design through to construction and their management in the context of the current regulatory framework. It also provides information about landscaping, waste management and costs, as well as maximising opportunities for community engagement.

Introduction to this document

SCOPE OF GUIDANCE

This publication provides guidance on the planning, design, construction and maintenance of Sustainable Drainage Systems (SUDS) to assist with their effective implementation within developments. The guidance addresses landscaping, biodiversity issues, public perception and community involvement as well as water quality treatment and flood risk management. A separate publication to complement this document, *Site handbook on the construction of SUDS* (C698), has also been produced.

This publication is intended for use by developers, site owners, landscape architects, consulting engineers, local authorities, architects, highway and road authorities, environmental regulators, planners, sewerage undertakers, contractors, and other organisations involved in the implementation and operation or maintenance of surface water drainage for both new and existing developments.

To help the reader navigate the guidance manual, the following table identifies where key information is located within the document and suggests key reader interest. The flowchart that follows shows how the material in the different chapters supports the SUDS implementation process. Each chapter is separated by a tab divider to make navigation easier.

Chapter	Content
1 Introduction	... presents the principal drivers for a more sustainable approach to drainage, describes the SUDS philosophy and processes involved, and summarises and categorises the main SUDS techniques. *All readers*
2 Roles, responsibilities & regulation	... presents the roles and responsibilities of the major stakeholders concerned with the effective planning, design, construction and operation of SUDS, including water utilities, environmental regulators and highway authorities. The chapter also provides details of the land use planning system and the legislative and regulatory framework that supports SUDS implementation. *Planners, regulators and SUDS practitioners*
3 Design criteria	... sets out a framework for designing a system to effectively drain the required area to protect the health and safety of the public and preserve the environment. SUDS should be designed to agreed standards that take account of hydraulic, water quality, amenity and ecology objectives. *Planners, regulators and SUDS practitioners*

4 Design methods

... presents the tools and techniques required to estimate storage, infiltration and conveyance systems in meeting the drainage criteria for the site.

SUDS practitioners

5 SUDS selection

... presents the process by which appropriate SUDS options may be selected for a site and discusses the requirements for, and development of, a suitable "management train".

Planners, regulators and SUDS practitioners

6 Source control

... presents the key options for managing stormwater as close to the "source" as possible, ie minimising the runoff rates and volumes transferred from property to site control and site control to regional controls. Good site design is discussed, followed by specific source control practices that are mainly concerned with the management, disposal and reuse of roof runoff (green roofs, soakaways and rainwater harvesting systems).

SUDS practitioners

7 Pre-treatment

... describes a range of pre-treatment devices that may be used to manage sediment and other debris upstream of SUDS components.

SUDS practitioners

8–18 SUDS components

... present the design, construction and specific maintenance details for sustainable drainage system components including:

- source control techniques
- pre-treatment systems
- green roofs
- soakaways
- water butts
- rainwater harvesting systems
- filter strips
- filter trenches
- infiltration trenches
- swales
- bioretention
- pervious pavements
- geocellular systems
- sand filters
- infiltration basins
- detention basins
- ponds
- stormwater wetlands.

SUDS practitioners

19 Inlets and outlets

... presents a sustainable approach to the provision of inlet and outlet infrastructure, including a range of hydraulic control options for both small and large SUDS systems.

SUDS practitioners

20 Landscaping

... presents site landscaping, plant selection and management, and planting guidance. Landscaping is critical to both the function and appearance of SUDS systems and has ecological and economic value that can be overlooked.

SUDS practitioners, owners and contractors

21 Construction

... describes construction best practices that are applicable to all SUDS techniques. This is critical as the construction of SUDS may require different skills from those employed for traditional drainage infrastructure. Poor construction practices can significantly affect SUDS performance and long-term maintenance requirements.

SUDS practitioners and contractors

22 Operation maintenance

... describes the different levels of operation and maintenance that may be required at a site, the different activity categories and detail on each activity and plant management practices. The chapter discusses the principles of landscape maintenance, including the preparation of relevant landscape documentation as a tool to facilitate SUDS management.

SUDS practitioners, owners and contractors

23 Waste management

... describes the properties and categorisation of SUDS waste, and the extraction, processing and disposal options available for waste such as sediments, vegetation, contaminated geotextiles and other structural material arising from the maintenance of SUDS schemes. This is set in the context of current regulations and legislation.

SUDS practitioners, owners and contractors

24 Community engagement

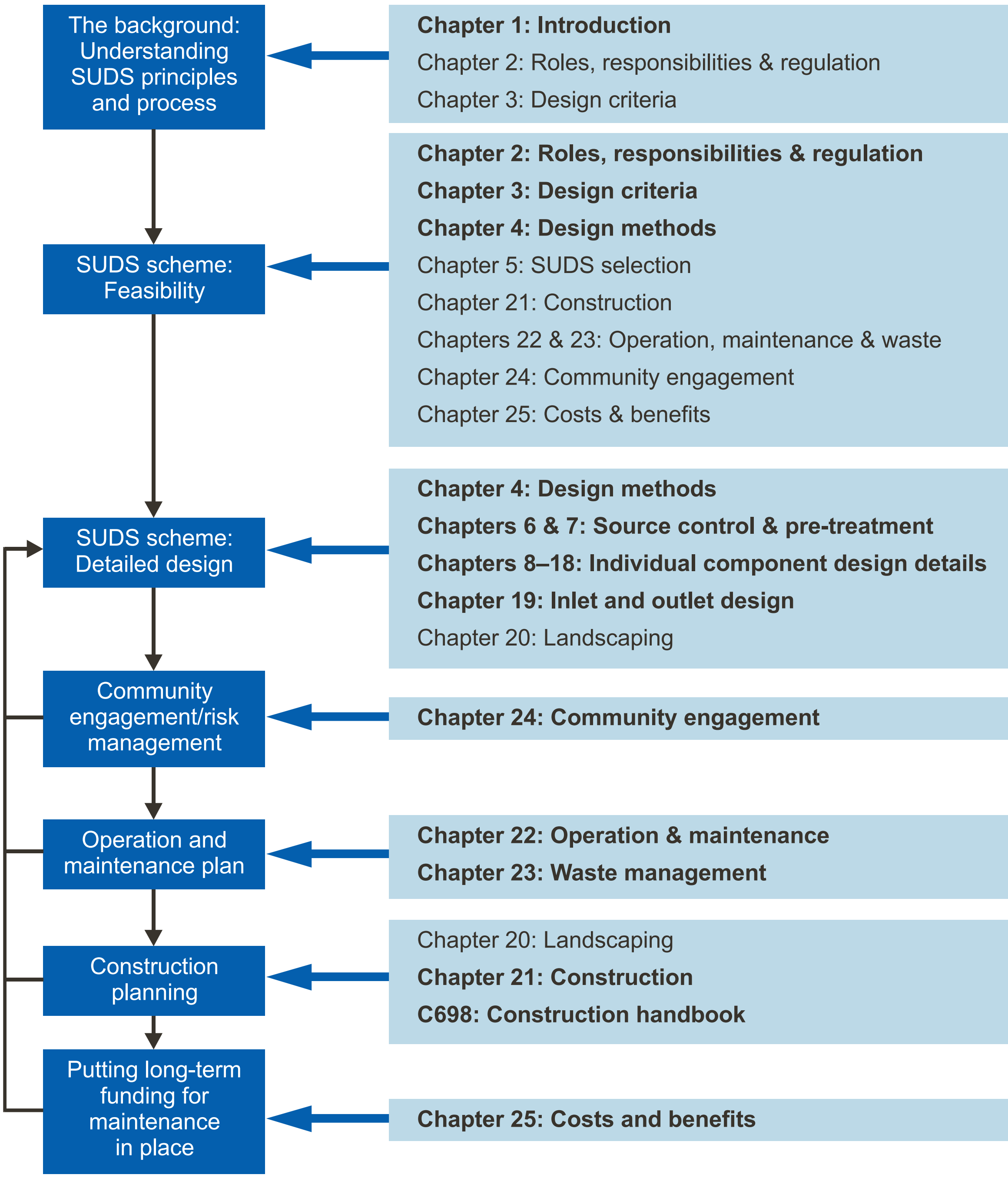
... describes the influences on public perception of surface water drainage components; methods of raising public awareness, public education and public engagement; facilitating the integration of SUDS within local communities, and managing public health and safety concerns.

Planners, SUDS practitioners, owners and contractors

25 Costs & benefits

... presents the suite of initial and long-term costs that are likely to be required to support optimum performance of a SUDS scheme, and the range of environmental benefits that may accrue. The chapter presents a framework for using a whole life costing approach for scheme costing, and discusses potential economic valuation options for benefit assessment.

Planners, SUDS practitioners and owners.


The background: Understanding SUDS principles and process
SUDS scheme: Feasibility
SUDS scheme: Detailed design
Community engagement/risk management
Operation and maintenance plan
Construction planning
Putting long-term funding for maintenance in place
Chapter 1: Introduction
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Chapter 2: Roles, responsibilities & regulation
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Chapter 4: Design methods
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Chapters 8–18: Individual component design details
Chapter 19: Inlet and outlet design
Chapter 20: Landscaping
Chapter 24: Community engagement
Chapter 22: Operation & maintenance
Chapter 23: Waste management
Chapter 20: Landscaping
Chapter 21: Construction
C698: Construction handbook
Chapter 25: Costs and benefits

RELATIONSHIP TO OTHER GUIDANCE

This document provides comprehensive guidance on the planning, design, construction and operation and maintenance of SUDS. This report is a compendium of current best practice guidance and provides an overview of key principles and technical detail required for the successful implementation of SUDS. This publication effectively replaces the *Sustainable urban drainage systems – design manual for Scotland and Northern Ireland* (C521) and *Sustainable urban drainage systems – design manual for England and Wales* (C522). It also provides a revised and rationalised compendium of the *Sustainable urban drainage systems – best practice manual for England, Scotland, Wales and Northern Ireland* (C523) and *Sustainable drainage systems. Hydraulic, structural and water quality advice* (C609).

Increasingly, SUDS are replacing traditional piped systems as the preferred or required drainage solution. As experience of SUDS implementation and long-term maintenance increases across the UK, so lessons will be learned. In addition, there are a number of organisations undertaking research on SUDS, both in the UK and overseas.

This document does not include information on the allocation of long-term responsibility for maintenance of SUDS which for England and Wales is currently covered in CIRIA publication C625 *Model agreements for SUDS* and the Interim Code of Practice for SUDS. In Scotland this will be covered by Sewers for Scotland However, it does outline the maintenance tasks required for the continued successful operation of SUDS components. In addition, this guidance does not cover the specific technical challenges and planning issues associated with the replacement of traditional drainage systems with SUDS solutions at existing development sites (SUDS retrofit). However the design of retrofit components should follow the same principles.

There are a large number of other guidance documents (including several CIRIA publications) which should be used to provide additional detail on specific areas. These are referenced at the end of individual chapters and a few of the key documents are given in the following table.

Document title	Description
Sustainable urban drainage systems – best practice manual, CIRIA publication C523 (Martin *et al*, 2001).	Provides good practice guidance in the use of SUDS and addresses issues surrounding their use. The main concepts are summarised in this document.
Source control using constructed pervious surfaces, CIRIA publication C582 (Pratt *et al*, 2002).	Provides technical detail on the design and construction of pervious pavements used for source control.
Sustainable drainage systems – hydraulic, structural and water quality advice, CIRIA publication C609 (Wilson *et al*, 2004).	Technical review of existing information on the performance and design of sustainable drainage systems. Design information is presented in this document.
Model agreements for sustainable water management systems. Model agreements for SUDS, CIRIA publication C625 (Shaffer *et al*, 2004).	Provides detailed guidance on the approach to securing long-term maintenance for SUDS and includes model agreements for maintaining SUDS through the planning process and a private SUDS model agreement.

Document title	Description
Designing for drainage exceedance in urban drainage – good practice, CIRIA publication C635 (Balmforth *et al*, 2006)	Provides detailed guidance on the design and management of urban sewerage and drainage systems to reduce the impacts that arise when flows exceed their capacity.
RP714 *Building Greener – guidance on the use of green roofs, green walls and complementary features on buildings*. (CIRIA publication C644) (Newton *et al*, in preparation	Provides an assessment of published data on green roof and wall performance providing guidance on their design, construction and operation.
Interim code of practice for SUDS, NSWG publication, (NSWG, 2004).	An overview of the technical and planning considerations for the implementation of SUDS as well providing options for allocating responsibility for the long term maintenance of SUDS.
Guide for the drainage of development sites (Kellagher, 2004) HR Wallingford Report SR574 and CIRIA publication X108 *Drainage of development sites – a guide*	Provides guidance on the design of foul and surface water drainage systems for developments.
Use of SUDS in high density developments (Kellagher *et al*, 2005) HR Wallingford Report SR666	Provides guidance on achieving sustainable drainage within high density developments.
Performance and Whole Life Costs of Best Management Practices and Sustainable Urban Drainage Systems (UKWIR Report 05/WW/03/6)	A detailed review of the performance and costs of systems across both the US and the UK. Outputs include a whole life cost model for a range of SUDS components.
Sewers for Adoption 6th Edition, (WRc 2006)	Provides guidance for those planning designing and constructing sewers and pumping stations for subsequent adoption by water companies.

There are also a wide range of policy statements and guidance relating to planning and building control. Further information on these can be found in Chapter 2.

Information can also be found on CIRIA's SUDS website at www.ciria.org/suds

Introduction to SUDS

1

Contents

Introduction to SUDS

1

This chapter presents the principal drivers for a more sustainable approach to drainage, describes the SUDS philosophy and processes involved, and summarises and categorises the main SUDS techniques.

1.1 SUSTAINABLE DRAINAGE SYSTEMS

Surface water drainage systems developed in line with the ideals of sustainable development are collectively referred to as Sustainable Drainage Systems (SUDS). At a particular site, these systems are designed both to manage the environmental risks resulting from urban runoff and to contribute wherever possible to environmental enhancement. SUDS objectives are, therefore, to minimise the impacts from the development on the quantity and quality of the runoff, and maximise amenity and biodiversity opportunities. The three-way concept, set out in Figure 1.1, shows the main objectives that the approach is attempting to achieve. The objectives should all have equal standing, and the ideal solution will achieve benefits in all three categories, although the extent to which this is possible will depend on site characteristics and constraints. The philosophy of SUDS is to replicate, as closely as possible, the natural drainage from a site before development.

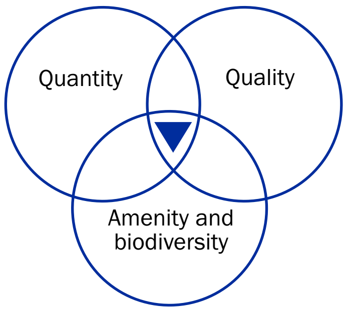


Figure 1.1 *Sustainable drainage objectives*

SUDS designs should aim to reduce runoff by integrating stormwater controls throughout the site in small, discrete units. Through effective control of runoff at source, the need for large flow attenuation and flow control structures should be minimised. Brief preliminary descriptions of a range of SUDS components are given in Table 1.1, and their capabilities are set out later in the chapter (Table 1.7).

Table 1.1 *Typical SUDS components*

Component	Description	Example
Filter strips	These are wide, gently sloping areas of grass or other dense vegetation that treat runoff from adjacent impermeable areas.	
Swales	Swales are broad, shallow channels covered by grass or other suitable vegetation. They are designed to convey and/or store runoff, and can infiltrate the water into the ground (if ground conditions allow).	
Infiltration basins	Infiltration basins are depressions in the surface that are designed to store runoff and infiltrate the water to the ground. They may also be landscaped to provide aesthetic and amenity value.	
Wet ponds	Wet ponds are basins that have a permanent pool of water for water quality treatment. They provide temporary storage for additional storm runoff above the permanent water level. Wet ponds may provide amenity and wildlife benefits.	
Extended detention basins	Extended detention basins are normally dry, though they may have small permanent pools at the inlet and outlet. They are designed to detain a certain volume of runoff as well as providing water quality treatment.	

Table 1.1 *Typical SUDS components (continued)*

Component	Description	Example
Constructed wetlands	Constructed wetlands are ponds with shallow areas and wetland vegetation to improve pollutant removal and enhance wildlife habitat.	
Filter drains and perforated pipes	Filter drains are trenches that are filled with permeable material. Surface water from the edge of paved areas flows into the trenches, is filtered and conveyed to other parts of the site. A slotted or perforated pipe may be built into the base of the trench to collect and convey the water.	
Infiltration devices	Infiltration devices temporarily store runoff from a development and allow it to percolate into the ground.	
Pervious surfaces	Pervious surfaces allow rainwater to infiltrate through the surface into an underlying storage layer, where water is stored before infiltration to the ground, reuse, or release to surface water.	
Green roofs	Green roofs are systems which cover a building's roof with vegetation. They are laid over a drainage layer, with other layers providing protection, waterproofing and insulation.	

1.2 DRIVERS FOR A SHIFT TO SUSTAINABLE DRAINAGE

1.2.1 Drainage – an historical context

The traditional method of draining excess surface water from built-up areas has been through underground pipe systems. These systems are designed to prevent flooding locally by conveying the water away as quickly as possibly. Historically, surface water runoff has been combined with sewage flows through a single, combined sewer. However surface water from rainfall can place a significant and unpredictable burden on wastewater treatment works, triggering some untreated sewage to spill into receiving watercourses via combined sewer overflows (CSOs) and cause pollution. Over the last 50 years, separate sewerage networks have generally been provided for the foul and the surface water systems. The foul water is piped to the wastewater treatment works, while the surface water is piped to the nearest watercourse. These separate surface water sewers reduce the risk of CSO spills but still transfer the pollutants present in runoff from the urban surface directly to the receiving water body.

The water cycle is one of the most critical processes to supporting life on this planet, and fresh waters are central to all aspects of our lives. Historically, urbanisation has led to the loss and degradation of wetlands, rivers and groundwater resources through pollution, resource depletion and construction within the natural floodplains. Traditional drainage systems have not generally been designed with sustainability in mind, and most have paid insufficient regard to effective catchment flood control, water quality management, water resources, amenity, or biodiversity requirements. The following sections introduce the key drivers for a move towards more sustainable drainage solutions.

1.2.2 The impacts of urbanisation

Rainfall runoff

Development may reduce the permeability of the land surface by replacing free draining ground with impermeable roofs, roads and paved areas that are drained by pipe or channel systems. Clearing of the area removes the natural vegetation that intercepts, slows and returns rainfall to the air through evapotranspiration (evaporation and transpiration). During development, the natural surface vegetated soils are removed and the subsoil is compacted. All these processes reduce the amount of water that can infiltrate into the ground, and significantly increase the rate at which water runs off the surface.

Figure 1.2 shows the change in pre- and post-development hydrological processes, and Figure 1.3 demonstrates the impact of these changes on the resulting runoff hydrograph.

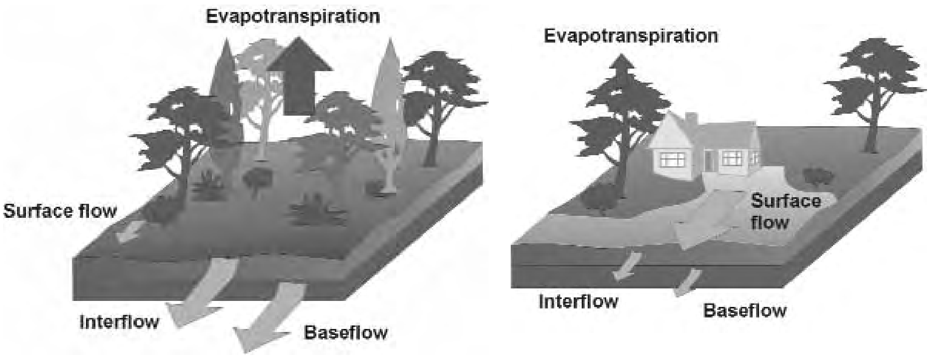


Figure 1.2 *Pre- and post-development hydrological processes*

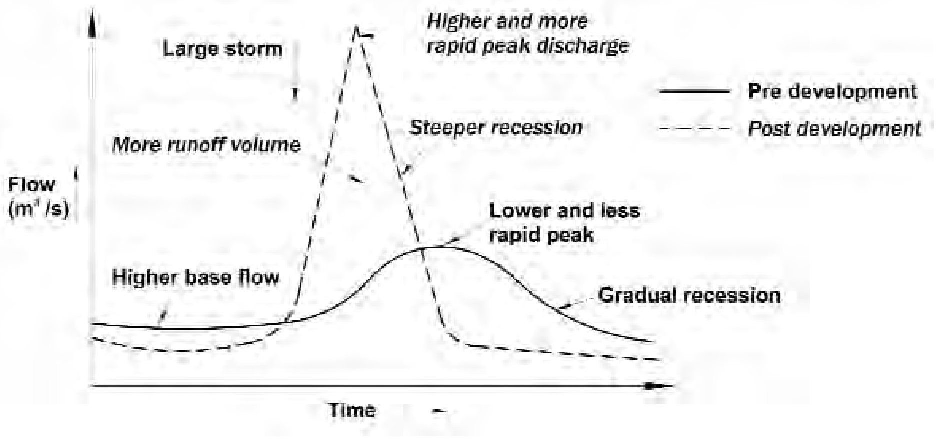


Figure 1.3 *Pre- and post-development runoff hydrographs following storm rainfall over an urban area*

The alteration of natural flow patterns (both in terms of the total quantity of runoff and the peak runoff rates) may lead to flooding and channel erosion downstream of the development. The decrease in percolation into the soil can lead to low baseflows in watercourses, reduced aquifer recharge, and damage to in-stream and streamside habitats.

Water quality

Man's activities give rise to a large number of pollutants such as sediments, oils, grits, metals, fertilisers, pesticides, salts, pathogens and litter that, along with animal waste, can affect public health and cause environmental damage. Contaminated land sites pose additional problems because of the risk that polluted soil and other debris may be washed into surface waters with rainfall runoff. Accidental spills can include liquids (eg oil or milk spills from tankers), or discharges resulting from vehicular accidents, misconnections, and industrial process leakage. These pollutants are collectively termed "urban diffuse pollution" as they do not arise from a single source or activity, but are the product of all the land use and human activity in the urban area. Rainwater mobilises these pollutants which are then washed into surface water sewers and eventually into rivers, or into groundwater.

The loss of topsoil and vegetation removes a valuable filtering mechanism for runoff, and because traditional drainage systems are designed to carry water away quickly without treatment, they transfer pollutants rapidly to receiving waters downstream of the development.

Table 1.2 summarises the impacts of urbanisation on runoff quantity and quality and on the morphology of the receiving watercourse. Table 1.3 presents the sources of pollution from impermeable surfaces, and the typical pollutant classes.

Table 1.2 *Impacts of development*

	Processes	Impacts	Environmental effects
Changes to stream flow	• reduced infiltration and evapotranspiration • rapid urban area drainage • reduced infiltration, interflow, recharge.	• increased runoff volumes • increased peak runoff rates • increased downstream flooding • reduced baseflows.	Unrestrained discharges from a developed catchment can be orders of magnitude greater than those for an undisturbed catchment.
Changes to stream morphology	• increased stream profile instability • increased erosion rates • sediment deposition • increased flow rates and flood frequency • floodplain development (including in-channel structures, bridges, culverts).	• stream widening • stream erosion • loss of streamside tree cover • changes in channel bed profiles.	Channels widen to accommodate and convey the increased runoff. More frequent events undercut and scour the stream bank. Tree root zones are eroded and trees uprooted. Channel erosion and extra sediment sources cause deposition as sandbars or substrate.
Impacts to aquatic habitat	• increased flow rates and flood frequency • loss of riparian vegetation • increased erosion rates • sediment deposition • reduced habitat variability • reduced baseflows • stored runoff, from warm urban areas.	• degradation to habitat structure • loss of pool-riffle structure • increased stream temperatures • decline in abundance and biodiversity • siltation/sedimentation.	Higher flows can wash away biological communities. Streambank erosion and loss of riparian vegetation reduce habitat. Sediment deposits can smother stream-bed aquatic habitat, and pools and riffles are replaced with more uniform streambeds. Increased temperatures reduce oxygen levels and disrupt the food chain. Composition of the aquatic community will deteriorate with poorer quality waters.
Water quality impacts	• decomposition of organic matter present in runoff (uses up oxygen) • wash-off of fertiliser, vegetative litter, animal wastes, sewer overflows, septic tank seepage, sewage spills, detergents • dash-off of oils, greases, diesel/petrol • wash-off from industrial and commercial sites, rooftops, vehicles, household chemicals, landfills, hazardous waste sites.	• reduced oxygen in receiving waters • nutrient enrichment (eg raised nitrogen, phosphorous concentrations) • pathogen contamination • hydrocarbon contamination (eg TPH, PAH, VOCs, MTBE) • increased levels of toxic materials (eg metals, pesticides, cyanides) • raised sediment loads, sedimentation • raised water temperatures • litter and debris • weed and algal growth.	Oxygen depletion weakens stream life and affects the release of toxic chemicals from sediments deposited in the watercourse. Increased nutrient levels promotes weed, algal growth, eutrophication. Can result in fish kills. The level of bacteria found in urban runoff can exceed public health standards for water contact recreation. Toxic materials (including hydrocarbons) kill aquatic organisms and accumulate in the food chain. Their presence increases drinking water treatment costs. Construction site runoff, exposed soils, street runoff, and stream erosion are the primary sources of sediment in urban runoff. Debris, litter, weed, algae and sewage spills are aesthetically unattractive, obstruct flow paths and present risks to humans, flora and fauna.

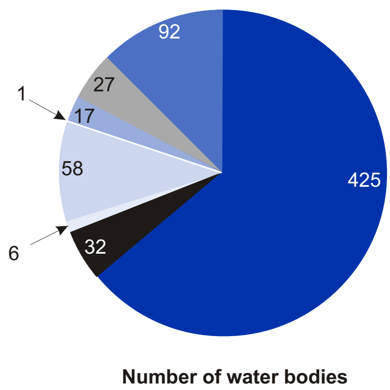
Table 1.3 *Sources of pollution from impermeable surfaces (adapted from Wilson et al, 2004)*

Source	Typical pollutants	Source details
Atmospheric deposition	Phosphorous, nitrogen, sulphur Heavy metals (lead, cadmium, copper, nickel, zinc, mercury) Hydrocarbons.	Industrial activities, traffic air pollution and agricultural activities all contribute to atmospheric pollution. This is deposited as particulates. Rain also absorbs atmospheric pollutants.
Traffic – exhausts	Hydrocarbons MTBE Cadmium, platinum, palladium, rhodium.	Vehicle emissions include polycyclic aromatic hydrocarbons (PAH) and unburned fuel and particles from catalytic converters.
Traffic – wear and corrosion	Sediment Heavy metals (lead, chromium, copper, nickel, zinc).	Abrasion of tyres and corrosion of vehicles deposits pollutants onto the road or car parking surfaces.
Leaks and spillages (eg from road vehicles)	Hydrocarbons Phosphates Heavy metals Glycols, alcohols.	Engines leak oil, hydraulic and de-icing fluids and spillages occur when refuelling. Lubricating oil can contain phosphates and metals. Accidental spillages can also occur.
Roofs – atmospheric deposition, bird droppings, corrosion and vegetation	Heavy metals (copper, lead, zinc) Bacteria, organic matter.	Roof water is often regarded as clean. It can, however, contain significant concentrations of heavy metals resulting from atmospheric deposition or the corrosion of metal roofing or from other coatings such as tar.
Litter/animal faeces	Bacteria, viruses Phosphorous, nitrogen.	Litter typically includes items such as drinks cans, paper, food, cigarettes, animal excreta, plastic and glass. Some of this will break down and cause pollutants to be washed off urban surfaces. Dead animals in roads decompose and release pollutants including bacteria. Pets leave faeces that wash into the drainage system.
Vegetation/ landscape maintenance	Phosphorous, nitrogen Herbicides, insecticides, fungicides Organic matter.	Leaves and grass cuttings are an organic source. Herbicides and pesticides used for weed and pest control in landscaped areas such as gardens, parks, recreation areas and golf courses, can be a major source of pollution.
Soil erosion	Sediment Phosphorous, nitrogen Herbicides, insecticides, fungicides.	Runoff from poorly-detailed landscaped or other areas can wash onto impervious surfaces and cause pollution of runoff.
De-icing activities	Sediment Chloride, sulphate Heavy metals (iron, nickel, lead, zinc), glycol Cyanide Phosphate.	De-icing salt is commonly used for de-icing roads and car parks. Rock salt used for this purpose comprises sodium chloride and grit. It can also include cyanide and phosphates as anti-caking and corrosion inhibitors, heavy metals, urea and ethylene glycol.
Cleaning activities	Sediment Phosphorous, nitrogen Detergents.	Washing vehicles, windows, bins or pressure washing hardstandings leads to silt, organic matter and detergents entering the surface water drainage.
Wrong sewer connections	Bacteria Detergents Organic matter.	Wrong connections of foul sewers to surface water sewers where separate sewers exist.
Illegal disposal of chemicals and oil	Hydrocarbons Various chemicals.	Illegal disposal of used engine oils or other chemicals can occur at small (domestic) or large (industrial) scales.

In their first assessment of the extent to which pressures from diffuse sources place water bodies in England and Wales at risk of failing to meet Water Framework Directive (WFD) objectives, the Department of Environment, Food and Rural Affairs (Defra, 2004a) has estimated that:

- 21 per cent of river lengths are at risk, or probably at risk, of failing WFD objectives from sediment delivery
- 46 per cent of river lengths and 45 per cent of groundwaters are at risk, or probably at risk, from diffuse sources of nitrates
- 39 per cent of river lengths, 23 per cent of lakes and 12 per cent of groundwaters are at risk, or probably at risk, from diffuse sources of phosphate
- 19 per cent of river lengths and 22 per cent of groundwaters are at risk, or probably at risk, from diffuse sources of pesticides and veterinary medicines of a pesticidal nature
- 25 per cent of river lengths and 14 per cent of groundwaters are at risk, or probably at risk, of failure from diffuse urban sources of pollution
- 7 per cent of river lengths and 13 per cent of groundwaters are at risk, or probably at risk, from pollution from mines and mine water
- 6 pe cent of groundwaters are at risk, or probably at risk, from diffuse sources of priority substances and chlorinated solvents.

The Scottish Environmental Protection Agency (SEPA) have categorised the general industry sectors affecting water considered to be at risk and this is shown in Figure 1.4. It should be noted that a water body is often affected by more than one sector and can therefore be counted more than once in the pie chart.



General industry sector

	Nr	(%)
Agricultural and forestry	425	(64)
Mining and quarrying	32	(5)
Manufacturing	6	(1)
Electricity, gas & water supply	58	(9)
Construction	1	(<1)
Transport, storage and communication	17	(3)
Sewage and refuses disposal	27	(4)
Land drainage, land claim, flood defence and urbanisation	92	(14)

Figure 1.4 *General industry sectors affecting water bodies at risk in Scotland (SEPA, 2004)*

1.2.3 Climate change

There is increasing evidence that the earth's climate is changing. The most recent predictions (from the revised scenarios published by the UK Climate Impacts Programme (Hulme *et al*, 2002), suggest that, by the 2080s:

- winters may become milder and wetter, with more intense rainfall events
- summers may be hotter and drier across all of the UK, particularly in the south and east
- some types of extreme weather events may become more frequent, such as heatwaves, extreme coastal high water levels and heavy spells of rain.

The main outcome of these climate change impacts on water resources and water quality will be to:

- reduce the availability of fresh water, leading to reduced dilution of pollutants at lower flows and increased consequences (eg eutrophication)
- increase evaporation from water bodies, and increase frequency of algal blooms
- lengthen the growing season – combined with wetter weather, this may increase the impact of nutrient leaching, soil compaction, and rapid runoff
- reduce the availability of water for groundwater recharge with consequent effects on water supplies and aquatic ecosystems dependent on groundwater
- lengthen the season for recreational and leisure activities involving water.

More frequent periods of intense rainfall will:

- increase runoff from urban and agricultural land and increase the input of pollutants to the water environment, particularly following periods of drought when land is hard and slow to absorb water
- erode topsoil, increasing inputs of sediment to surface water runoff, which may harm some fish species and increase contaminant concentrations
- increase flooding and the frequency of sewer overflows discharging untreated sewage into the water environment
- increase input of pollutants from contaminated returning floodwater.

The Foresight Future Flooding Report released in April 2004 (Evans *et al*, 2004), analyses the future risks of flooding and coastal erosion for four different future socioeconomic and climate change scenarios. The report concluded that climate change, together with land use planning, are important contributory factors to increasing flood risk and that effective land management (including drainage) must be put in place to protect our urban areas for the future.

1.2.4 Sustainability

Sustainable development aims to ensure a better quality of life for everyone, now and for generations to come. It means meeting the following objectives:

1. Social equity.
2. Effective protection of the environment.
3. Prudent use of natural resources.

As part of the Government's commitment to sustainable development, it has set priorities for sustainable management of water in the future. These include:

- prudent use of water resources and keeping water use within the limits of its replenishment
- tackling diffuse pollution of water
- minimising the creation of new flood risks, effectively managing increasing risks, and enhancing flood resistance and resilience.

In Autumn 2004, the Government launched their consultation document *Making space for water: developing a new Government strategy for flood and coastal erosion risk management in England* (Defra, 2004b). This sets out government proposals for future flood risk management, sustainability criteria, land use policy and management objectives under the pressures of both climate change and the increasing requirement for new houses.

In 2003 the Scottish Executive issued a National Flooding Framework on their strategy for tackling floods, including commitments to reduce the risks and impacts of flooding in Scotland. The growth in new houses required across the country will also pose challenges for both water resource availability and water quality. Defra and the environmental regulators are promoting a new holistic and integrated approach to drainage management that facilitates the implementation of SUDS, rainwater harvesting and reuse, improving water management and environmental protection while contributing to biodiversity and amenity objectives.

1.2.5 Land use planning

All development decisions must comply with local planning policy that, in turn, must take account of national and regional planning guidance. SUDS are promoted as the preferred drainage option by national planning policies presented in Table 1.4.

Table 1.4 *National planning policies on development and flooding*

UK Country	National planning policy
England	PPS25: Development and Flood Risk, December 2006 (DCLG, 2006).
Scotland	SPP7: Planning and Flooding, January 2004 (Scottish Executive, 2004).
Wales	TAN15: Development and Flood Risk, July 2004 (National Assembly for Wales, 2004).
Northern Ireland	PPS15: Planning and Flood Risk, June 2006 (DoENI, 2006).

Building regulations for all areas of the UK explains the benefits of and provide guidance on the incorporation of SUDS in drainage systems, with an emphasis on infiltration. Planning and regulation is discussed in detail in Chapter 2.

1.2.6 The European Union Water Framework Directive

The European Union Water Framework Directive (European Commission, 2000) was transposed into UK national legislation in December 2003. The Directive takes account of all the different objectives for which the aquatic environment is protected (ecology, drinking water, health and particular habitats), and ensures that measures taken to achieve the objectives are coordinated properly.

The Water Framework Directive encourages a more sustainable approach to drainage by:

- establishing a holistic approach to managing the water environment, based on river basins, integrating water quantity with quality considerations
- establishing quality objectives for all water bodies in order to achieve good status
- establishing a quality classification system for surface water that includes chemical, hydromorphological and ecological parameters
- establishing a quality classification system for groundwater status and a requirement for the quality of groundwater not to result in any significant damage to terrestrial ecosystems
- establishing statutory controls in relation to pollution of water bodies from point and diffuse sources
- preventing deterioration in the status of water bodies
- promoting sustainable water use based on long-term protection of water resources
- achieving environmental objectives in a cost-effective way.

A specific condition is the requirement for the control of surface water discharges. This means that all discharges of urban runoff will have to be managed so that their impact on the receiving environment is mitigated. This effectively precludes the use of the traditional approach to drainage.

1.3 SUSTAINABLE DRAINAGE SYSTEMS

1.3.1 The SUDS philosophy

Appropriately designed, constructed and maintained SUDS are more sustainable than conventional drainage methods because they can mitigate many of the adverse effects on the environment of stormwater runoff. They achieve this through:

- reducing runoff rates, thus reducing the risk of downstream flooding
- reducing the additional runoff volumes and runoff frequencies that tend to be increased as a result of urbanisation, and which can exacerbate flood risk and damage receiving water quality
- encouraging natural groundwater recharge (where appropriate) to minimise the impacts on aquifers and river baseflows in the receiving catchment
- reducing pollutant concentrations in stormwater, thus protecting the quality of the receiving water body
- acting as a buffer for accidental spills by preventing a direct discharge of high concentrations of contaminants to the receiving water body
- reducing the volume of surface water runoff discharging to combined sewer systems, thus reducing discharges of polluted water to watercourses via CSO spills
- contributing to the enhanced amenity and aesthetic value of developed areas
- providing habitats for wildlife in urban areas and opportunities for biodiversity enhancement.

A vision of a fully-sustainable drainage system has been developed by The Natural Step in their 2020 Vision Series on SUDS (*The Natural Step*, 2001), and is summarised in the following table.

Table 1.5 *The natural step vision for fully sustainable drainage systems*

Sustainability objective	SUDS criteria
Not systematically increase concentrations of substances extracted from the Earth's crust.	• no/low energy use, with energy needs met by renewable means • aggregates should be from recycled sources • pollutants from Earth's crust minimised at source • minimal release of persistent pollutants (eg oils, brake linings etc).
Not systematically increase concentration of substances produced by society.	• manage pollutants at front end • synthetic pipework should be from recycled sources • no increase in contribution of chemical inputs to sewage treatment works.
Not systematically increase degradation by physical means.	• enhance natural aquifer recharge • enhance and support biodiversity • restore natural hydrological processes • reuse water where possible • minimise impermeable areas.
Human needs should be met worldwide.	• encourage social expectation for more sustainable solution to urban drainage • long-term system management agreements in place • enhance amenity where possible, adding community value • minimise risks (human and environmental).

Additional, tangible benefits include an increased value of developable land as a result of the environmental and amenity enhancements, and the reduced whole life cost associated with implementing the drainage solution.

1.3.2 The SUDS management train

To mimic natural catchment processes as closely as possible, a "management train" is required. This concept is fundamental to designing a successful SUDS scheme – it uses drainage techniques in series to incrementally reduce pollution, flow rates and volumes.

The hierarchy of techniques that should be considered in developing the management train are as follows:

1. **Prevention** – the use of good site design and site housekeeping measures to prevent runoff and pollution (eg sweeping to remove surface dust and detritus from car parks), and rainwater reuse/harvesting. Prevention policies should generally be included within the site management plan.
2. **Source control** – control of runoff at or very near its source (eg soakaways, other infiltration methods, green roofs, pervious pavements).
3. **Site control** – management of water in a local area or site (eg routing water from building roofs and car parks to a large soakaway, infiltration or detention basin).
4. **Regional control** – management of runoff from a site or several sites, typically in a balancing pond or wetland.

The management train is summarised in Figure 1.5. Wherever possible, stormwater should be managed in small, cost-effective landscape features located within small sub-catchments rather than being conveyed to and managed in large systems at the bottom of drainage areas (end of pipe solutions). The techniques that are higher in the hierarchy are preferred to those further down so that prevention and control of water at source should always be considered before site or regional controls. However, where upstream control opportunities are restricted, a number of lower hierarchy options should be used in series. Water should be conveyed elsewhere only if it cannot be dealt with on site.

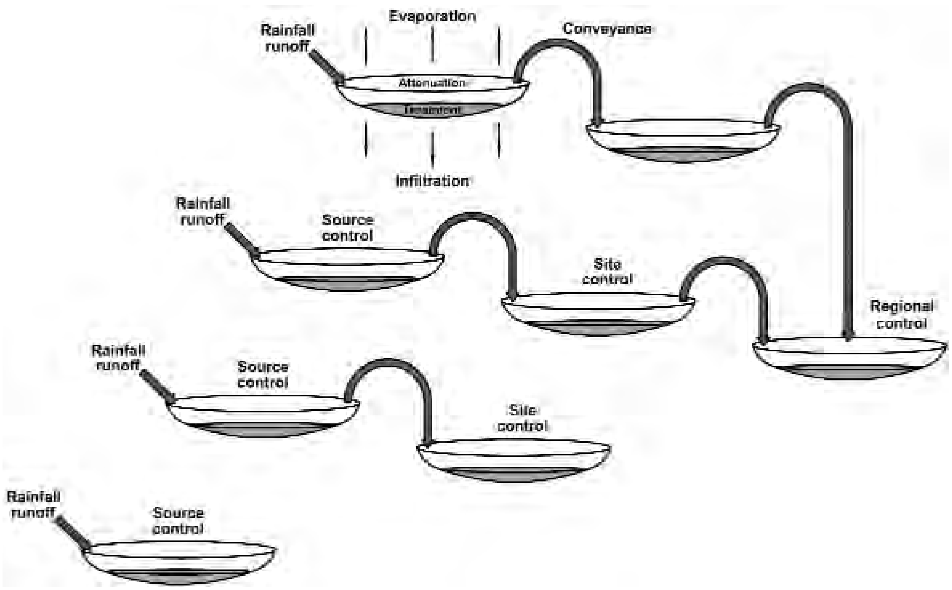


Figure 1.5 *The SUDS management train (adapted from Berry, 2002)*

The passage of water between individual parts of the management train should be considered through the use of natural conveyance systems (eg swales and filter trenches) wherever possible, although pipework and sub-surface proprietary products may be required, especially where space is limited. Pre-treatment (the removal of gross silt or sediment loads) and maintenance is vital to ensure the long-term effectiveness of all SUDS techniques. Overland flow routes will also be required to convey and control floodwater safely during extreme events. In general, the greater the number of techniques used in series, the better the performance is likely to be, and the lower the risk of overall system failure.

A SUDS approach to drainage can be implemented for all development sites, although individual site constraints may limit the potential for a solution to achieve maximum benefits for all functions. The variety of design options available allows designers and planners to consider local land use, land take, future management scenarios and the needs of local people when undertaking the drainage design. Active decisions have to be made that balance the wishes of different stakeholders and the risks associated with each design option.

1.3.3 Runoff quantity control processes

There are several processes that can be used to manage and control the runoff from developed areas. Each management option can provide unique opportunities for stormwater control, flood risk management, water conservation, and/or groundwater recharge.

(a) Infiltration

This is the soaking of water into the ground. It is different from conveyance and detention because it transfers water to a different part of the environment and can therefore physically reduce the volume of drained runoff. Where there is no risk of contamination, the process can be used to recharge underlying groundwater sources and feed the baseflows of local watercourses. This is the most desirable solution to runoff management because it restores the natural hydrologic processes. However infiltration rates vary with soil type and condition, antecedent conditions, and with time. In general, infiltration cannot be used in areas where groundwater sources are vulnerable.

(b) Detention/attenuation

Detention or attenuation is the slowing down of surface flows before their transfer downstream. This is usually achieved through the use of a storage volume and constrained outlet. The storage volume can be accommodated within a dry basin, above a permanent pond volume or beneath the ground within subsurface structures. In general, although storage can help reduce the peak flow rate of runoff, the duration of runoff will be extended and the total volume of flow will remain the same.

(c) Conveyance

Conveyance is the transfer of surface runoff from one place to another. It can take place through a range of systems including open channels, pipes and trenches. Uncontrolled conveyance to a point of discharge into the environment is no longer considered sustainable. Controlled conveyance is still an essential tool for managing flows and linking SUDS components together.

(d) Water harvesting

This is the direct capture and use of runoff on site. Rainfall runoff can be extracted for domestic use (eg flushing toilets), or irrigation of urban landscapes. The contribution to flood risk management from such systems will be dependent on the scale of the water harvesting system. Designs will need to ensure that storage for runoff control is always available, and that there is an acceptably low risk that the system will be full (and therefore storage bypassed) when a flood occurs.

1.3.4 Runoff quality control processes

There is a range of natural water quality treatment processes that can be exploited within the design of a sustainable drainage system. These are presented in Box 1.1. Different processes will predominate for each SUDS technique and will therefore be present at different stages in the treatment train.

Box 1.1 *Pollutant removal mechanisms in SUDS (adapted from Wilson* et al*, 2004)*

Sedimentation

Sedimentation is one of the primary removal mechanisms in SUDS. Most pollution in runoff is attached to sediment particles and therefore removal of sediment results in a significant reduction in pollutant loads. Sedimentation is achieved by reducing flow velocities to a level at which the sediment particles fall out of suspension. Care has to be taken in design to minimise the risk of re-suspension when extreme rainfall events occur.

Filtration and biofiltration

Pollutants that are conveyed in association with sediment may be filtered from percolating waters. This may occur through trapping within the soil or aggregate matrix, on plants or on geotextile layers within the construction. The location of any filtration will depend upon the internal structure of the particular SUDS technique, for example whether a geotextile layer is near the surface or at the subgrade in a pervious surface.

Adsorption

Adsorption occurs when pollutants attach or bind to the surface of soil or aggregate particles. The actual process is complex but tends to be a combination of surface reactions grouped as sorption processes:

Adsorption	Pollutants bind to surface of soil/aggregate
Cation exchange	Attraction between cations and clay minerals
Chemisorption	Solute is incorporated in the structure of a soil/aggregate
Absorption	The solute diffuses into the soil/aggregate/organic matter.

Change in acidity of runoff can either increase or decrease the adsorption of pollutants by construction materials or soils. Eventually the materials onto which pollutants adsorb will become saturated and thus this method of treatment will stop.

Biodegradation

In addition to the physical and chemical processes, which may occur on and within a SUDS technique, biological treatment may also occur. Microbial communities may be established within the ground, using the oxygen within the free-draining materials and the nutrients supplied with the inflows, to degrade organic pollutants such as oils and grease. The level of activity of such bioremediation will be affected by the environmental conditions such as temperature and the supply of oxygen and nutrients. It also depends on the physical conditions within the ground such as the suitability of the materials for colonisation.

Volatilisation

Volatilisation comprises the transfer of a compound from solution in water to the soil atmosphere and then to the general atmosphere. The conversion to a gas or vapour occurs due to heat, reducing pressure, chemical reaction or a combination of these processes. The rate of volatilisation of a compound is controlled by a number of its properties and those of the surrounding soil. In SUDS schemes volatilisation is primarily concerned with organic compounds in petroleum products and pesticides.

Box 1.1 *Pollutant removal mechanisms in SUDS (continued)*

Precipitation

This process is the most common mechanism for removing soluble metals. Precipitation involves chemical reactions between pollutants and the soil or aggregate that transform dissolved constituents to form a suspension of particles of insoluble precipitates. Metals are precipitated as hydroxides, sulphides, and carbonates depending on which precipitants are present and the pH level. Precipitation can remove most metals (arsenic, cadmium, chromium III, copper, iron, lead, mercury, nickel, zinc) and many anionic species (phosphates, sulphates, fluorides).

Uptake by plants

In ponds and wetlands, uptake by plants is an important removal mechanism for nutrients (phosphorous and nitrogen). Metals can also be removed in this manner (although intermittent maintenance is required to remove the plants otherwise the metals will be returned to the water when the plants die). Plants also create suitable conditions for deposition of metals, for example as sulphides in the root zone.

Nitrification

Ammonia and ammonium ions can be oxidised by bacteria in the ground to form nitrate, which is a highly soluble form of nitrogen. Nitrate is readily used as a nutrient by plants.

Photolysis

The breakdown of organic pollutants by exposure to ultra-violet light.

The removal mechanisms appropriate for each pollutant category are presented in Table 1.6.

Table 1.6 *Removal mechanisms for each pollutant category (adapted from Wilson* et al, *2004)*

Pollutant	Removal mechanisms in SUDS
Nutrients Phosphorous, nitrogen	Sedimentation, biodegradation, precipitation, de-nitrification.
Sediments Total suspended solids	Sedimentation, filtration.
Hydrocarbons TPH, PAH, VOC, MTBE	Biodegradation, photolysis, filtration and adsorption.
Metals Lead, copper, cadmium, mercury, zinc, chromium, aluminium	Sedimentation, adsorption, filtration, precipitation, plant uptake.
Pesticides	Biodegradation, adsorption, volatilisation.
Chlorides	Prevention.
Cyanides	Volatilisation, photolysis.
Litter	Trapping, removal during routine maintenance.
Organic matter, BOD	Filtration, sedimentation, biodegradation.

1.3.5 SUDS techniques

There is a wide range of individual techniques of components that can be used to form part of the management train. These can be categorised broadly by whether their primary use is considered to be pre-treatment, conveyance, source, site or regional controls, and can be ranked in a simple manner, based on their hydraulic and water quality performance potential.

Table 1.7 categorises the main SUDS components in use in this country. The list is not comprehensive – and innovative techniques should be encouraged providing there is sufficient documentation relating to their effectiveness and reliability. Detail on each technique is provided in subsequent chapters.

Table 1.7 *Capability of different SUDS techniques*

Technique	Description	Management train suitability						Water quantity				Water quality								Environmental benefits		
		Prevention	Conveyance	Pre-treatment	Source control	Site control	Regional control	Conveyance	Detention	Infiltration	Water harvesting	Sedimentation	Filtration	Adsorption	Biodegradation	Volatilisation	Precipitation	Uptake by plants	Nitrification	Aesthetics	Amenity	Ecology
Water butts, site layout & management	Good housekeeping and good design practices.	♦	⊗		♦			⊗	⊗	♦	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Pervious pavements	Allow inflow of rainwater into underlying construction/soil.	♦			♦	⊗			♦	♦	⊗	♦	♦	♦	♦	♦				⊗	⊗	⊗
Filter drain	Linear drains/trenches filled with a permeable material, often with a perforated pipe in the base of the trench.		♦		♦	⊗		♦	♦				♦	♦	♦	♦						
Filter strips	Vegetated strips of gently sloping ground designed to drain water evenly from impermeable areas and filter out silt and other particulates.			♦	♦			⊗	⊗	⊗		♦	♦	♦	♦					⊗	⊗	⊗
Swales	Shallow vegetated channels that conduct and/or retain water (and can permit infiltration when un-lined). The vegetation filters particulates.		♦		♦	♦		♦	♦	⊗		♦	♦	♦	♦			⊗		⊗	⊗	⊗
Ponds	Depressions used for storing and treating water. They have a permanent pool and bankside emergent and aquatic vegetation.					♦	♦		♦	⊗	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦
Wetlands	As ponds, but the runoff flows slowly but continuously through aquatic vegetation that attenuates and filters the flow. Shallower than ponds.		⊗			♦	♦	⊗	♦	⊗	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦
Detention basin	Dry depressions designed to store water for a specified retention time.					♦	♦		♦			♦	⊗	⊗	♦			⊗		⊗	⊗	⊗
Soakaways	Sub-surface structures that store and dispose of water via infiltration.				♦					♦			♦	♦	♦							
Infiltration trenches	As filter drains, but allowing infiltration through trench base and sides.		⊗		♦	♦		⊗	♦	♦			♦	♦	♦	♦						
Infiltration basins	Depressions that store and dispose of water via infiltration.					♦	♦		♦	♦			♦	♦	♦	♦				⊗	⊗	⊗
Green roofs	Vegetated roofs that reduce runoff volume and rate.	♦		♦	♦				♦				♦	♦	♦	♦	♦	♦	♦	♦	⊗	♦
Bioretention areas	Vegetated areas for collecting and treating water before discharge downstream, or to the ground via infiltration.				♦	♦			♦	♦		♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦
Sand filters	Treatment devices using sand beds as filter media.			♦		♦	⊗		♦	⊗			♦	♦	♦	♦	♦					
Silt removal devices	Manhole and/or proprietary devices to remove silt.			♦								♦										
Pipes, subsurface storage	Conduits and their accessories as conveyance measures and/or storage. Water quality can be targeted using sedimentation and filter media.		♦			♦		♦	♦			⊗	⊗									

Key to symbols ♦ High/primary process ⊗ Some opportunities, subject to design

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Roles, responsibilities and regulation

2

Contents

Continued overleaf

Roles, responsibilities and regulation 2

The effective planning, design, construction and operation of SUDS requires the involvement of a wide range of stakeholders. The roles and responsibilities of these organisations are presented in this chapter, together with details of the land use planning system and the legislative and regulatory framework that supports SUDS implementation.

2.1 INTRODUCTION

Drainage responsibilities may involve a number of different stakeholders including:

- local authorities (in Northern Ireland the role is undertaken by the Planning Service)
- environmental regulators
- sewerage undertakers
- highways authorities
- private landowners or land managers
- internal drainage boards (IDBs); (in Northern Ireland the role of flood defence is undertaken by teh Rivers Agency).

The key to the consistent and successful consideration of SUDS for all development sites is inclusion of a sustainable drainage policy within national, regional and local planning documents. This should be implemented in collaboration with the environmental regulator and other stakeholders. Successful decision making with respect to SUDS design and maintenance requires consultation between developers, planners, drainage engineers and regulatory authorities from the conceptual design stage onwards and, ideally, before land purchase. This strategy maximises the opportunities for developing the most appropriate solutions to the implementation of SUDS and will help to ensure that the systems are designed correctly and are well understood by those involved.

This chapter describes:

- the roles and responsibilities of the main surface water drainage stakeholders
- the planning system, through which policies for the implementation of SUDS can be established
- the legislative and regulatory framework.

2.2 SURFACE WATER DRAINAGE STAKEHOLDERS

2.2.1 Regional assemblies

English Regional Assemblies were established under the Regional Development Agencies Act (DETR, 1998a), which provides for "regional chambers" to scrutinise the work of the development agencies in each English region. They tend to be made up of appropriate members of county and district councils and unitary authorities in each region, together with appointees from other regional interest groups. The Assemblies have roles as the "voice of the region", speaking out on behalf of regional interests and concerns, and lobbying government and the EU to influence a wide range of decisions and policies. Each Assembly acts as the Regional Planning Body; the Planning and

Compulsory Purchase Act (ODPM, 2004a) gave the Assemblies statutory responsibility for preparing the Regional Spatial Strategy (see Section 2.3.3).

2.2.2 Regional Development Agencies (RDAs)

These are non-departmental public bodies in England established for the purpose of development (primarily economic) of each government office region. Similar activities are carried out in Wales by the Welsh Development Agency, in Northern Ireland by the Department of Enterprise, Trade and Investment, and in Scotland by Scottish Enterprise (and its assorted Local Enterprise Companies) and Highlands and Islands Enterprise.

The statutory objectives of the RDAs are, at present, to:

- further economic development and regeneration
- promote business efficiency and competitiveness
- promote employment
- enhance the development and application of skills relevant to employees
- contribute to sustainable development.

These are expanded upon in the Regional Economic Strategy (RES) for each region.

2.2.3 Local authorities

Local authorities are planning and building control authorities and may also have responsibilities for local roads, public landscaping, and local land drainage. Some parts of the country have unitary authorities (single tier administrations); others are covered by county councils that control several local authority districts. Where authorities are not unitary, roads will be under the control of the county, while planning and other issues are the responsibility of the district. In Scotland there is a single tier of local councils.

Planning authorities drive development policy and approve new development, including drainage. Their role is pivotal in ensuring that SUDS are incorporated into new developments and redeveloped brownfield sites.

Local authorities may have two drainage roles: as the highways/roads authority (local roads, excluding trunk road drainage) and the land drainage authority. In Scotland, the local authority has the primary flood management responsibility and will therefore be concerned over rates and volumes of surface water discharges. Local authority-led flood liaison and advice groups coordinate flood risk assessment and management actions on a catchment basis.

Local authorities may also be responsible for administering and enforcing the building regulations and they have to be satisfied that adequate provision has been made for drainage and that it will not affect the integrity of buildings.

2.2.4 Environmental regulators

In England and Wales, the Environment Agency is a non-departmental public body reporting to the Department of the Environment, Food & Rural Affairs (Defra). It has wide-ranging responsibilities including the management of water resources, control of pollution in inland, estuarial and coastal waters, and flood defence. The Agency's principal aim is "to protect or enhance the environment, taken as a whole, in order to play its part in attaining the objective of sustainable development."

The Environment Agency has general flood defence and land drainage powers, including a supervisory duty over all flooding (but primarily in respect of main rivers). It is responsible for advising the local authorities on planning conditions relating to volumes and rates of runoff. The Rivers Agency is the equivalent organisation responsible for watercourses in Northern Ireland. In Scotland, this is a local authority function.

To meet statutory duties related to securing the proper use of water resources and as part of its role as statutory consultee to the land-use planning process, the Environment Agency provides guidance and recommendations on the potential for pollution within a catchment and on good practice to prevent water pollution. The Environment Agency is the competent authority for implementation of the Water Framework Directive, which requires that all dischargers obtain consents or authorisation from the relevant body. Moreover, the Environment Agency has powers to serve notices requiring works to be carried out to protect watercourses and groundwater quality. The Scottish Environmental Protection Agency (SEPA) and the Northern Ireland Environment and Heritage Services (EHS) have similar powers. Further details are set out in Section 2.5.

All the environmental regulators have policies that promote SUDS as the preferred solution for drainage of surface water runoff, including roof water, for all proposed developments. In general, they will serve prohibition notices (and the associated requirement to apply for consent) only in relation to SUDS discharges, where the system has not been designed and constructed in accordance with latest guidance. However, conditional prohibition notices may be served before construction to ensure that the drainage system is constructed to the agreed design.

2.2.5 Sewerage undertakers

There are nine water and sewerage companies in England, with individual companies serving Scotland (Scottish Water), Wales (Welsh Water) and Northern Ireland (Northern Ireland Water Service). These are both water undertakers (suppliers) and sewerage undertakers (ie they are responsible for removing wastewater). In addition, there are a number of "water-only" companies in England who do not have sewerage responsibilities.

Figure 2.1 shows the locations of all the sewerage undertakers in the UK.

Figure 2.1 *UK sewerage undertakers*

One of the principal duties of a sewerage undertaker under the Water Industry Act (DoE, 1991a), is to provide a public sewer connection to be used for drainage of domestic premises in its area (if served notice by the owner or the occupier of the premise, and/or the local planning authority, and/or a development board or corporation). This process is known as requisitioning. The Act also allows a highway authority to enter into an agreement with the sewerage undertaker to use its sewers for conveying surface water from roads repairable by the authority. Similarly, the sewerage undertaker can enter into an agreement with the highway authority to use the authority's drains to carry surface water from premises or streets. The Act prohibits either party from refusing to enter into or consent to such an agreement on unreasonable grounds. *Sewers for adoption, 6th edition* (WRc, 2006) includes some guidance on SUDS and other drainage systems that water companies may be prepared to consider for adoption.

In Scotland, the Water Environment and Water Services (WEWS) Act (Scottish Executive, 2003) amended the Sewerage (Scotland) Act (Scottish Office, 1968), to include a definition of SUDS, giving public SUDS the same legal status as traditional sewers. The Act gives responsibility to Scottish Water for the adoption and maintenance of public SUDS in Scotland. The definition does not include private SUDS that are located entirely within the curtilage of a property, or SUDS that convey road drainage only. It should be noted that, at the time of publication, SUDS in England, Wales and Northern Ireland do not hold an equivalent legal status. The WEWS Regulation Manual (*SUDS for Adoption*) is expected to be published in 2007 and Scottish Water will see these standards as their adoptable standards.

Water companies have a wide range of environmental policies through which they seek to minimise the environmental impact and maximise the sustainability of their core activities. They have a statutory duty to promote the efficient use of water, environmental good practice and the use of cost-effective solutions.

2.2.6 Highway and roads authorities

Highway/roads authorities have the power to construct, adopt and maintain highway drainage infrastructure. Each authority sets down standards which developers must follow throughout the construction process to ensure that adoptable roads are of satisfactory construction, safe for the public to use and able to be maintained easily. Effective road drainage is fundamentally important to road safety and to the integrity and structural stability of the road, including its footways, verges and margins.

When considering construction consent applications, local authorities may want to be satisfied that SUDS employed in particular locations meet their road drainage requirements and will not require onerous maintenance.

Trunk road drainage is the responsibility of the Department for Transport via the Highways Agency, the Welsh Assembly Government via their Transport Directorate, The Department of Environment (Northern Ireland) via their Roads Service, and the Scottish Executive. Guidance on drainage systems for such roads is set out in the *Design Manual for Roads and Bridges* (Highways Agency *et al*, 2001).In Scotland highways are often referred to as roads.

2.2.7 Conservation organisations

Natural England has responsibility for enhancing biodiversity, landscape and wildlife in rural, urban, coastal and marine areas; promoting access, recreation and public well-being, and contributing to the way natural resources are managed. The functions of Natural England include:

- promoting nature conservation and protecting biodiversity
- conserving and enhancing the English landscape
- securing the provision and improvement of facilities for the study, understanding and enjoyment of nature
- promoting access to the countryside/open spaces and encouraging open-air recreation
- contributing in other ways to social and economic well-being through management of the natural environment.

It has powers to award grants, give advice and information, designate Sites of Special Scientific Interest (SSSIs), national parks and Areas of Outstanding Natural Beauty (AONB), manage National Nature Reserves (NNRs), and enforce the associated regulations.

The Countryside Council for Wales (CCW), Scottish Natural Heritage (SNH), and the Environment and Heritage Service of Northern Ireland are the relevant bodies for other parts of the UK.

These organisations should be consulted during the planning process for any significant development and all developments requiring an EIA (environmental impact assessment) – see Section 2.3.7 – so that issues relating to wildlife and conservation can be addressed.

2.2.8 The Royal Society for the Prevention of Accidents (RoSPA)

RoSPA is a registered charity providing information and advice associated with the promotion of safety in all areas of life, including on or near water. RoSPA's water and leisure department covers not only leisure pursuits in or near water, but also accident prevention around canals, rivers, the sea and lakes. They consider the increasing number of public and private sites with decorative or SUDS water features to be an especially important area for them, and have produced fact-sheets on water safety, and pond safety in particular.

2.2.9 The insurance industry

The insurance industry has two main interests with respect to SUDS:

1. The associated flood risk.
2. The associated health and safety risks.

The Association of British Insurers is the trade association for the UK's insurance industry and acts as the voice of the industry in influencing relevant decisions made by government, the regulator and other public authorities.

All systems should be designed so that the water that cannot be contained within the system during extreme events (and in the case of blockage/ineffective performance) is diverted via overland flood routing towards receiving watercourses, and away from property. This should ensure that housing flood risk is minimised and that there is little risk that the proposed drainage system will exacerbate potential flooding problems under any conditions. This issue is covered in CIRIA publication C635, *Designing for exceedance in urban drainage – good practice* (Digman *et al*, 2006).

Where SUDS are well planned, designed and maintained, the risk of civil liability is low. However, wherever a permanent or semi-permanent pool of surface water is proposed for the purpose of attenuation of floodwater, for example, there is the question of public access to consider. Careful thought needs to be given to the degree of hazard posed by such a facility, particularly in relation to children, and the appropriateness and adequacy of proposed safety measures. This is not suggesting that SUDS are inherently more hazardous than traditional drainage, but that they require different considerations to be addressed.

2.2.10 Developers/landowners/homeowners

Decisions regarding long-term ownership and operation of SUDS must be made early on in the planning process (see Figure 2.4). The relevant stakeholders should then form an important element in the planning and design consultation process. They must be in agreement over the type and scale of the system that they are taking on, and the particular features that they will need to maintain.

Ownership of land may change through the development process with, in the case of housing developments, a landowner selling the land to a developer and this then being sold to the final homeowner. Homeowners are generally responsible for drainage within the curtilage of their properties.

Each party should, therefore, be made aware of any drainage constraints in terms of land use restrictions or maintenance requirements, and relevant drainage details should be included within land transfer documentation.

2.2.11 Drainage planners and designers

SUDS planning and design may require a multi-disciplinary approach. Although the skills required to implement the majority of small schemes will be well within the capability of the practical drainage engineer, large, complex schemes (or those with specific technical challenges) may require specialist advice from technical experts.

Figure 2.2 highlights the broad range of issues that need to be considered and evaluated for appropriate SUDS planning and design, further confirming the importance of early consultation and conceptual design work.

Figure 2.2 *SUDS design and planning: issues for consideration*

2.2.12 SUDS contractors

SUDS may be constructed by standard building contractors, groundworks contractors, or landscape contractors. Landscaping expertise may be more relevant for the creation of surface water features, and other organisations may require training in appropriate construction methods and processes. As SUDS are different from conventional drainage solutions, contractors should be part of design discussions, so they can advise on potential buildability issues and be made aware of the important drainage issues relevant to construction.

2.3 DRAINAGE AND PLANNING

2.3.1 The planning process

The land-use planning system controls development and the use of land in the public interest. It is a plan-led system, requiring forward planning through development plans, and it gives plan policies pre-eminence in the determination of applications for planning permissions. This permission is required for all development, as defined in the Town and Country Planning Act (DTLR, 1990).

Figure 2.3 illustrates the main components of the planning process.

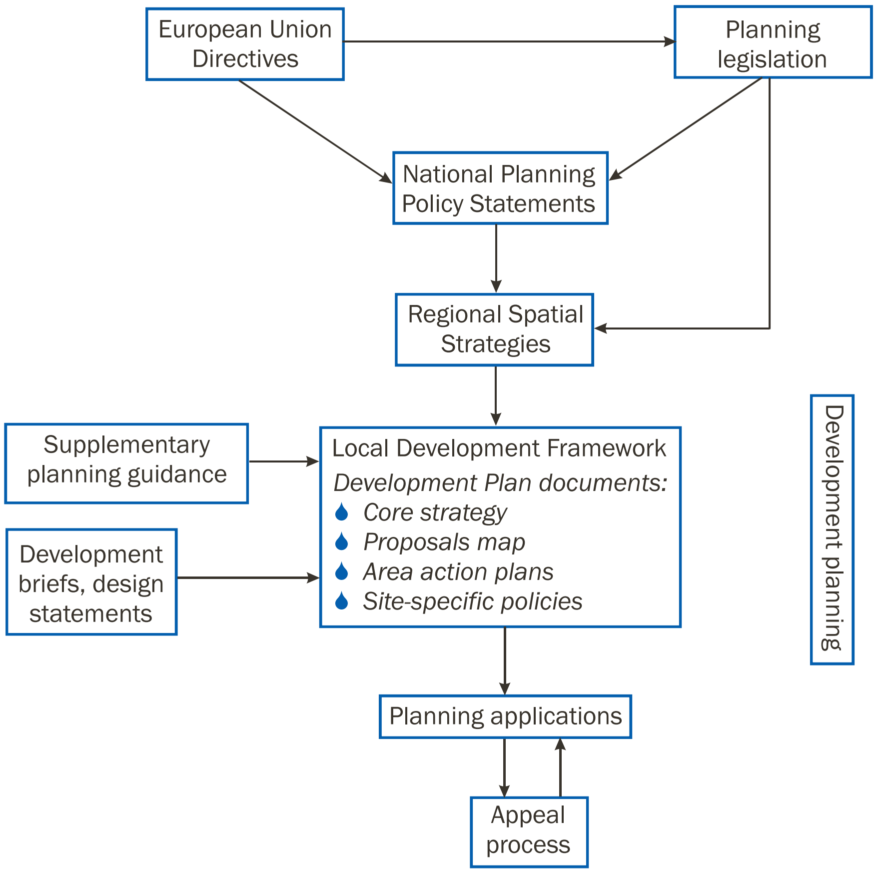

Figure 2.3 *The land-use planning process*

Drainage is an important planning consideration for any new or modified development. The planning system can promote and encourage the use of SUDS by including them in policy documents at various stages in the planning process. The decisions that local authorities make on planning applications must conform with the local development plan, and the inclusion of SUDS in developments may be an enabler where planning approval is at risk.

The planning system is used to bring together the views of statutory consultees. Other interested parties, eg non-governmental organisations and the general public, are encouraged to make use of the planning process to promote their views.

2.3.2 National planning policy

In England, the Government issues advice as Planning Policy Statements (PPSs), which update the former Planning Policy Guidance notes (PPGs). Government policy on SUDS is clear in PPS25 *Development and flood risk* (DCLG, 2006). The document discusses the impact of new development on flood risk and advises that the restriction and reduction of surface water runoff should be encouraged via the implementation of SUDS. It recognises that SUDS can also contribute to good design in improving the amenity and wildlife interest of a development as well as encouraging infiltration and groundwater recharge. The range of national planning policies in England that currently give credence to SUDS are presented in Table 2.1.

Table 2.1 *National planning policy statements relevant to SUDS (for England)*

PPS	Policy
PPS 1 (ODPM, 2005)	**Delivering sustainable development** • regional planning bodies and local authorities should promote sustainable drainage.
PPS 3 (DCLG, 2006a)	**Housing** • greening of residential development • landscaping to increase permeability and contribute to biodiversity • high density development in appropriate locations.
PPS 9 (ODPM, 2005)	**Biodiversity and geological conservation** • nature conservation objectives • prevention of damage to habitat or important physical features.
PPS 23 (ODPM, 2004b)	**Planning and pollution control** • runoff pollution control • diffuse pollution management • consultation with environmental regulator.
PPS 25 (DCLG, 2006b)	**Development and flood risk** • incorporating SUDS to manage future flood risk • implement SUDS where practicable for all future development.

In Scotland, national planning policy guidance SPP7: *Planning and flooding* (Scottish Executive, 2004a) sets out some of the issues relating to planning and flood management and calls for the consideration of SUDS for all new development. The Scottish Executive Planning Advice Notes PAN61: *Planning and sustainable urban drainage systems* (Scottish Executive, 2001) and PAN69: *Planning and building standards advice on flooding* (Scottish Executive, 2004b) also provide specific guidance and recommendations.

For Wales, a revised Technical Advice Note TAN 15 (National Assembly of Wales, 2004) *Development and flood risk* provides further advice on the use of SUDS where appropriate and in Northern Ireland Planning Policy Statement 15 *Planning and flood risk* (DoENI, 2006) suggests that SUDS may be a useful tool in managing flood risk (SUDS are described in detail in Annex C of that document).

2.3.3 Regional Spatial Strategies

In England, Regional Spatial Strategies (RSSs) define, in broad terms, the overall 20-year strategic development scenario for a particular region – policies and proposals for the number and general location of new houses, ports, airports, new settlements and major infrastructure provision. The proposals are not site-specific, but may fix the general location for new development.

These strategies form part of the statutory development plan (a change from the previous Regional Planning Guidance (RPGs), which were non-statutory documents). RSSs will be subject to a formal sustainability appraisal, so policies that require the implementation of a sustainable approach to water management, including surface water drainage and disposal, must be included within these documents. RSSs are drafted by the Regional Assembly and approved by the Secretary of State.

In Scotland the National Planning Framework sets out a vision to guide spatial development to 2025. Local councils, sometimes working with neighbouring councils, prepare Structure Plans which provide the long term strategic vision of an area's development requirements, general scale and location. Each council also prepares local plans which set out more detailed policies and site specific proposals. Under the provisions of the Planning etc. (Scotland) Act 2006, structure plans will be superseded by strategic development plans for the four main city regions, there will be local development plans for all areas and the second National Planning Framework is given statutory status.

2.3.4 Development planning

The Planning and Compulsory Purchase Act (ODPM, 2004a) replaces the previous hierarchy of plans in England. After a period of transition, structure plans will be abolished, and local and unitary development plans replaced by Local Development Frameworks (LDFs). LDFs can be seen as a folder of Local Development Documents, some of which will have development plan status (Development Plan Documents) and others not (these will be called Supplementary Planning Documents, equivalent to the previous Supplementary Planning Guidance). This will allow local planning authorities to make a series of plans, each of which can be reviewed separately, and can therefore be more responsive to change.

Table 2.2 gives a comparison between the current development planning system and that which existed before the Planning and Compulsory Purchase Act. LDFs will not be prepared in Wales, where the Act replaces the present Unitary Development Plans (UDPs) with Local Development Plans, but the same general principles will apply.

Table 2.2 *Influence of Planning and Compulsory Purchase Act (ODPM, 2004a) on planning documents*

Previous documents	New documents
Planning Policy Guidance	Planning Policy Statements
Regional Planning Guidance	Regional Spatial Strategy
Unitary Development Plan	Local Development Framework
Structure Plan	
Local Plan	
Supplementary Planning Guidance	Supplementary Planning Document

Scotland still operates on a Structure and Local Plan basis and in Northern Ireland the equivalent documents are Area and Local Plans. Guidance on planning issues is given by the Scottish Executive and the Planning Service of the Northern Ireland Assembly.

Development plans determine how housing, industry, shopping and other developments are to be distributed and will include policies for the conservation of natural beauty, the improvement of the environment, and traffic management. They should also have regard in general terms to economic, environmental and social well being of the community. Local plans will usually give site-specific land allocations for housing, industry and other developments and include detailed general requirements and standards for all new developments.

All planning documents in the new development planning arrangements will be required to undergo a sustainability appraisal, providing stakeholders with the opportunity to ensure that SUDS is placed at the centre of planning considerations, and that appropriate policies are implemented in development plans. This will support the use of the development control process as a lever to ensure that requirements for sustainable drainage solutions are met.

The Environment Agency has suggested that policies should be included in development plans that:

1. Ensure that developers incorporate SUDS in their proposals to prevent the water environment being adversely affected by:
   - increasing surface water runoff (flow rates and volumes)
   - increasing the risk of pollution, in particular diffuse pollution
   - reducing the recharge of groundwater
   - increasing the risk to property from rising groundwater
   - causing physical damage to the beds and banks of watercourses.
2. Ensure that any SUDS implemented have adequate provision for their future maintenance.

2.3.5 Supplementary Planning Documents

To assist the development planning process, local planning authorities can prepare Supplementary Planning Documents (SPDs, previously Supplementary Planning Guidance) or Supplementary Guidance in Scotland. These may set out the main features of SUDS, providing guidance on how the planning authority would expect these features to be incorporated into development schemes.

Such guidance and/or documents relating to SUDS should normally include information on:

- the potential problems caused by surface water runoff
- the aims of the SUDS approach to drainage
- the benefits of SUDS
- the planning policy context
- sustainable drainage techniques
- SUDS and the planning process
- adoption and maintenance
- choosing the right combination of SUDS techniques
- local soil permeability and hydrology characteristics
- other relevant source documents.

2.3.6 Planning applications and the development control system

Planning applications for individual development proposals will be dealt with by the local planning authority, who must determine applications in accordance with the development plans, unless material considerations indicate otherwise. Where the authority refuses planning permission or attaches conditions which the applicant does not accept, or where there is non-determination within eight weeks (13 weeks for major developments involving and EIA), the applicant may appeal to the Secretary of State. In Scotland the period is two or four months and appeals are made to the Scottish Ministers.

When granting planning permission, the local planning authority may need to secure an agreement under Section 106 of the Town and Country Planning Act (DTLR, 1990) to clarify and establish the implementation of proposed SUDS surface water drainage proposals.

If a suitable scheme has been proposed, then a condition such as the following may be appropriate:

The drainage scheme approved, incorporating sustainable drainage principles, shall be implemented in accordance with the approved details before the development is completed/occupied.

In the absence of a suitable drainage proposal, then a different condition may be relevant, such as:

> Development shall not begin until drainage details, incorporating sustainable drainage principles and an assessment of the hydrological and hydro-geological context of the development, have been submitted to and approved by the local planning authority. The scheme shall subsequently be implemented in accordance with the approved details before the development is completed/occupied.

2.3.7 Environmental Impact Assessment (EIA) and Sustainability Appraisal

Planning applications for certain types of major development projects may fall within the scope of the Town and Country Planning (Assessment of Environmental Effects) Regulations (DETR, 1999a). Where this is the case, various factors then have to be considered in deciding whether an Environmental Impact Assessment (EIA) is or is not required as part of the planning application. The environmental regulator will provide guidance on the requirements for an EIA and the extent to which drainage proposals require consideration.

Under UK legislation, a Sustainability Appraisal must be prepared for regional and local plans. However its application is now expanding to development scenarios. It can be defined as a single appraisal tool which provides for the systematic identification and evaluation of the economic, social and environmental impact of a proposal. Flood risk assessment and management will therefore be a fundamental component.

2.4 THE DEVELOPMENT PROCESS

2.4.1 Incorporating SUDS in new or brownfield development

A successful SUDS scheme will require the design team to liaise and integrate with other stakeholders involved in the development process. The design team and stakeholders should consider SUDS at the feasibility stage of development and at each subsequent stage so that as sustainable a solution as possible can be realised. The retrofitting of SUDS as a drainage solution on brownfield sites may require additional issues to be taken into account, such as the separation of combined sewers.

SUDS design that integrates the features into the overall site design should result in cost-effective solutions. If SUDS are considered as a bolt-on to a conventional site design, then the result may be unnecessarily large and costly.

Each party involved in a development is likely to have its own interests and different perceptions of the advantages and disadvantages of different drainage systems. Consensus must be reached by all stakeholders and all challenges identified and overcome during the early stages of planning. In particular, the ownership and long-term maintenance responsibilities for the system should be clearly defined and agreed at the outset (National SUDS Working Group, 2004).

Figure 2.4 presents a flowchart of the drainage design and planning approval process, and indicates key stages for data collection and stakeholder consultation and agreement. Each stage is then discussed.

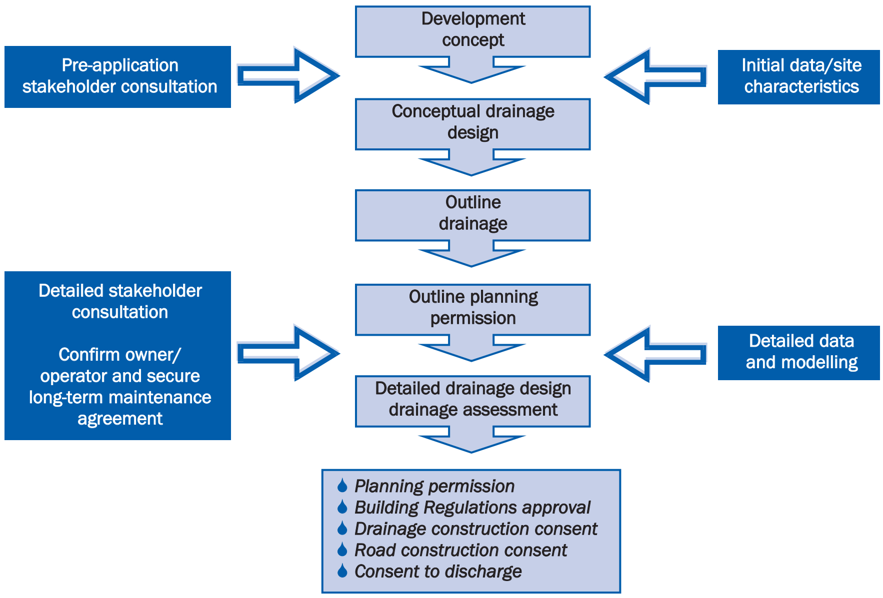

Figure 2.4 *The development process*

2.4.2 Pre-application stakeholder consultation

The purpose of this early consultation is to:

- make all interested parties aware that development is proposed
- identify opportunities, constraints and criteria for drainage design
- ensure that the purchase price of the site makes allowance for the appropriate drainage costs.

Ideally, the developer should contact the planning authority as early as possible to discuss proposed schemes. This pre-application stage may be when a landowner is considering selling property or when a developer is considering purchasing a site for development. After the developer has contacted the planning authority, the planners may convene a meeting if considered appropriate. This is likely to be decided in consultation with interested stakeholders such as the environmental regulator and sewerage undertaker. The statutory authorities need to attend the meeting ready to advise the developer on the design criteria for water quantity, quality and amenity issues appropriate to the site.

For large developments, where there is an intention to separate the development into zones which may be constructed at different stages or by different developers, a drainage masterplan may be required. This will ensure effective communication between all developers in the selection and implementation of source control, site and regional drainage components.

Where possible, the meeting should be attended by some or all of the following:

- the local authority planner
- the developer
- the drainage designers
- a representative from the environmental regulator
- a representative from the sewerage undertaker
- a building control representative
- a highways authority representative
- other local authority representatives if appropriate.

The meeting should have the following outcomes:

- authorities should be aware of the proposed scale and type of development
- the developer should have guidance from the authorities on the surface water drainage criteria
- information should be exchanged on any special site features
- lines of communication for further consultation should be clear
- authorities should decide if more detailed proposals on the drainage system need to be submitted in advance of a planning application, eg drainage assessment or drainage masterplan, and whether an EIA is likely to be required.

The authorities will need to be aware of impacts that might occur outside the site and so may need to consult with organisations with interests up or downstream of the development. As with any development, the designers may also contact, where appropriate, bodies such as RoSPA and Natural England, together with any stakeholders listed above not attending the initial meeting. Consultation could cover design, construction, safety and operational issues.

2.4.3 Outline drainage proposals

Initial consultation should provide sufficient information for an outline drainage proposal to be drawn up. If planners require information in advance of the full planning application, a more detailed drainage proposal should be submitted, indicating the number and types of SUDS components that are proposed to drain each part of the development.

The proposal should describe ideas for integrating the drainage system into the landscape or required public open space and the methods that will be used for linking systems together and managing flows in excess of the design event. At this stage there should be no need to submit initial calculations, but they should be carried out to roughly size any significant drainage structures. This will allow the percentage land take of different options to be estimated.

The capital and ongoing operation and maintenance costs (and whole life costs) should be estimated at this stage so that the options can be compared and so that informed discussions can take place with those taking responsibility for the systems in the long-term.

Depending on the outcome of the initial consultation and the scale and complexity of the proposed development, further informal liaison with regulatory authorities might be required when drawing up the drainage strategy. A strategy is likely to be required as part of the outline planning permission submission.

2.4.4 Detailed drainage assessment, design and consultation

This stage involves preparation of a detailed drainage design for submission with the full planning application and the applications for other approvals. Five steps are needed:

1. The planning authority should agree, with the other regulatory authorities, the type of information that needs to be included in the planning application. The planning authority should inform the developer of the requirements.
2. The developer and drainage designer should liaise as necessary with the regulatory authorities to agree appropriate criteria.
3. The drainage designer should follow the procedures in this manual for selection of drainage techniques (Chapter 5).
4. The developer should confirm with the regulatory authorities that the selected techniques are appropriate.
5. The drainage designer should follow the guidance in this manual to produce designs for the planning, building control, drainage and road construction applications.

Further meetings between the developer and the authorities may be required if there is a need for further discussion about design criteria or techniques, or if the development is very large and complex. It is becoming increasingly common, particularly in Scotland, for local planning authorities to request a "drainage assessment" in support of a planning application. A drainage assessment will generally demonstrate that the surface water drainage for the site is satisfactory so that:

- the site can be adequately developed
- any land-take required for the proposed drainage has been allowed for and due consideration has been given to the impact of the proposed development on the downstream catchment area.

In the unlikely event that SUDS are not appropriate for the site, the drainage assessment should identify the principles behind the adopted approach and demonstrate that the drainage method adopted gives the best available environmental protection.

The scope of the drainage assessment will depend on the type and scale of the development and the sensitivity of the area, and should be agreed in advance with the local planning authority. It is likely to cover the issues set out in Box 2.1 below, plus additional issues where specified by planners.

Box 2.1 *Basic requirements of a drainage assessment*

- A method statement detailing how surface water arising during construction will be dealt with and, if temporary or sacrificial SUDS will be established, for dealing with construction runoff (refer to Masters-Williams *et al*, 2001 and *Pollution Prevention Guideline* (PPG) 6: *Working at construction and demolition sites* (EA/SEPA/EHS (2006)).
- An examination of the current and historical drainage patterns including watercourses, ditches, culverts, sewers and general land drainage, both within and adjoining the site to ensure that drainage proposals integrate with and do not compromise the function of natural drainage systems.
- A statement of SUDS to be incorporated and final discharge point(s) where relevant, including how the drainage design satisfies SUDS techniques, both in terms of water quality and attenuation of water quantity, in accordance with best practice and design.
- For full applications, a drainage plan identifying the type(s) of SUDS to be incorporated and SUDS land take.
- Proposals, where relevant, for integrating the drainage system into the landscape or required publicly accessible open space and providing habitat and social enhancement.
- The soil classification for the site, stating the method used for determination.
- Evidence of soil porosity tests at the location of any intended infiltration device and the proximity of the winter water table.
- Calculations showing the pre- and post- development peak runoff flow rate for the critical rainfall event.
- Attenuation designed for small, frequent rainfall events, designed to provide the appropriate treatment.
- Calculations showing the drain down time of the SUDS system, following an extreme event.
- Provision of drainage for larger storm events, including protection for SUDS systems.
- Indication of overland flow routes and safeguarding of properties from flooding.
- Attenuation designed to contain the critical site design storm.
- Details of which body will be responsible for vesting and maintenance for individual aspects of the drainage proposals.
- Confirmation of land ownership of all land required for drainage.
- Foul drainage proposals.

Additional requirements that may be selectively specified are described in Box 2.2.

Box 2.2 *Additional requirements of a drainage assessment*

- take into account possible future development
- description of safety measures to render SUDS acceptably safe
- calculations showing that the post-development runoff volume does not exceed that for pre-development for the critical rainfall events
- assessment of flood risk including consideration of the flow route for extreme return period flood events showing no detriment to land or property as a result of overland flow
- calculation of the treatment volume and demonstration that the level of treatment and available treatment volume is adequate
- consider impact of development on pollution risk to groundwater, and/or mobilisation of groundwater contamination
- possible additional level of treatment for discharge to sensitive receiving waters
- survey of habitats and species with reference to the Local Biodiversity Action Plan
- demonstration of good ecological practice including habitat enhancement and de-culverting
- take account of surface water/groundwater entering the development from adjacent land.

Throughout this process the planning authority should act as coordinator and maintain contact with the environmental regulator, the sewerage undertaker and other local authority functions. At the end of this stage, the information needed by all regulatory authorities will have been assembled. Although separate applications will be made to each organisation, the drainage proposals should be approved by all of them.

2.5 LEGISLATION AND CONTROLS ON SURFACE WATER DRAINAGE

2.5.1 General

Consideration needs to be given to the legal aspects of installing SUDS as opposed to conventional drainage facilities. All drainage (including SUDS) must comply with all relevant UK statutes, and designs should adhere to relevant codes of practice and available flood control and pollution prevention legislation and guidance. CIRIA publication C625: *Model agreements for sustainable water management systems* (Shaffer *et al*, 2004), provides a comprehensive review of legislation and guidance. A summary of some of the main documents relevant to SUDS is provided here.

Compliance with the relevant environmental legislation is a vital consideration for all drainage systems, including SUDS. The environmental regulator controls pollution of controlled waters through the issue of authorisations, permits or consents, and any discharge of pollutants must be authorised by them in advance.

In Scotland, the Water Environment and Water Services (WEWS) (Scotland) Act (Scottish Executive, 2003) gave SEPA powers to introduce regulatory controls over activities to protect and improve Scotland's water environment. These regulatory controls – the Water Environment (Controlled Activities) (Scotland) Regulations (CAR) (Scottish Executive, 2005) – mean that it is an offence to discharge to any wetlands, surface water systems, and groundwater systems without a CAR authorisation (replacing the Control of Pollution Act (DoE, 1974a)).

Three types of authorisation under CAR allow for proportionate and risk-based regulation. The three levels of authorisation are:

a) General Binding Rules (GBRs).

b) Registration.

c) Licence.

GBRs represent the lowest level of control and cover specific low-risk activities, including discharges of surface water runoff, and discharges into a surface water drainage system.

GBR activities taking place in accordance with the rules do not require an application for authorisation from SEPA. The following GBRs are relevant to point source discharges from SUDS.

Box 2.3 *General Binding Rule 10 (Scottish Executive, 2005)*

GBR10: Discharge of surface water runoff from a surface water drainage system to the water environment from construction sites, buildings, roads, yards and any other built-up areas

Rules:

1. If the surface water runoff is from areas constructed after 1 April 2006 or from a construction site operated after 1 April 2006, these sites must be drained by a Sustainable Urban [*sic*] Drainage System (SUDS) or equivalent. The only exceptions are (i) if the run-off is from a single dwelling and its cartilage and (ii) the discharge is to coastal water.
2. The discharge must not result in pollution of the water environment.
3. The discharge must not contain any trade effluent and must not result in visible discolouration, iridescence, foaming or sewage fungus in the water environment.
4. The discharge must not result in the destabilisation of the banks or bed of the receiving surface water.
5. The discharge must not contain any water runoff from any of the following areas constructed after 1 April 2006:
   - fuel delivery areas and areas where vehicles, plant and equipment are refuelled
   - vehicle loading or unloading bays where potentially polluting matter is handled
   - oil and chemical storage, handling and delivery areas.
6. All treatment systems (including oil interceptors, silt traps and SUDS) must be maintained in a good state of repair.
7. All reasonable steps must be taken to ensure that any matter liable to block, obstruct, or otherwise impair the ability of the surface water drainage system to avoid pollution of the water environment is prevented from entering the drainage system.

Box 2.4 *General Binding Rule 11 (Scottish Executive, 2005)*

GBRII: Discharge into a surface water drainage system.

Rules:

1. Oil, paint thinners, pesticides, detergents, disinfectant or other pollutants must not be disposed of into a surface water system or onto any surface which drains into a surface water drainage system.
2. Any matter liable to block, obstruct or otherwise impair the ability of the surface water drainage system to avoid pollution of the water environment must not be disposed of into a surface water drainage system or onto a surface that drains into a surface water drainage system.
3. Sewage and trade effluent must not be discharged into any surface water drainage system.

2.5.2 Groundwater pollution prevention: regulation and guidance

Surface water runoff from urban areas can contain a variety of pollutants including oil, heavy metals, sediment and organic matter, and therefore poses a risk to receiving waters, particularly groundwater. Where SUDS involve infiltration, there is a potential for groundwater to be impacted by the surface water discharge.

Regulation

Groundwater's importance is reflected in the legislation that has been produced to protect and manage it. Legislation exists at both UK and European level.

The key European Directives are the Groundwater Directive (EC, 1980), Water Framework Directive (EC, 2000), Nitrate Directive (EC, 1991a) and Plant Products Directive (EC, 1991b). The Groundwater Directive's aim is to protect groundwater by preventing or limiting the discharge of a range of substances to groundwater. The Water Framework Directive introduces a more holistic and integrated approach to protecting both groundwater and surface water. It also places more emphasis on protecting ecosystems as well as drinking water. Nitrate is a widespread pollutant in groundwater and surface water. To protect ecosystems and water use in general the Nitrates Directive requires the UK to prevent pollution of water by nitrate from agricultural sources. The Plant Products Directive controls the approval and use of pesticides to protect groundwater and the environment and human and animal health. The Groundwater Directive is implemented in the UK through the Groundwater Regulations (DETR, 1998).

The requirements of the Groundwater Regulations are that List I substances must be prevented from entering groundwater and List II substances must be controlled to prevent pollution of groundwater.

Table 2.3 provides examples of the listed substances.

Table 2.3 *Examples of listed substances in Groundwater Regulations (DETR, 1998b) relevant to SUDS*

List I	Toxic heavy metals (eg cadmium, mercury), mineral oils and hydrocarbons, organohalogen, organotin, organophosphorous compounds (includes many pesticides that may be found in runoff), carcinogens and cyanides.
List II	Substances such as other heavy metals, ammonia and nitrites, some silicon and phosphorous compounds, fluorides and substances with a deleterious effect on the taste and odour of groundwater (MTBE is in this group) that may be found in runoff.

The Water Framework Directive (WFD) (EC, 2000) classifies broad bands of substances as "main pollutants", the content of which is similar to the combined lists of the Groundwater Directive. Additionally, the WFD prohibits discharges of pollutants direct to groundwater from both traditional and sustainable drainage systems.

For England and Wales, regulatory guidance is contained within the Environment Agency's Groundwater Protection: Policy and Practice documentation (EA, 2007). SEPA's policy is set out within their Groundwater Protection Policy (SEPA, 2003). In Northern Ireland, regulatory guidance is provided by Policy and Practice for the Protection of Groundwater in Northern Ireland (EHS, 2001).

Discharge consents

Unless they are covered by a specific exemption, the Groundwater Directive requires that discharges of listed substances to groundwater are subject to prior investigation and authorisation. This applies to both direct (to the water table) or indirect (to the unsaturated zone) discharges or disposals. The Environment Agency will control most runoff discharges to groundwater using a Water Resources Act discharge consent acting as a Groundwater Authorisation for the purposes of the Groundwater Regulations. In Northern Ireland the discharge of listed materials to groundwater is controlled by authorisation under the Groundwater Regulations (Northern Ireland, 1998)

In Scotland, in line with SEPA's Groundwater Protection Policy (SEPA, 2003), it is considered that, as a minimum, the following sites will require a prior investigation to be carried out for SUDS which utilise infiltration serving the following types of development:

- brownfield sites
- industrial sites
- commercial sites
- petrol stations
- lorry parks.

In England and Wales, an acceptability matrix has been developed to indicate whether prior investigation and authorisation of the discharge is required (National SUDS Working Group, 2004). There are two points to consider when using this matrix:

1. The matrix gives a crude hazard assessment of the source area of the SUDS discharge (area to be drained) to determine its significance. This is used to assess whether, in principle, the requirement to authorise the discharge under the Groundwater Directive may be relaxed. If a discharge authorisation is not required no further assessment is needed.

2. If the discharge is from a highway drain, and there is the potential for List I substances to enter, or for List II substances to pollute groundwater, then control is effected using Prohibition Notices. These are issued by the Environment Agency, or the Scottish Environmental Protection Agency, via Section 86 of the Water Resources Act (DoE, 1991b) or the WEWS CAR regulations (Scottish Executive, 2005) respectively in order to ensure compliance with the Groundwater Directive.

If the matrix (for England and Wales) indicates that a Groundwater Authorisation is needed then a prior investigation is necessary. This will determine whether the discharge can be authorised and under what conditions.

The matrix is presented as Table 2.4.

Table 2.4 *Source hazard assessment for SUDS to determine whether the requirement for an authorisation for the discharge may be relaxed (England and Wales)*

Source (catchment)	Requirement for authorisation [1,2]
Roof drainage	Not normally required – provided it is via a sealed system[3].
Residential area, amenity soakaway area	Not normally required – provided discharge is not direct to and in accordance with good practice.
Car park	Not normally required – if properly constructed (ie in accordance with the principles described in best practice guidance documents).
Lorry park, garage forecourt – outside canopy	Required.
Local roads[4]	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.
Major road[4]	Not normally required – but if necessary to prevent listed substances entering or polluting groundwater the Environment Agency will serve notice to control the discharge.
Industrial site, major commercial site	Required.

Notes:

1 For general guidance only and should be read in conjunction with the Environment Agency Groundwater Strategy. Individual circumstances may vary depending on specific activities in the catchment of the SUDS.

2 It is assumed that no treatment is included (such as oil separators, wetlands or reed beds).

3 Sealed system for roof drainage means downpipes are cemented in or otherwise connected directly to the surface water drainage system and do not discharge via an open grating to an opening to the drain.

4 The Environment Agency has a duty to control the discharge of road drainage by serving a notice under Section 86 of the WRA 1991 if it is necessary to do so for the purpose of:

(i) preventing the introduction of List I substances into groundwater, or
(ii) pollution of groundwater by List II substances, or
(iii) pollution of a surface water. (Groundwater Regulations 1998 Regulation 4(4) and 5(3) and WRA 1991 S86(1).)

The Environment Agency will generally only serve such a notice where it considers that the pollution risk is too great.

2.5.3 Surface water pollution prevention: regulation and guidance

Regulation

The statutory framework for regulating discharges from SUDS to surface waters is detailed in Water Resources Act (DoE, 1991b) and the Control of Pollution Act (DoE, 1974a) (as amended), which make it an offence to discharge polluting matter to controlled waters without a discharge consent from the environmental regulator. The Water Framework Directive (EC, 2000) requires the control of all surface water discharges. Controlled waters in Scotland are defined in the CAR regulations (Scottish Executive, 2005), and in Ireland are defined by the Water Order (DoENI, 1999) which replaces the Water Act (DoENI, 1972).

The current regulatory regime in Scotland is set out in Section 2.5.1. Surface water discharges from SUDS do not require a licence under the WEWS CAR regulations, unless they are draining:

- >1000 residential houses
- >1000 car parking spaces
- industrial areas
- major roads/motorways

in which case a simple license would be required.

Discharge consents

A discharge consent may specify conditions, which can include limits on quantity and quality that must be met.

For a surface water discharge, the level of regulation should be proportionate to the risk of contamination of that discharge. Generally:

- if the discharge is uncontaminated surface water, then a discharge consent will not be required
- where the surface water has a high risk of contamination and/or the runoff requires treatment before it can be discharged to a controlled water, then it will require a discharge consent.

For SUDS discharges that lie between these situations the developer will be required to conduct a proportionate risk assessment of the SUDS to identify the potential sources of pollution, pathways and consequences of a possible pollution incident on the receiving water and include contingencies to deal with such scenarios. The regulator should be consulted at an early stage on this assessment so that the nature and scope can be discussed along with any pre-application requirements. Once the risk assessment has been completed a decision on the discharge consent requirements can be made.

Some receiving waters are more sensitive than others to pollution and, in the absence of more robust assessment, a degree of flexibility and pragmatism is appropriate.

It is generally agreed that, where possible, SUDS should neutralise the impact of the development on the local hydrology and in most cases a precautionary approach should be adopted.

Developers should be aware that the statutory time frame for the determination of an application for a discharge consent is four months (this cannot be reduced and some complex determinations may take longer) and includes statutory and public consultations.

A discharge consent can be granted only to a named holder, which must be a legal person (eg an individual or company or other corporate body). The consent holder accepts responsibility for holding (and complying with) the discharge consent. Thus the operator or controller of the SUDS would normally hold the discharge consent. The discharge consent for SUDS will normally be framed in descriptive terms to protect the receiving water, focusing on the periodic need for maintenance in relation to pre-identified causes of a potential deterioration of performance (eg vegetation removal, de-silting, etc). Enforcement, if necessary, is likely to be via an Enforcement Notice specifying the action to be taken to ensure the discharge consent meets its conditions (eg restoring the SUDS to their intended function).

Highway and roads drainage consents

Highway and roads authorities do not require discharge consents for highway runoff either to surface waters or to ground. The environmental regulator has the power (and in respect of discharges to ground, a duty) in the event of evidence that a highway discharge is causing pollution, to control that discharge by serving notice under Section 86 of the Water Resources Act (DoE, 1991b) and the Control of Pollution Act (DoE, 1974a), Section 30(g).

The consequence of the above is that highway authorities have a responsibility to ensure that discharges are not causing pollution and that it is for them to determine how pollution control is carried out. Highway authorities consult with the Environment Agency and SEPA to reach agreement on any treatment measures to be provided, but formal approval is not be required.

2.5.4 Waste management

Sedimentation is likely to occur to some degree in SUDS; many systems are designed to promote sedimentation as a treatment function and the silt must be managed. Consequently, there will be a requirement periodically to remove deposited sediment to ensure that the system continues to operate efficiently and effectively (ie as designed) and to control the risk of environmental pollution. However, depending upon the characteristics of the SUDS catchment, these sediments could be contaminated to varying degrees. This presents a potential risk to the land upon which the sediments are deposited and any receiving surface or groundwater.

Whether sediment arisings from SUDS maintenance are retained on site or removed off site, they must be treated as “waste” and are subject to control under the Waste Management Licensing Regulations (DoE, 1994b) and the Waste Management Licensing Regulations (England and Wales) (Amendments and Related Provisions) Regulations (Defra, 2005). The detail of this regulation is discussed in Chapter 20 which deals specifically with waste. Site-specific advice can be sought from the environmental regulator.

2.5.5 Flood management regulation and guidance

In England, flood control management and guidance is set out in PPS 25 (DCLG, 2006). SPP7 (Scottish Executive, 2004), TAN 15 (National Assembly for Wales, 2004) and PPS 15 (DoENI, 2006) are equivalent Scottish, Welsh and Northern Ireland documents respectively. These explain how flood risk should be considered at all stages of the planning and development process to reduce future damage to property and loss of life. They set out the importance government attaches to the management and reduction of flood risk in the land-use planning process, to acting on a precautionary basis and to taking account of climate change predictions. They summarise the responsibilities of various parties in the development process.

The guidance requires the planning system to ensure that new development is safe and not exposed unnecessarily to flooding by considering flood risk on a catchment-wide basis and, where necessary, across administrative boundaries. It requires that developments, where possible, reduce and certainly not increase flood risk, and that flood plains are used for their natural purposes, continue to function effectively and are protected from inappropriate development. The guidance also outlines how flood risk issues should be addressed in regional planning guidance, development plans and in the consideration of planning applications.

2.5.6 Reservoir safety

Any reservoir that is designed to hold more than 25 000 m^3 of water above any part of the natural ground level around the reservoir, will fall under the requirements of the Reservoirs Act (DoE, 1975a). The Act applies in England, Wales and Scotland but does not apply in Northern Ireland, although the Department of the Environment (NI) generally follows its provisions.

SUDS techniques such as ponds, infiltration basins and wetlands could fall into this category if they are formed by constructing embankments to impound water above the natural ground levels. Under the Act there are panels of civil engineers that are specialists in dams and reservoirs. The owner of a reservoir that falls under the Act must appoint a "panel engineer", as they are known, to be responsible for the design and construction of the reservoir. A different panel engineer must then be appointed to inspect the reservoir and dam at a frequency of not less than every 10 years. The engineer who carries out the inspection cannot be an employee of the owner.

The Act is enforced by the local authorities (county councils, unitary authorities, regional authorities) and they must be informed of any intention to construct a reservoir that falls under the Act. Failure to comply with the Act is a criminal offence and if there is any doubt about whether a SUDS structure is likely to fall under the Act a qualified civil engineer from the appropriate panel should be sought (the names of panel engineers may be obtained from the Institution of Civil Engineers). Further information is provided in CIRIA B14 *Design of flood storage reservoirs* (Hall *et al*, 1993).

There has been concern in recent years that many small British reservoirs that do not come within the ambit of the Act may, nevertheless, represent a significant hazard to some communities by virtue of such issues as their particular location, steepness of the valley, height of the structures and state of repair. The designer should be aware of such issues. Nothing in this document should be taken as overriding or diminishing the responsibilities resulting from the Reservoirs Act (DoE, 1975a); nor the responsibilities resulting from the design, construction or ownership of bodies of water which – while not coming within the ambit of the Act – could represent a significant hazard to people and property situated downstream.

2.5.7 Drainage regulation and guidance

The Highways Act (DoE, 1980)

The Highways Act sets out legislation with respect to Highways. With respect to drainage, the incorporation of SUDS which involve road drainage usually requires the developer either to enter into an agreement under Section 38 of the Highways Act, if involving new development, or an agreement under Section 278 of the Act, if existing arrangements are to be modified.

The Roads (Scotland) Act (Scottish Development Department, 1984)

Under the Roads (Scotland) Act 1984 the roads authority is responsible for the provision of surface water drainage for adopted roads and for the issue of roads construction consent.

Design Manual for Roads and Bridges (DMRB) (Highways Agency *et al*, 2001)

Although not a statutory document, many highways authorities will refer to the DMRB (published by the Highways Agency and others) when assessing drainage schemes for roads on new developments. The DMRB includes advice on the design of components that are used in SUDS design in HA 103/01 *Vegetative treatment systems for highway runoff* and also covers gravel filter drains.

Building control

Building control (under the Building Act (DoE, 1984)) requires those undertaking building work to provide full plans of the work proposed and to submit their construction activities for inspection. The most recent edition of the Building Control Regulations for England and Wales came into effect in 2001. Section H3 addresses issues of surface water drainage. Of particular relevance to SUDS is the section that addresses soakaways and other infiltration drainage systems. It requires that disposal of surface water drainage should preferably be by infiltration, secondly by discharge to a watercourse and lastly by discharge to a surface water sewer. The Building (Scotland) Regulations 2004 (Scottish Building Standards Agency) require every building, and hard surface within the curtilage of a building, to be designed and constructed with a surface water drainage system that will:

- ensure the disposal of surface water without threatening the building and the health and safety of the people in and around the building
- have facilities for the separation and removal of silt, grit and pollutants.

The Building Regulations recommend the use of SUDS in preference to traditional piped drainage techniques.

In Scotland the Technical Handbooks providing guidance on ways to comply with the Building Regulations offer several options on compliance with the standard. The benefits of adopting SUDS are explained but there is no prioritisation list as in England and Wales. Surface water drainage may be made a 'material consideration' under the planning system.

Part C of the Building Regulations – Site Preparation and Resistance to Contaminants and Moisture (DTLR, 2004) – contains guidance that elevates floor levels within buildings above the external ground and also reminds developers that the integrity of pre-existing land drainage should be maintained after a site is developed.

In Scotland the guidance to standard 3.4 recommends that the level of a solum (the prepared area within the containing walls of a building) below a suspended timber floor should not be below the level of the adjacent ground to prevent standing water. Guidance to standard 3.5 recommends that existing drains within a building site should remain active or, where this is not practical, re-routed or re-constructed. Where there is the possibility of flooding, guidance is provided to standard 3.3 on precautionary measures that should be taken with regard to forms of construction and to reduce the risk of flood damage in buildings.

Sewers for adoption

Sewers for Adoption 6th ed. (WRc, 2006) and *Sewers for Scotland* 2nd ed (Scottish Water, in preparation) provides guidance on the standards of flood protection to be achieved by the drainage system. They are guides to assist in the submission of a drainage scheme to a sewerage undertaker before entering an Adoption Agreement under Section 104 of the Water Industry Act (DoE, 1991a). The philosophy is such that a developer, for example, should be expected to work to the same standards as those used by the sewerage undertaker. The documents are well-recognised within the industry and work well, as they set common and clear standards for constructing drainage infrastructure.

Maintenance agreements

In granting planning permission, the local planning authority may need to secure a Section 106 Agreement of the Town and Country Planning Act (DTLR, 1990) to clarify and establish appropriate mechanisms for adoption and long-term maintenance of the SUDS. In some instances it will be necessary to ensure that a properly guaranteed or bonded maintenance arrangement is put in place, or a commuted sum is secured to fund maintenance by another agency (such as the local authority). Since planning permission cannot be granted subject to obtaining an agreement, the agreement of the adopting agency should be obtained by the local planning authority before the SUDS are approved through the development control process. This may require a restrictive condition to prevent the development progressing before the drainage arrangements are in place.

In England and Wales, the National SUDS Working Group and CIRIA have produced an *Interim Code of Practice for SUDS* (National SUDS Working Group, 2004) that provides guidance on which SUDS components are likely to be appropriate for adoption by local authorities, highway authorities and sewerage undertakers. The Code also provides model agreements that can either use the Town and Country Planning Act Section 106 agreement or a planning condition to facilitate maintenance. In Scotland, the Water Environment and Water Services (Scotland) Act (Scottish Executive, 2003) means that some public SUDS systems will be maintained by Scottish Water, provided they are constructed to specified standards.

2.5.8 Water quality regulation and guidance

Water Supply (Water Fittings) Regulations (DETR, 1999b)

The main consideration regarding the installation and operation of rainwater harvesting and greywater use systems is to ensure that no possibility of contamination exists by cross-connection of pipes carrying reused water and potable water. The commonest point of potential cross-connection is where the potable water backup system meets the non-potable water storage tank, and where the various potable and non-potable water pipes are routed within the structure of a building and could therefore be confused during work carried out at a later date. It is therefore necessary to ensure that current codes of practice are enforced where applicable, and where pipes are to carry reused water, they should be labelled in accordance with the guidelines described by the Water Regulations Advisory Scheme (WRAS).

Additional technical guidance

In addition to the above legally enforceable requirements, there are a number of technical guidance documents which relate to the quality of rainwater/greywater for cases other than irrigation. Guidelines have been produced by the following organisations:

- *Buildings that save water*, CIRIA (Leggett *et al*, 2001)
- *Water reclamation standard* BSRIA (Brown and Palmer, 2002)
- *Guidelines for water reuse* (USEPA, 2004)
- *Information guidance notes* (WRAS, 1999).

If these guidelines are followed, they will ensure that minimal risk of disease transfer exists from the use of rainwater or greywater. Currently, within the UK, there is no universal agreement on the parameters to be measured, although the commonest concerns are microbial activity and residual nutrient in the form of soluble BOD[5].

2.5.9 Habitat/biodiversity

Guidance on national and local biodiversity action plans and on the integration of nature conservation priorities and land use planning is provided in PPG9 (Nature Conservation) (DoE, 1994a) and TAN5 (Nature Conservation and Planning) (National Assembly for Wales, 1996).

The Wildlife and Countryside Act (WCA) (DoE, 1981) is the principal piece of legislation protecting wildlife in Great Britain. Broadly, it seeks to protect habitats and individual species, through designated areas. The Conservation (Natural Habitats etc) Regulations (DoE, 1994c) implement the EU Habitats Directive (EC, 1992) in Great Britain. Among other things, the regulations require that the Secretary of State (or equivalent) draws up a list of sites of European Community importance that are then designated, and places a statutory requirement on local planning authorities to undertake appropriate assessment of any proposed project on these sites. The Countryside and Rights of Way Act (DETR, 2000b) applies only to England and Wales and strengthens the protection to SSSIs, placing a duty on government and officials to take into account biodiversity action plans in decision-making. The Act also amends the WCA in making it a criminal offence to "recklessly disturb" specified birds and other species. This has important implications for construction contractors. The Town and Country Planning (Trees) Regulations (DETR, 1999c) (England and Wales only) includes provisions for protecting any tree, group of trees or woodland, and the Hedgerow Regulations (DoE, 1997) introduced protection for hedgerows.

In Northern Ireland, wildlife is protected principally by the Wildlife Order (DoENI, 1985) and the Environment Order (DoENI, 2003). The Nature Conservation (Scotland) Act (Scottish Executive, 2004) places responsibilities on all public bodies in Scotland to further the conservation of habitat when exercising their function.

2.5.10 Health and safety regulation and guidance

Health and Safety at Work etc. Act (DoE, 1974b)

The Health and Safety at Work Act and regulations under it apply to SUDS. The Act provides a global framework for all parties involved in the workplace to promote effective safe working practices.

Of significance is the general duty in regard to the safety of employees and others, which includes the minimisation of exposure to biological risks (Control of Substances Hazardous to Health (Amendment) (COSHH) Regulations (Defra, 2004)). This means that the management, maintenance and use of SUDS in a workplace should be subject to a risk assessment.

The Construction (Design and Management) Regulations (DETR, 1994)

The Construction (Design and Management) (CDM) Regulations apply throughout the UK. They were enacted to stem the increasing number of accidents and fatalities that occur on construction sites.

The regulations are relevant for all contracts involving demolition and all other projects which last more than 30 days or 500 person days, or involve having five or more people on a site at one time.

The accidents that may occur could affect construction workers, the public and maintenance workers. Many accidents on construction sites can be prevented by giving due consideration to the safety of construction workers at the design stage. The Regulations place duties on people involved in construction including clients, designers, specifiers and contractors. The Planning Supervisor appointed under the Regulations is responsible for overseeing the consideration of health and safety on a project and ensuring that Health and Safety Plans and files are maintained and implemented.

The CDM Regulations apply to most construction work except for very small projects and projects where householders are the client. Most SUDS schemes will need to comply with their requirements.

Clients must undertake the following:

- appoint a planning supervisor
- provide information on health and safety to the planning supervisor
- appoint a principal contractor
- ensure that designers and contractors are competent to carry out the work safely and have allowed sufficient resources.

Designers must assess all foreseeable risks during construction and maintenance and the design must minimise them by the following (in order of preference):

- avoid
- reduce
- identify residual risks that require mitigation.

They must also make contractors and others aware of risks in the Health and Safety File, which is a record of the key health and safety risks that will need to be managed during future maintenance work. For example, the file for a SUDS pond should contain information on the collection of hazardous compounds in the sediment so that maintenance contractors are aware of it and can take appropriate precautions.

During construction the residual risks must be identified and an action plan developed to deal with them safely (the Health and Safety Plan). The use of SUDS in many cases is beneficial in respect of CDM because it minimises the need for deep excavations and construction of large engineered structures. The CDM regulations are specifically aimed at construction and maintenance operations but the principles can easily be extended to cover risks posed to occupiers/public by completed SUDS schemes. Further information is provided in CIRIA C604 *CDM Regulations – work sector guidance for designers* (Ove Arup and Gilbertson, 2004).

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Design criteria

3

Contents

Design criteria

3

The purpose of design criteria is to provide a framework for designing a system to drain effectively the required area to protect public health and safety, and the environment. SUDS should be designed to agreed standards which take account of hydraulic, water quality, amenity and ecology objectives. Although individual regions may have specific requirements, this chapter presents a set of principles from which robust design criteria may be developed.

3.1 INTRODUCTION TO DESIGN CRITERIA

The purpose of design criteria is to provide a framework for designing a system to effectively drain the required area to protect public health and safety, and the environment.

Complementary and associated objectives are to:

- store or safely pass the runoff from extreme storm events, without putting public or property at risk
- reduce if possible, or at least not increase, the pre-development risk of flooding associated with the receiving watercourse
- prevent downstream stream bank and channel erosion
- reduce urban runoff pollutants and improve stormwater water quality before discharge
- provide amenity and ecological benefits, wherever practicable.

It is not possible to design for all events and there will always be instances when the design criteria will be exceeded. The design process should, therefore, be one of risk assessment and management. The consequences of events larger than the design event should be assessed for their physical, economic, social and environmental impacts, and managed through good site design as far as possible.

This chapter presents a set of design criteria for drainage design for developments. The overall aim is to provide an integrated approach to address:

1. Hydraulics	(Section 3.2).
2. Water quality	(Section 3.3).
3. Amenity	(Section 3.4).
4. Ecology	(Section 3.5).

The criteria presented here are recommendations that may either be adopted or modified to meet local or catchment management goals or objectives. Developments in environmentally sensitive areas may be subject to additional performance and/or regulatory criteria. Additional guidance and recommendations are proposed as principles of drainage good practice.

When selecting design criteria for a specific site, the following principles must be given full consideration:

1. Level of service required.
2. Sustainability of the drainage solution.
3. Cost of the drainage solution.

These principles are expanded in the Table 3.1.

Table 3.1 *Principles driving drainage design criteria selection*

Principles	Objectives
Level of service	1. Flood protection should be provided to a minimum level of service. 2. Risks to people and amenity benefits should be addressed (including safety).
Sustainability	1. Drainage systems should aim to replicate the natural rainfall-runoff processes occurring on the site, pre-development. 2. Water quality treatment should minimise environmental impact. 3. Ecological benefits should be maximised. 4. Drainage systems should aim to utilise natural resources that can be reused and are energy efficient in terms of constituent products, construction processes and operation and maintenance activities.
Cost	1. A Whole Life Cost analysis of the system should demonstrate cost-effectiveness (through option appraisal) and financial viability (through security of long-term funding).

3.2 HYDRAULIC CRITERIA

3.2.1 General principles

There are two key principles that should be followed when developing hydraulic design criteria for the development site:

a) Ensure that people and property on the site are protected from flooding.
b) Ensure that the impact of the development does not exacerbate flood risk at any other point (either upstream or downstream) in the catchment of the receiving watercourse.

3.2.2 On-site flood protection

Three key criteria should be met to protect the public from flooding, both on site and in downstream areas. These are:

1. Protection against flooding from the watercourse.
2. Protection against flooding from the drainage system.
3. Protection against flooding from overland flows (from sources within or external to the site).

Not all sites need to consider flooding from a watercourse or flooding from adjacent land, but all sites will need to consider the risks of flooding from the proposed drainage system. Although this guidance document relates to SUDS design, the principles being discussed are applicable to all drainage systems. Flooding from a drainage system during an extreme event should not be classed as "failure" providing the system operates as designed and the excess flows are managed appropriately. It should be noted that the consequences of exceedance are usually less dramatic with SUDS than with traditional drainage systems.

Protection against flooding from the watercourse

Generally development should not be undertaken within a functional floodplain and, wherever possible, should be excluded from areas that lie within the 1 in 100 year (or 1 in 200 year) flood risk zone. Specific guidance is given in national planning policy statements.

All floor levels of houses need to have a suitable freeboard above the predicted maximum 1 in 100 year/200 year return period for the critical storm relevant to each location. A value of 600 mm is often used, although this should be increased where there is a significant level of uncertainty and/or where predicted water levels are particularly sensitive to the assumptions and analysis parameters being used. An allowance should also be made for climate change (see Table 3.2). The design water levels and freeboard should be agreed with the relevant authority (environmental regulator or local planning authority). More extreme events may need to be considered where there is a risk to people.

Where the development lies behind a flood defence, the local planning authority may have a stated position with respect to development in these locations. In all cases, however, a flood risk assessment should be undertaken of the extreme water levels, the standard of the defence, and the distance of the properties from the defence. The methodology and results should be discussed and agreed with the relevant authorities and regulators so that a planning position may be secured. Guidance on how to assess flood risk for developments behind both fluvial and coastal defences has been developed as part of a number of Defra and EA R&D projects (including FD2320 *Flood risk assessment guidance for new development* (HR Wallingford, 2005a), FD2321 *Flood risks to people* (HR Wallingford, 2005b), and W5B-030 *Risk assessment for flood and coastal defence for strategic planning* (RASP) (HR Wallingford, 2004)). At the time of writing, these approaches have yet to be adopted by the Environment Agency or other environmental regulators and therefore further advice regarding the assessment approach should be sought.

Protection against flooding from the drainage system

It is advised that the drainage system should be designed to cater for the 30 year critical event for the site without causing any significant unplanned flooding. This is in line with the requirements set out in Sewers for Adoption and Sewers for Scotland for drainage systems to be adopted by the sewerage undertaker. Such a requirement should be open to variation depending on the type of development being served and the drainage system proposed.

Although the uncertainty associated with design water levels from drainage within the site is lower than that associated with watercourse levels, it is still important to make sure that property floor levels have an appropriate freeboard above the 100 year (200 year for Scotland and when required by the environmental regulator) predicted flood level for areas of temporary flood ponding and designated storage units.

In addition, consideration should be given to the following scenarios:

1. The risk of high water levels (100/200 year) in the receiving watercourse at times of extreme rainfall over the site, affecting the outfall and the drainage system performance (a joint probability appraisal may be required).
2. The impact of extreme event flooding if a blockage occurs at any point in the drainage system.
3. Failure of any embanked storage facility.

A precautionary approach should generally be adopted (in agreement with the relevant planning authority and flood control regulator) in minimising risks to people and property.

Protection against flooding from overland flows

The system performance should be tested for the short, very high intensity, thunderstorm-type event, which may overwhelm the capacity of the drainage system. A short duration, 100 year site design storm (usually less than 1 hour) should be applied to the drainage system to ensure that any impacts are fully accounted for and managed.

This is particularly relevant for areas served by a pipe-based network. Potential flows into the site from external sources, eg adjacent land drainage, should also be identified and quantified.

The following issues should be considered specifically:

1. Overland flood routes (eg roads), should be identified, and vulnerable structures and properties positioned away from or above potential flood paths.
2. Sites should take into account topography to maximise the benefits of potential storage at low-points.
3. Basements are likely to be particularly at risk and should be protected to prevent entry of overland flows.
4. Basements can also be flooded due to surcharged sewers when connected to the system or even due to basements being unlined, that are located close to sewers and should normally be protected from such risks. Pumps can be used rather than gravity-based systems.
5. Access to institutional buildings must be possible at all times during an extreme event.

If there are points in the drainage system that may be at risk of blockage, then simulations should be undertaken to ensure that the potential consequences are minimised through appropriate design. Particular consideration should be given to low points on the site.

More guidance is available on designing drainage systems for rainfall exceedance in the CIRIA publication, C635, *Designing for exceedance in urban drainage – good practice* (Balmforth *et al*, 2006).

3.2.3 Protection of receiving watercourse

There are two key principles that should be met to protect the receiving watercourse from the threat of increased flood risk as a result of the proposed development. These are:

1. Ensure that frequency of discharge rates from the new development is, wherever possible, equal to the frequency of discharge rates that would be discharged under equivalent greenfield conditions.
2. Ensure that the frequency of volumes of runoff from the new development is, wherever possible, equal to the frequency of volumes that would be discharged under equivalent greenfield conditions.

For the initial stormwater drainage design assessment (given in Figure 4.1) and the "Performance Assessment" route for the detailed drainage design process (set out in Figure 4.11), the "matching" of discharge rate frequency is checked using specific design events, and the volume criteria is addressed through provision of the Long-Term Storage volume. The full "Sustainability Assessment" route (set out in Figure 4.11) would require a comparison of the frequency distribution of both peak discharge rates and volumes through the use of extreme rainfall time series as input to relevant system models.

Runoff rate

Development runoff, if allowed to discharge unchecked, will flow into receiving waters at orders of magnitude faster than from the undeveloped site. This can cause flash flows in the river and increased frequencies of bankfull flows.

Such an impact is likely to cause scour and erosion that could seriously affect the morphology and ecology of the stream.

The rate of discharge of the urban runoff to the receiving water should be limited to the equivalent **Greenfield Runoff Rate** for the site via the provision of storage (**Attenuation Storage**) and flow constraints (**Downstream Flow Controls**). The flow control will constrain the rate of discharge, and the attenuation storage will fill when the rate of inflow from the upstream drainage system is greater than the allowable rate of discharge to the receiving watercourse. The attenuation storage will empty once the event has passed.

In the case of brownfield sites, drainage discharges should preferably still aim to achieve greenfield runoff characteristics, but minimum requirements are based on the existing drainage conditions and ensuring discharge rates are not increased.

In certain rare situations, where flood risk is particularly high, runoff off-site may be precluded altogether, in which case a design solution based on infiltration has to be developed.

Design criteria should be that, for the range of return periods up to and including the design event (1 in 100/200 year), the rate of runoff from the development into a watercourse should be similar to the undeveloped rate of runoff. The likely return periods to be specified are as follows:

The 1 in 1 year event (Q_{bar} or Mean Annual Flood) is the highest probability event to be specifically considered to ensure that flows to the watercourse are tightly controlled for frequent events. This criterion aims to ensure the morphological conditions in the stream remain the same.

The 1 in 30 year event is a useful intermediary event for which to assess on-site system performance, because of its relevance for adoptable pipework design (eg Sewers for Adoption requirements).

The 1 in 100 year event represents the boundary between high and medium risks of fluvial flooding defined by PPS25. This limit recognises that it is not practicable to fully limit flows for the most extreme events. 1 in 200 year may be specified in some circumstances, and universally in Scotland.

The actual rate of runoff for any given event will not replicate the greenfield runoff, due to the difference in drainage characteristics between the developed and undeveloped site but the frequency of the rates of runoff must be matched as closely as possible. Compliance with this objective is tested using the **Critical Duration Event** for each return period. An alternative (and preferred) method would be to examine the performance of the system under an extreme rainfall time series where both the pre- and post-development conditions can be modelled. The latter method is more cumbersome but provides a better demonstration of the level of compliance achieved and may be appropriate for larger sites in the future.

The methods available for calculating **Greenfield Runoff Rates** and **Attenuation Storage** volumes are presented in Chapter 4. Design of downstream flow controls are set out in Chapter 19.

Runoff volume

It is important to match the frequency of runoff volumes from a development with its greenfield equivalent for a number of reasons:

1. Increased runoff volumes from the development site (particularly for small, frequent events) means that less water is infiltrating into the ground and available to contribute to groundwater recharge and to sustain watercourse baseflows.
2. It is the small frequent runoff events from developed areas that contribute the largest total pollutant load to a receiving system. Therefore, minimising runoff volumes from these events will significantly reduce pollutant loads to the receiving watercourse.
3. Increased runoff volumes during extreme events means that the volumes of flood waters in the receiving watercourse are greater. This can contribute to increased flood levels, particularly where flows are constrained by, for example bridges or culverts, and where local increases in volumes of runoff are significant.

These issues are discussed in detail below.

Volume of stormwater runoff – small rainfall events

Around 50 per cent of rainfall events are sufficiently small that there is no measurable runoff taking place from greenfield areas. In contrast, runoff from impermeable areas takes place for virtually every rainfall event. The difference means that streams and rivers receiving runoff from impermeable sites become more “flashy” and groundwater recharge and river baseflows are reduced. In addition, development runoff flushes surface pollutants directly into the receiving waters with every rainfall event.

Therefore, wherever it is possible to provide replication of this natural behaviour (described as **Interception Storage**) by preventing any runoff from rainfall of up to 5 mm, then this should be provided (ie through the use of infiltration or other source control techniques).

Volume of stormwater runoff – large rainfall events

In extreme rainfall events, the total volume of runoff from a developed site is typically between 1 and 10 times the runoff volume from the same site in a greenfield state. It is important to control this additional volume from the developed site for three reasons:

1. A large proportion of runoff tends to be released much more quickly than the greenfield runoff, even where attenuation storage is provided to address the difference in the rate of runoff.
2. The extended duration of runoff discharge from the site can have impacts on flood flow rates downstream (see Figure 3.1).
3. Due to the finite storage volume provided by flood plains, by definition there must be greater depths of flooding if more water is discharged.

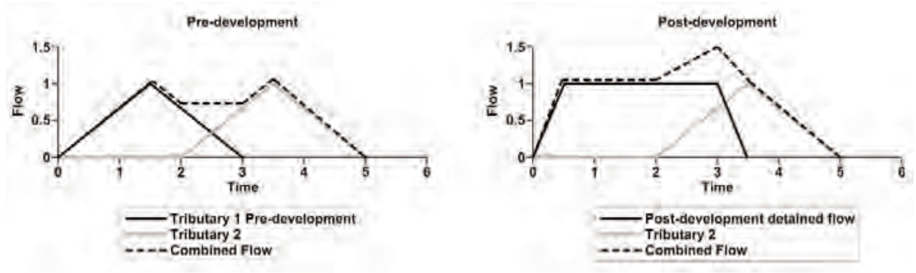

Figure 3.1 *Effects of increased volume and duration of runoff*

Control of the additional runoff volume is therefore required to minimise the risk of additional flood volumes being discharged from a development site during periods of high river flows. Options for volumetric runoff control are presented in Box 3.1.

Box 3.1 *Storage options for volumetric runoff control*

1. **Long-term storage**

Volumetric control can be achieved for the design event by spilling from the attenuation storage system to an area that will drain very slowly, preferably by infiltration. This is termed "Long-Term Storage". As extreme river flooding is by definition a rare event, it may be possible to accommodate long-term storage within a park or football field with appropriate land drainage provision to ensure infiltration is effective and prevents the flooding damaging the area. To achieve the necessary volumes of long-term stored runoff, the return period at which runoff will start to pass to such an area will need to take place for events significantly less than the 100 year event. If flooding of the area occurs too regularly, then the level of service for a public open space may be considered to be inadequate. This should be investigated using detailed hydraulic modelling.

2. **Infiltration**

An alternative approach may be to manage an equivalent volume through infiltration, which comes into effect for all storm events. This is a simple design approach and provides a high level of environmental benefits (eg groundwater recharge). In some locations it may be possible to create an allowable "infiltration zone" around the pond between the top of a pond liner and the invert level of the pond outfall.

3. **Extended attenuation storage**

It is possible that long-term storage or additional infiltration cannot be provided at certain sites. In these situations it is recommended that the maximum discharge rate for the attenuation storage is reduced to the region of QBAR or 2 l/s/ha whichever is the greater. Analysis has shown that this ensures that sufficient runoff is retained on site for extreme events to protect the receiving water course in times of flooding. This will probably result in a less cost-effective solution as a result of the large storage volumes required.

4. **Water harvesting**

Rainwater harvesting systems can be designed to maximise rainwater "capture" during extreme events. Where such devices are implemented widely and designed appropriately, there may be scope for a significant contribution to runoff reduction during design events.

The required long-term storage volume is usually quantified by calculating the difference between the runoff volume generated by the development site and that for the greenfield site, for the 6 hour, 100 year event. The volume derived will be largely influenced by the soil type of the site (which determines the greenfield runoff volume). Methods for calculating this volume are given in Chapter 4, Section 4.5.5. Long-term storage can contribute to a reduction in the attenuation storage volumes required. As in the case of the rate of runoff, a more appropriate method would be to use an extreme time series of events to compare likely frequency of pre- and post-development runoff volumes. The use of the 100 year, 6 hour event is a simple rule of thumb, which is particularly aimed at protecting the smaller watercourses.

It should be noted that extended attenuation storage results in critical duration events which are in the order of a day or more. This highlights the need to be aware of the risks associated with multiple events with the storage system remaining partially full when a second event takes place.

An important consideration is that SUDS systems can often provide significantly more storage than traditional drainage systems with greater potential for infiltration. For both these reasons, the use of SUDS makes it much easier to comply with the criteria on volume reduction of runoff.

3.2.4 Principles of good drainage practice: hydraulics

Good site design practices

All proposed development sites should implement good site design practices as far as practicable. The goal should be to reduce the amount of stormwater runoff generated on the site, provide for on-site control of runoff where appropriate, and optimise the location of stormwater management facilities. Natural drainage patterns should be followed and original ditches and streams retained and integrated within the design, wherever possible. Good site design practices can influence both water quantity and quality and can reduce the size and cost of structural SUDS controls. They are described in detail in Chapter 6.

Drain-down of storage systems

The time for the storage to empty (drain-down time) so that it can accept further storm flow should be considered, especially if downstream flood levels can affect the outfall. Generally, the temporary storage provided by the system should empty from full within 24 to 48 hours so that it can receive runoff from subsequent storms.

If the drain down time is more than 24 hours, then long duration events should be assessed to ensure that the storage is not overwhelmed by long periods of rainfall. If such events are found to be significant in terms of system performance, then consideration should be given to use of historic or appropriately generated time series rainfall rather than design event-based storms.

Hydraulic performance during periods of high groundwater levels

SUDS should be designed to ensure infiltration and storage systems operate during periods of extreme (up to 1 per cent annual probability) groundwater levels. Guidance on extreme groundwater levels beneath the site should be obtained from the environment regulator or local authority, or evaluated by a geotechnical specialist.

Hydraulic performance accounting for climate change

It is recommended that the factors given in Table 3.2 are applied when accounting for climate change in the design of drainage systems. As a precaution it is advised that the same uplift is not applied to the calculated flow rates for greenfield runoff. This provides an additional safety factor on the uncertainty related to climate change. However the uncertainty associated with change in rainfall characteristics is much greater than sea level rise. The use of 20 per cent or 30 per cent increase in rainfall intensity for design horizons after 2055 will result in storage volumes that are 50 per cent greater than present day rainfall. Fixing greenfield runoff criteria to present day conditions may therefore be considered as being rather too conservative an assumption in this situation. It is therefore suggested that as predictions for greenfield runoff have not been related to climate change that rainfall intensity increases are kept to 10% (for normal development design horizons) to allow the continued use of current greenfield runoff equations for assessment of storage, and that all aspects of conveyance and flood routing should use the factors given in Table 3.2.

The safety factors applied to sea level and river flows are only pertinent where they have an affect on the ability to discharge runoff from the development.

As with all issues on climate change, best practice will evolve rapidly as new knowledge and research takes place.

Table 3.2 *Climate change factors to be applied to drainage design*

Category	Proposed climate change factors			
	1990–2025	2025–2055	2055–2085	2085–2115
Sea level – SE England	4.0mm/yr	8.5mm/yr	12.0mm/yr	15.0mm/yr
Sea level – SW England	3.5 mm/yr	8.0mm/yr	11.5mm/yr	14.5mm/yr
Sea level – NE & NW England, Scotland and N.Ireland	2.5 mm/yr	7.0mm/yr	10.0mm/yr	13.0mm/yr
Rainfall	5%	10%	20%	30%
River flow	10%	20%	20%	20%

Annex B PPS25, DCLG, 2007

Size of pipes and hydraulic controls

The minimum pipe or throttle diameter acceptable for adoption by the sewerage undertaker is normally 150 mm, as required by Sewers for Adoption 6th edition (WRc, 2006) and Sewers for Scotland 2nd edition (in preparation). Diameters of control orifices down to 80 mm are allowed subject to appropriate design and agreement with the sewerage undertaker. Pipe diameters as small as 50 mm may be acceptable for privately owned SUDS or for locations downstream of pervious pavements or other filtration devices where the risk of blockage is very small. The size of hydraulic controls should always be agreed with the site operator.

For a small site, a 150 mm pipe is unlikely to provide sufficient flow control to meet design criteria. For such situations, restricted flow devices such as hydrobrakes, perforated pipes or orifice plates can be used with careful design to minimise the risk of blockage. Details on inlet and outlet structures are provided in Chapter 19.

Downstream analysis

Where a significant change in the level of urbanisation of the receiving water catchment is being considered (eg greater than 10 per cent), a catchment-wide flood risk assessment may be required and may influence the design criteria for discharges from the site.

Erosion control

As some SUDS components are vegetated, velocity control, energy dissipation, streambank stabilisation, and erosion prevention practices and structures should be considered. These are described in detail in Chapter 19.

Floodplain protection and stream buffers

The establishment or preservation of riverside buffers and natural floodplains will:

- minimise the risk of increasing flood levels as a result of encroaching on floodplain
- provide opportunities for using the buffer/floodplain area to contribute additional water quality treatment during summer, low flow periods
- provide ecological benefits through the provision of continuous wildlife corridors.

Groundwater recharge

Recharge to groundwater should be implemented to the extent practicable (within the constraints of the Building Regulations) through the use of site design techniques that allow for recharge of stormwater runoff into the soil. The annual recharge from the development site should ideally be the same or more than the annual recharge from the pre-development state.

Implementing whole life sustainable solutions

SUDS, as with any engineering design, should be designed to provide an effective "whole life", sustainable solution to drainage. In particular designs should:

- ensure that the systems operate efficiently for long periods (20–50 years) before replacement or rehabilitation is needed
- ensure that the systems operate efficiently for long periods (1–5 years) before significant maintenance activities are required
- ensure that the regular operating and maintenance needs of the systems are easy to understand and implement by relatively unskilled labour
- aim to utilise natural resources that can be reused and are energy efficient in terms of constituent products, construction processes, and operation and maintenance activities.

Finance should be available to carry out the required maintenance throughout the life of the system.

3.3 WATER QUALITY CRITERIA

3.3.1 General principles

The key principle that should be followed to protect the receiving watercourse from the threat of increased pollution as a result of the proposed development is:

> An appropriate management "train" of SUDS components should be implemented to effectively mitigate the pollution risks associated with different site users/activities.

3.3.2 Protection of receiving watercourse

The level of pollution associated with any runoff event depends on a number of factors including:

- the type of site – industrial areas will generally have higher levels of pollution
- the length of time since the last rainfall event – runoff that occurs after long dry periods will tend to be more polluted
- the duration and intensity of the rainfall itself.

If the pollution concentration during a storm were constant, then the shape of the pollution loading with time would exactly match that of the hydrograph. However, the pollution frequently exhibits considerably higher concentrations near the beginning of the storm. This is known as the "first flush" phenomenon and is due to higher initial rainfall intensities, greater erosion potential and to greater availability of solids and pollutants that have built up on urban surfaces during the preceding dry weather period.

Studies have shown that small, frequently-occurring storms produce the majority of surface runoff from developed sites, and the quality of stormwater runoff for small events is therefore often a particular problem. This is compounded by many of these small events tending to occur during the summer when the receiving water flows are low, providing a minimum level of dilution. For large events or during periods of high river flow, the water quality impact is much reduced.

To remove the major proportion of the pollution, it is therefore necessary to:

1. Capture and treat the runoff from frequent, small events.
2. Capture and treat a proportion of the initial runoff (first flush) from larger and rarer events.

This will ensure that any runoff discharged to the receiving water is of improved quality compared to a direct discharge from a traditional drainage system. There are different methods of achieving these requirements, as set out in Box 3.2.

Box 3.2 *Water quality treatment options*

1. Treatment of stormwater using Infiltration (Interception storage)

Good site design does not allow runoff from impermeable surfaces to pass to the river for the range of smaller, polluting events (at least 5 mm, preferably 10 mm). This is likely to be through the use of infiltration techniques that treat smaller events via filtration through the soil and discharge them to groundwater. Rainwater harvesting can also be used.

2. Treatment of stormwater using filtration

Improvements to stormwater quality can be achieved by filtering the runoff (particularly for small, frequent events) using a variety of filtration media eg sands (eg sand filters), gravels (eg permeable pavements, filter trenches), soils (eg bioretention), grasses and other surface vegetation (eg swales, detention basins) or aquatic vegetation (eg wetlands). The travel time or flow velocity through the system is specified to maximise treatment benefits.

3. Treatment of stormwater using detention

Storing runoff volumes within basins, using outflow controls, contributes primarily to meeting hydraulic criteria, but such systems also allow sedimentation to take place which contributes to water quality improvement.

4. Treatment of stormwater using permanent pond volumes

Ponds can provide significant water quality improvements by capturing small events which allow the settling out of fine silts and promote plant and microbial activity to encourage adsorption and biodegradation of contaminants and nutrient removal. The permanent pond volume is effectively the volume of water that remains in ponds during the dry weather periods between rainfall events. It is often known as the **Water Quality Treatment Volume (or Vt)** and should be sized to accommodate at least 10 mm of runoff from the impermeable surfaces (see Section 4.5.6 for calculation details), although this can be reduced where upstream treatment components are part of the SUDS management train.

Infiltration (interception) storage should be provided wherever practicable. In practice, there may be constraints to providing such solutions for certain soil types, however attempts should be made to implement this as far as possible – interception and/or infiltration of smaller rainfall depths will still provide considerable benefits. The provision of interception storage will contribute to the provision of both long-term and attenuation storage by the amount provided.

3.3.3 Using the SUDS management train to manage pollution risks

The approach to implementing an appropriate SUDS management train is described in Section 1.3.2. If this philosophy is implemented correctly, then stormwater should be managed at source wherever possible and only high flows should be passed downstream. Within a large development, the conveyance and management of water will tend to require a larger number of SUDS components in series.

By including a number of components, the following benefits can be realised:

1. A multi-component treatment train utilises a range of treatment processes which will maximise the treatment efficiency of a wide range of pollutants.
2. Serious pollution events can be contained within upper SUDS components so minimising the damage to the drainage system, and helping ensure that high concentrations of contaminants are not conveyed to the receiving watercourse.
3. Treatment can be combined with both conveyance and storage components.
4. Coarse sediments can be removed by systems that reduce flow velocities and offer periods of detention. Removal of fine sediments can be targeted using permanent water bodies where runoff is contained for longer periods.
5. Protection is provided to the final stage in the train so as to maximise potential wildlife and amenity benefits.

Although hydraulic efficiencies are relatively easy to determine and design for, it is difficult to put figures on water quality performance of specific techniques, as this will tend to vary with climatic conditions and inflow concentrations. Where risks posed to the environment are likely to be high, then a larger number of components should be included within the management train. Where risks are low then, provided hydraulic criteria are met, a reduced number of components may be adequate. Table 3.3 gives an indication of the minimum number of components likely to be appropriate for different contributing and receiving catchment characteristics. However, for larger sites, an <u>increased number of components will generally be required</u> to meet all design criteria. It is recommended that areas much greater than 2 ha do not drain to a single component, but that the catchment is split into subcatchments and several smaller features are included that drain to a final site control.

Table 3.3 *Number of treatment train components (assuming effective pre-treatment is in place)*

Receiving water sensitivity → / Runoff catchment characteristic ↓	Low	Medium	High
Roofs only	1	1	1
Residential roads, parking areas, commercial zones	2	2	2
Refuse collection/ industrial areas/ loading bays/lorry parks/highways	3	3	3

Examples of appropriate treatment train combinations and SUDS selection protocols are given in Chapter 5.

3.3.4 Principles of good drainage practice: water quality

Good site design practices

All proposed development sites should implement good site design practices as far as practicable. The goal should be to reduce the amount of pollutants generated on the site, provide for natural on-site treatment of runoff, and optimise the location of stormwater management facilities. Site design can influence both water quantity and quality and can reduce the size and cost of structural SUDS controls. The opportunities are described in detail in Chapter 6.

Construction erosion and sedimentation control

Site design practices and techniques that reduce the total area that needs to be cleared and graded should be implemented wherever possible. To prevent damage to the SUDS and receiving watercourse, erosion and sediment control for both the construction and operation phases should be considered within the design.

Operation and maintenance

SUDS designs should consider the system operation and maintenance requirements. Maintenance should be easy to understand and implement, and safety measures to protect maintenance staff should be included.

3.4 AMENITY CRITERIA

3.4.1 General principles

The design of SUDS requires specific attention given to their visual impact and their interaction with the local environment and residents.

Criteria should be derived from consideration of three key principles:

1. Health & safety.
2. Visual impact.
3. Amenity benefit.

3.4.2 Health and safety

There is a perception by some that SUDS features, especially ponds and wetlands, are unsafe. Specifically, there is a fear of drowning occurring. Another perceived risk is the overturning of vehicles into swales. **With careful thought these risks can be designed out.** If ponds are properly designed, with shallow side slopes, shallow shelving edges and strategically placed vegetation, they will be as safe as the many watercourses, ponds and lakes that are unfenced in parks, country parks and similar locations throughout the country. Swales alongside roads that are designed with side slopes less than 1 in 3, and are generally shallow, will pose much less of a hazard than the ditches that line many kilometres of roads in the UK.

A further perceived risk is that SUDS features will become breeding grounds for mosquitoes which can then transmit diseases such as the West Nile virus or malaria. However, the risk of malaria becoming re-established as a disease in Britain is extremely unlikely, even allowing for the effects of climate change (Lindsay and Hutchinson, 2002). Many wildlife trusts do not consider mosquito breeding as a significant problem in wetland design. The choice of SUDS technique and design can be optimised to deter breeding of mosquitoes. Most SUDS techniques that have temporary ponding of water will be designed to drain in a short period and so should not provide mosquito habitat. Mosquitoes generally require shallow stagnant water that is in an aerobic condition to breed (such as stagnant water in buckets). In a well-designed and well-constructed pond or wetland the water should be moving with a residence time of only a few days, thereby reducing the risk. If there is any concern over mosquitoes at a site then the advice of a biologist should be sought so that design features, such as size and hydraulics of ponds, together with the choice of vegetation, can be incorporated in the SUDS to deter mosquito breeding.

Emergent vegetation that has minimal submerged growth reduces the available locations for larvae to develop.

Safe design practice for each SUDS component is presented in individual chapters of this guidance. Further information can be obtained from the Royal Society for the Prevention of Accidents (RoSPA) and in UKWIR report *SUDS: increased liability for the water industry, Phase 2* (Kellagher *et al*, 2006).

Risk assessment and management

The Construction, Design and Management (CDM) Regulations (DETR, 1994) must be applied to the planning, design, construction and long-term maintenance of SUDS systems (see Section 2.5.10). Risk assessments should be undertaken for all SUDS sites, taking into consideration public and operator access and safety, to determine an appropriate level of control. This may be incorporated into the risk assessments carried out to meet the requirements of the CDM Regulations. An example of a site-specific risk assessment for a SUDS detention basin is provided in Table 3.4.

Table 3.4 *Example of a risk assessment for a SUDS detention basin*

Hazard	Who is at risk?	Avoid	Reduce	Mitigate	Residual risk
Sudden inflow of water	Public and maintenance staff.	Design to avoid sudden inflows so that warning of flooding is given.	Shallow banks so easy to get out.	Reed beds or brushes to act as barrier.	Very low
Drowning	Public and maintenance staff.		Shallow banks so easy to get out, shallow depth to discourage swimming.	Reed beds or brushes to act as barrier, shallow slopes, warning signs, life jackets for maintenance staff.	Very low
Falling from inlet/outlet structure	Public.	Design inlets/outlets with minimum use of vertical walls.	Provide barrier.	Education boards. Warning signs.	Very low
Entering inlet or outlet pipes	Public/pets/ wildlife.	Use small pipes so entry not possible.	Provide grilles.	Education boards. Warning signs.	Very low
Contact with contaminated sediment	Maintenance workers.	Design vehicular access to sediment forebays so that excavation is possible using machines.		Personal protective equipment for workers during de-silting.	Very low

There are no specific residual risks for construction workers as the pond is a shallow earthworks operation.The total elimination of risk at open water sites is not usually possible and, therefore, an appropriate risk control philosophy should be employed and the following risk reduction approaches implemented:

1. All drainage systems should be designed for safe access for maintenance.
2. Designs should minimise the risk of falls. Where a person could fall more than 2 m, the provision of a fence should be considered.
3. Access around the pond (safety bench) which is suitable for maintenance vehicles and pedestrians should be provided (subject to local requirements) with cross-falls of 1:15 and width of 3.5 m.
4. The aquatic bench should be at least 1 m wide, with the design taking into account the results of a risk assessment for the site. Gradients in the pond beyond the aquatic bench, if designed to be steeper than 1:3, should have a mimimum transitional width of 1 m at a maximum gradient of 1:3.
5. Gradients between the safety bench and the lower "aquatic bench" (see Section 3.5) should be less than 1 in 3 (and preferably a minimum of 1:4) to reduce risks of the public slipping into the water and ensuring easy access from it..
6. Where risks are considered to be significant, education boards should be used to inform the public and encourage them to take personal responsibility, and life saving equipment should be provided where this is thought necessary.
7. Where ponds are located within eight miles of an airport, guidance provided by the Civil Aviation Authority (CAA) should be applied in designing ponds which minimise the risk of inappropriate types of birds (swans etc) colonising the area. This reduces the risks of aircraft bird strikes causing accidents (see Section 20.3.5 for more detail).

3.4.3 Visual impact and amenity benefit

SUDS are likely to form part of widely-used public open spaces. High quality visual impact is essential to ensuring public acceptability and maximising amenity benefits. Public acceptability should be addressed through consideration of the following issues:

1. Maximising aesthetic appeal of the system through the use of vegetation and landscaping techniques.
2. Linking open water areas to recreation sites.
3. Setting an appropriate maintenance programme that ensures areas are visually attractive throughout the year.
4. Informing and educating the public (particularly local homeowners) of the role played by the SUDS systems in draining the site and protecting the environment.

Details on planting and landscaping is provided in Chapter 20. Public education and awareness is dealt with in Chapter 24.

3.5 ECOLOGY CRITERIA

Maximising the ecological value of SUDS can provide an important contribution to biodiversity enhancement at a development site and can facilitate the movement of wildlife through the creation of green corridors within urban areas. Good ecology is also generally linked to a high quality environment that has wide public appeal. Ecological diversity should be maximised through consideration of the following issues:

1. The use of native planting.
3. Locating SUDS in or near non-intensively managed landscapes (where possible) eg close to natural pond and wetland habitats.
4. Retaining and enhancing natural drainage systems.
5. Creating a range of habitat types.
6. Including a shallow, aquatic bench in pond designs (ie a maximum depth of 0.45 m depth below the permanent water level, with a minimum width of 1 m).
7. Implementing an appropriate maintenance and management plan.

Additional detail on designing for biodiversity is provided in Chapter 20.

3.6 SUSTAINABILITY PRINCIPLES

SUDS should be considered within a holistic science-based framework of sustainability (Everard and Street, 2001). This means that all environmental costs, together with economic and social factors, should be assessed in the decision-making process, especially when comparing SUDS to conventional drainage.

A detailed sustainability analysis based on the preceding framework is provided in *Sustainable Drainage Systems: an evaluation using the natural step framework* (Everard and Street, 2001). This identifies factors that need to be considered, such as the energy required to construct trenches for conventional drainage, loss of habitat through development and impacts of flooding on property values. Other system factors to consider include the energy used and other environmental costs in the extraction and processing of plastics compared to the use of quarried aggregate. In this respect the use of recycled plastics or aggregate may be more acceptable than virgin materials.

A SUDS scheme should aim to protect the environment but, at the same time minimise the use of finite natural resources and energy and provide reasonable value to those involved in its design, construction and operation.

Further information on undertaking sustainability analyses that can be applied to the design and construction of SUDS schemes is provided in CIRIA publication C563 *Sustainable construction: company indicators* (Atkins, 2001).

Some key factors that may be considered are the way that material use can be minimised in SUDS:

- reuse and recycling of on-site earthworks and demolition materials in SUDS
- reduction of waste by monitoring the volume of materials ordered and used
- use of aggregates or plastics produced from recycled or waste materials
- on site treatment and composting of silt and other waste from SUDS to reduce the volumes of material removed from site.

The impact of aggregate and landfill taxes and transport costs may mean that considering these more sustainable options also produces cost savings.

3.7 SUMMARY OF DRAINAGE CRITERIA

Adoption of these various criteria is likely to lead to the use of more than one drainage technique on large sites to achieve the required hydraulic, water quality and amenity performance. Source control will be particularly effective in achieving many of these requirements. However, care should be taken to ensure that the storage and treatment volumes are properly assessed and are provided in the correct location to efficiently manage the runoff.

Table 3.5 *Summary of SUDS design criteria*

Criteria	Design event	Design objective
Hydraulic		
Protection against flooding:		
Protection against flooding from watercourse.	Catchment, 100/200 year event.	Control risks to people and property. Floor levels = Max river level + appropriate freeboard
Protection against flooding from drainage system.	Site, 10/30 year event.	No flooding on site, except where planned and approved.
	Site, 100/200 year event.	Control risks to people and property. Floor levels = Max flood storage levels + freeboard.
Protection against flooding from overland flows.	Site, 100/200 year event, short duration events.	Planned flood routing and temporary storage accommodated on site.
Protection against flooding from adjacent land.	Adjacent catchment, 100/200 year event.	Planned flood routing.
Protection of watercourse:		
Rate of discharge.	Catchment, 1 year event.	***Attenuation storage*** to control 1 year site discharge rate to ≤ 1 in 1 year greenfield peak rate (or 2 l/s/ha).
	Catchment, 100/200 year event.	100/200 year site discharge rate to ≤ 1 in 100/200 year greenfield peak rate.
	All events.	Where possible, ***interception storage*** to prevent runoff from first 5 mm of rainfall.
Volume of discharge.	Catchment, 100 year event.	Where possible, ***long-term storage***/ infiltration to control 1 in 100 year discharge volume to ≤ 1 in 100 year greenfield volume. Usually applied to 6 hr event.
Water quality		
Protection of watercourse:	Site, < 1 year.	Where possible, ***interception storage*** to prevent runoff from first 5 –10 mm of rainfall. Treatment via SUDS components in series as a treatment train, the number of components depending on the pollution levels and environmental sensitivity.
Amenity		
Managing public safety:	N/A	Safe maintenance access (safety bench). Fencing or vegetative barriers to constrain public access where appropriate. Aquatic bench and shallow edges to water bodies. Sign-boarding, where appropriate.
Maximising visual impact and amenity benefit:	N/A	Maximising aesthetic appeal. Linking systems to recreation opportunities. Appropriate maintenance. Public education programmes.
Ecology		
Maximising ecological value:	N/A	Native planting and varied habitat types. Close to diverse, natural ecosystems. Aquatic bench. Appropriate maintenance.

Notes

1. The provision of ***interception storage*** will contribute to the provision of ***long-term storage*** by the amount provided.
2. Both ***long-term storage*** and ***interception storage*** will reduce the ***attenuation storage*** volume (unless the analysis explicitly excludes areas that are expected to contribute to these volumes separately).
3. ***Water quality treatment volume*** is not storage for attenuation of rainfall runoff. It is used to define the permanent wet pond volume/volume of runoff to be treated.

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Hydraulic design methods 4

Contents

Hydraulic design methods

4

This chapter presents the tools and techniques required to size storage, infiltration and conveyance systems to meet the drainage criteria.

4.1 INTRODUCTION

4.1.1 Describing storm events

The following technical terms (associated with the frequency at which rainfall/flow events occur) are used in describing rainfall and flow rates.

Event probability is the probability of a particular threshold being equalled or exceeded in any particular event.

eg if a flow time series contains 146 individual flow events, with three peak flows that measure above 4 m^3/s, then the probability of a 4 m^3/s flow being equalled or exceeded is 3/146 = 0.02

Annual probability of exceedance is the statistical probability of a hydrological event (rainfall or flow) of a given magnitude being equalled or exceeded in any given year.

Annual probability of exceedance = $1 - (1 - P)^{\text{No. of events in one year}}$

Where P = Event probability

eg if the number of flow events in any given year is 16, then the annual probability of exceedance is $1-(1-0.02)^{16} = 0.28$

Annual exceedance frequency. This refers to the number of times per year, or frequency, that a particular level may be expected to occur.

Return period is the average time interval between occurrences of a hydrological event (rainfall or flow) of a given or greater magnitude, usually expressed in years. Traditionally, expected frequency of occurrence has been described using return period. It is the reciprocal of the annual exceedance frequency. It is not a reciprocal of the annual probability of exceedance – although this is a reasonable approximation at higher return periods (>100 years). A 1 in 50 year event occurs, on average, once every 50 years and will have an annual exceedance frequency of 0.02.

Design life probability of exceedance is the probability of a particular event being equalled or exceeded during a stated design life. This is the same calculation as for the annual probability of exceedance, with the number of events reflecting the number to be encountered during the stated design life.

The probability of an event occurring or being exceeded during the system design life can be determined using the equation given in Box 4.1.

Box 4.1 *Probability of an event occurring during system design life*

$$Pr = 1 - [1 - (1/T)]^L$$

where:

Pr = Probability of event occurring or being exceeded within design life

T = Return period (ie the rainfall event is exceeded, on average, once every T years)

L = design life (years)

Using the equation in Box 4.1, the annual probability of occurrence has been calculated for a range of return periods. Table 4.1 also includes the probability of a particular design storm event occurring during a 25, 50 or 100 year design life.

Table 4.1 *Probability associated with extreme events*

Return period (years)	Probability of occurrence during design life of...		
	25 years	50 years	100 years
1	>99%	>99%	>99%
2	>99%	>99%	>99%
5	>99%	>99%	>99%
10	93%	99%	>99%
30	57%	82%	97%
50	40%	64%	87%
100	22%	39%	63%
200	12%	22%	39%

Critical duration is the length of rainfall event that results in the greatest flow rate, flood volume or flood level (depending on the purpose of the analysis) at a particular location. It is common for the critical duration to be different for different annual probabilities (or return periods), different hydrological regions, for developed and undeveloped sites, and for different types of SUDS units.

4.1.2 Design practice

The objectives of the site stormwater design and design criteria for SUDS systems are discussed in detail in Chapter 3. The criteria relevant to hydraulic design of storage are based on a comparison of the site runoff characteristics to the pre-development state. It is therefore necessary to be able to quantify the rate and volume of runoff for both the greenfield situation and the development runoff. Methods of quantifying these are all detailed in the following sections.

The regulatory authorities will normally require the developed rate of runoff to be no greater than the greenfield runoff rate for a range of annual flow rate probabilities, up to and including the 1 per cent annual probability (1 in 100 year return period). Volumes of runoff should also be reduced where possible. These criteria can be relaxed by regulators where appropriate, or where it is impractical to meet these requirements.

Figure 4.1 shows the approach required for an initial assessment of drainage design requirements and developing a conceptual drainage solution for the site. Such an approach will always be required initially and may be sufficient for very simple sites and drainage solutions. However, for the majority of sites, a detailed drainage model will be required to demonstrate compliance with agreed criteria. A detailed design approach is presented in Section 4.7.

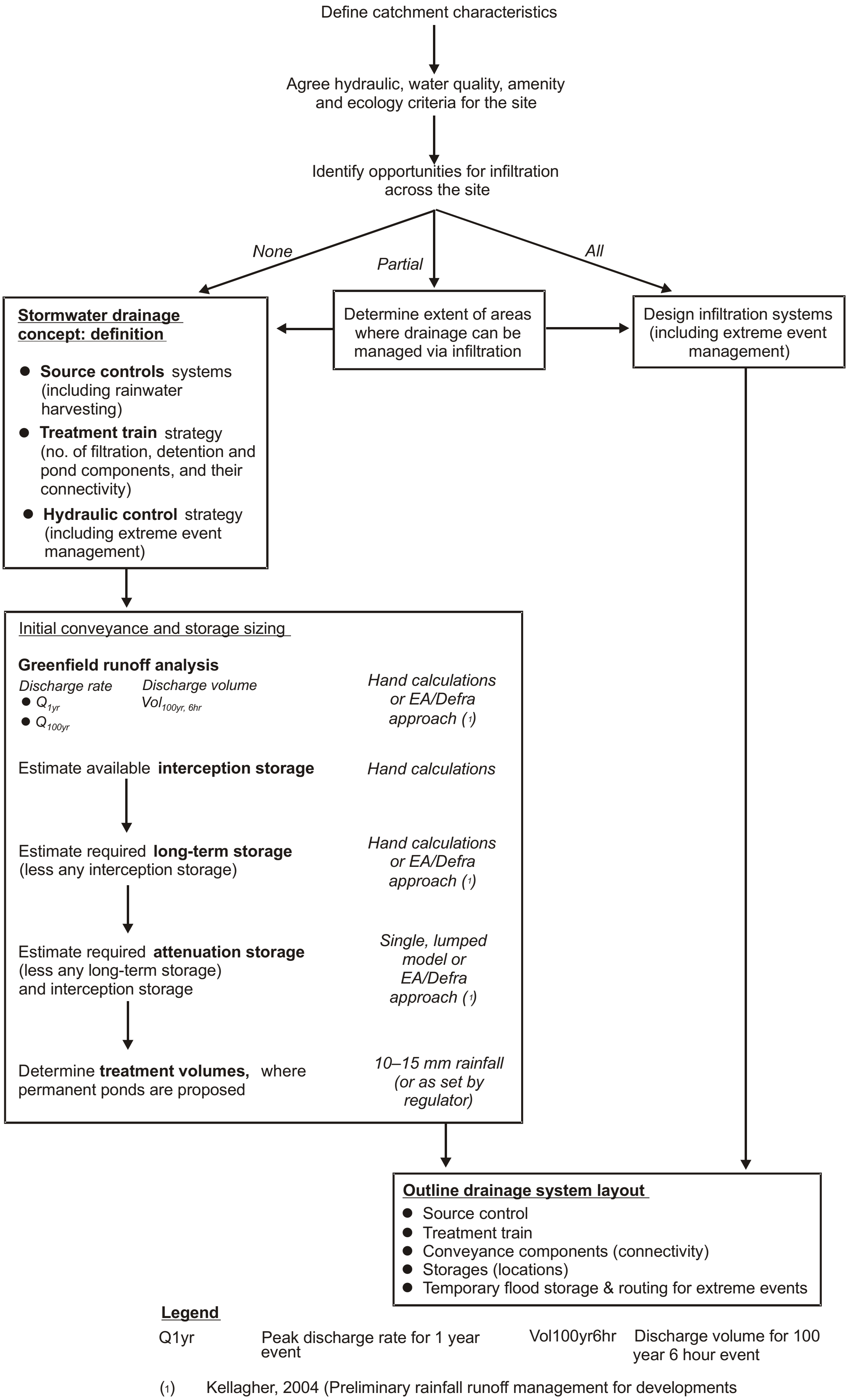

Figure 4.1 *Initial stormwater drainage design assessment*

4.2 GREENFIELD RUNOFF

4.2.1 Estimating greenfield runoff rates

Greenfield runoff rates are calculated to determine the level of acceptable rate of discharge from the site to the receiving watercourse and are likely to be used by the environmental regulator to set site-specific drainage constraints. The calculation of peak rates of runoff from greenfield areas is related to catchment size. The values derived should be regarded as indicative because prediction of runoff from any catchment will always be imprecise and estimation of runoff from part of a catchment (as most development sites are) will be even less accurate. Table 4.2 summarises the approaches that may be used to calculate greenfield runoff rate. However the method used at a particular site should always be agreed with the environmental regulator.

Table 4.2 *Greenfield runoff rate estimation methods (National SUDS Working Group, 2004)*

Development size	Method
0 – 50 ha	The Institute of Hydrology Report 124 *Flood estimation for small catchments* (Marshall & Bayliss, 1994) is to be used to determine peak greenfield runoff rates for QBAR. Where developments are smaller than 50 ha, the analysis for determining greenfield discharge rate should use 50 ha in the formula but linearly interpolate the flow rate value based on the ratio of the size of the development to 50 ha. FSSR 14 (IH, 1993) regional growth curve factors should be used to calculate greenfield peak flow rates for 1-, 30- and 100-year return periods.
50-200 ha	IH Report 124 should be used to calculate greenfield peak flow rates. Regional growth factors to be applied.
Above 200 ha	IH Report 124 can be used for catchments that are much larger than 200 ha. However, for schemes of this size it is recommended that the Flood Estimation Handbook (FEH) (IH, 1999) should be applied. Both the statistical approach and the unit hydrograph approach should be used to calculate peak flow rates. However, where FEH is not considered appropriate for the calculation of greenfield runoff for the development site, for whatever reasons, IH 124 should be used.

This is the national position taken by the Environment Agency at the time of publication. The overall objective of using an agreed method is to provide a consistent and reasonable estimate upon which storage design can be carried out, rather than finding the exact runoff rate for any specific site.

Flood estimation for small catchments

The methodology described in the Institute of Hydrology Report No. 124 was developed to apply to small catchments of less than 25 km^2. The research was based on 71 small rural catchments.

A regression equation was produced to calculate the mean annual flood flow rate for greenfield catchments, $QBAR_{rural}$ as shown in Box 4.2.

Box 4.2 *IH124 mean annual flood flow rate equation*

$$QBAR_{rural} = 0.00108AREA^{0.89}.SAAR^{1.17}.SOIL^{2.17}$$

Where:

$QBAR_{rural}$	=	Catchment mean annual peak flow (approximately 43% annual probability or 2.3 year return period) (m^3/s)
AREA	=	Catchment area (km^2)
SAAR	=	Standard average annual rainfall for the period 1941 to 1970 (mm)
SOIL	=	Soil index (from Flood Studies or Wallingford Procedure WRAP maps). It is a weighted sum of individual soil class fractions, where:

$$SOIL = 0.1\ SOIL_1 + 0.3\ SOIL_2 + 0.37\ SOIL_3 + 0.47\ SOIL_4 + 0.53\ SOIL_5$$

Values of SAAR and SOIL for a specific catchment can be obtained from the *Flood Studies Report* (IH, 1975), *The Wallingford Procedure* (HR and IH, 1981), or the *Wallingford Procedure for Europe* (Kellagher, 2000).

Greenfield peak flow rates for other probabilities can be estimated using the Q/QBAR factor from the appropriate growth curve contained in the Flood Studies Supplementary Report, FSSR 16 (IH, 1985). The hydrological areas and corresponding growth curves are given as Figures 4.2 and 4.3, and Table 4.3 below.

Figure 4.2 *Hydrological areas*

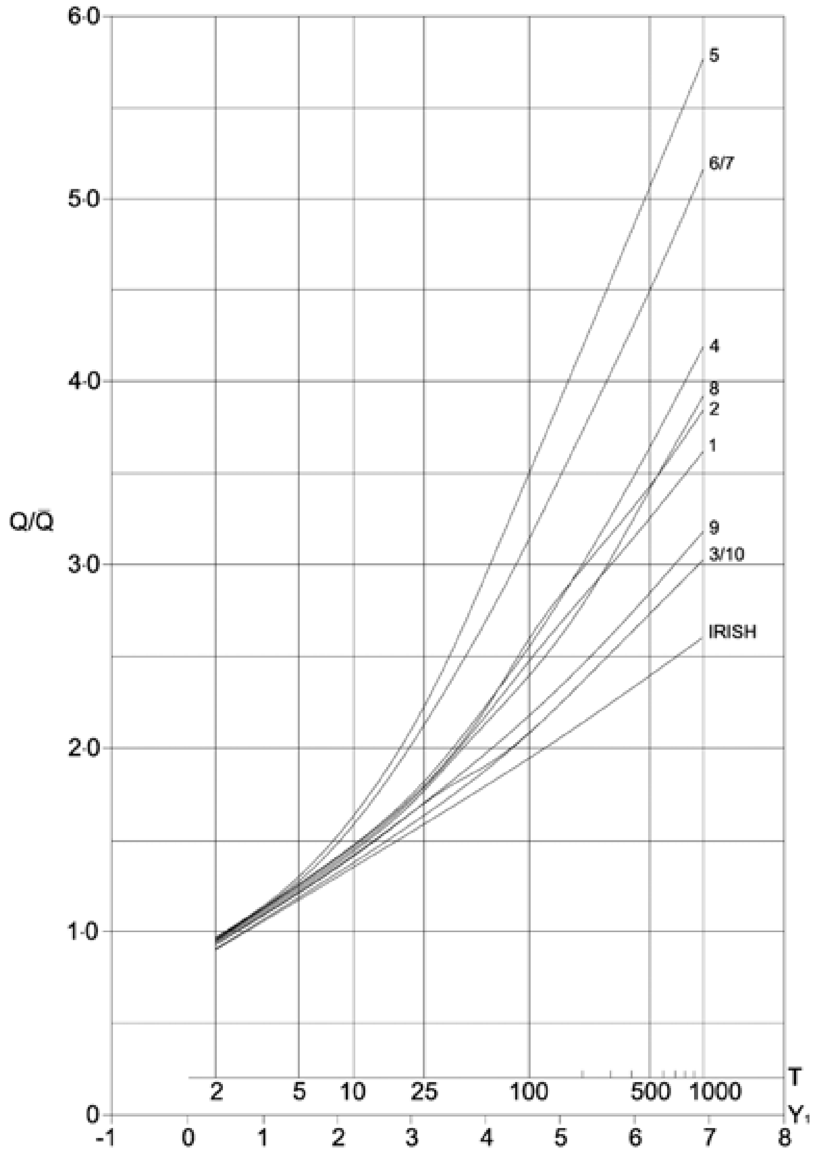

Figure 4.3 *UK growth curves*

Table 4.3 *UK growth curve factors*

Region	Hydrometric Area	Return period						
		2	5	10	25	50	100	500
NW	1	0.90	1.20	1.45	1.81	2.12	2.48	3.25
	2	0.91	1.11	1.42	1.81	2.17	2.63	3.45
	3	0.94	1.25	1.45	1.70	1.90	2.08	2.73
	9	0.93	1.21	1.42	1.71	1.94	2.18	2.86
	10	0.93	1.19	1.38	1.64	1.85	2.08	2.73
SE	4	0.89	1.23	1.49	1.87	2.20	2.57	3.62
	5	0.89	1.29	1.65	2.25	2.83	3.56	5.02
	6/7	0.88	1.28	1.62	2.14	2.62	3.19	4.49
	8	0.88	1.23	1.49	1.84	2.12	2.42	3.41
Ireland		0.95	1.20	1.37	1.60	1.77	1.96	2.40

Flood estimation handbook method (FEH)

The Centre for Ecology and Hydrology (CEH, formerly the Institute of Hydrology, IH) produced this handbook in 1999. The methods of flood estimation detailed in it are generally considered to supersede the *Flood studies report* (FSR) and the *Flood studies supplementary reports* (FSSR), as standard practice for rainfall and runoff analysis in the UK.

Two main approaches for flood frequency estimation are provided:

- statistical methods
- FSR rainfall-runoff methods.

The general philosophy of the *Flood estimation handbook* (FEH) is that extreme flood flows are best estimated from gauged data and that estimation from catchment characteristics alone should be used as a last resort. The statistical approach is the preferred option for peak flow estimation. The method uses software tools to aid calculations. It does however state in the FEH that "in sizing minor infrastructure works, such as culverts under forest roads, calculations based on FEH should not necessarily take precedence over those based on simpler formulae".

The FEH is not generally considered appropriate for the calculation of greenfield runoff for sites less than 200 ha as very small catchments are poorly represented in the data sets used to calibrate the models and the digital terrain and thematic data are not well resolved on very small catchments. For many developments, the simpler method of IH124 is likely to be preferred.

4.2.2 Estimating greenfield runoff volumes

Greenfield runoff volumes are calculated to determine the maximum volume that should ideally be discharged from the development site and that may be used by the environmental regulator to set site-specific drainage constraints.

The options for controlling volumes are presented in Chapter 3, Box 3.1. To calculate the greenfield runoff volume, it is recommended that one of the following methods is used:

1. FSSR 16 (IH, 1993) runoff model: fixed percentage runoff.
2. FSSR 16 runoff model: variable percentage runoff.

The value of PR (percentage runoff) is then used to determine the runoff volume by multiplying it by the catchment area and rainfall depth.

Runoff Volume = Percentage Runoff (PR) x Catchment Area x Rainfall Depth

The fixed PR method is more easily estimated, but is only applicable for large rainfall depths. The variable PR method is applicable for all rainfall, and should be used for smaller events, as the effect of soil moisture deficit is relatively more important. It is suggested that the fixed percentage method is not used for events which are more frequent than a 1 year event or less than 40 mm.

It should be noted that a simplified approach to the calculation of long-term storage volume is provided in the EA/Defra R&D technical report *Preliminary rainfall runoff management for developments*, W5-074 (Kellagher, 2004).

FSSR 16 runoff model – fixed percentage runoff

The FSSR 16 model is a simple tool, derived from the Flood Studies Report (IH, 1975), which correlates runoff volume (as percentage runoff) with soil type, storm depth and other easily derived parameters. It is aimed at predicting runoff volumes for extreme events. The FSSR 16 fixed percentage runoff formula is given in Box 4.3.

Box 4.3 *FSSR 16 fixed percentage runoff model*

$$PR_{RURAL} = SPR + DPR_{CWI} + DPR_{RAIN}$$

Where:

PR = total percentage runoff for the greenfield catchment for a particular event

SPR = standard percentage runoff, which is the fixed component of the percentage runoff and is a function of the five soil class fractions defined by the FSR WRAP map:

SPR = $10S_1 + 30S_2 + 37S_3 + 47S_4 + 53S_5$

or, more recently, of the percentage runoff characteristics of the soil class fractions defined by the FEH HOST mapping, ie

SPR = $SPR_1HOST_1 + SPR_2HOST_2 + \ldots\ldots\_ + SPR_{29}HOST_{29}$

DPRCWI = the dynamic component of the percentage runoff. This parameter reflects the increase in percentage runoff with increasing catchment wetness. The catchment wetness index (CWI) is a function of the average annual rainfall, shown in Figure 4.4 below:

DPRCWI = 0.25 (CWI – 125)

The DPR_{RAIN} is the second dynamic component that increases the percentage runoff from large rainfall events.

DPRRAIN = $0.45(P - 40)^{0.7}$ for P > 40 mm (where P is rainfall depth)

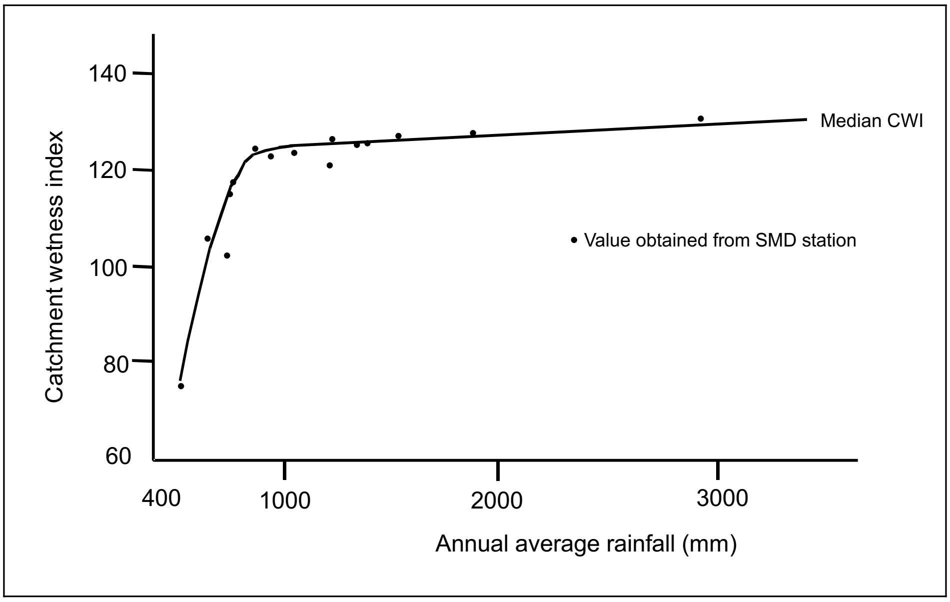

Figure 4.4 *Catchment Wetness Index (CWI) vs Standard Average Annual Rainfall (SAAR) (IH, 1975)*

It can be seen from the formula that the runoff proportion is slightly greater than the value of SPR for all areas where the SAAR value is greater than 800 mm, however SPR is by far the most dominant factor.

The key feature of this formula is the important influence of soil type. In practice it indicates that developments on sandy soils create significant additional runoff compared to the pre-development condition, but development on clays do not.

The use of infiltration should minimise the need for the greater storage requirements for sandy soil sites.

To calculate runoff percentage from a greenfield site, two options are available. Either the full formula is applied, or a simple assumption is made that the runoff from a greenfield site is equal to the SPR (***Standard Percentage Runoff***) value for the soil type. The assumption that SPR is the runoff proportion is a reasonable approximation for extreme events even though the actual runoff is clearly also related to catchment wetness.

FSSR 16 runoff model – variable percentage runoff

This alternative FSSR 16 model allows the percentage runoff to be related to increasing catchment wetness, depending on preceding rainfall.

Instead of CWI being related to SAAR, it becomes a function of the antecedent rainfall and soil moisture deficit, and is given by the equation in Box 4.4.

Box 4.4 *FSSR 16 variable percentage runoff model*

CWI = 125 + API5 – SMD
Where
API5 = 5-day antecedent moisture precipitation index, mm
SMD = pre-event soil moisture deficit, mm

SMD values are a function of the soil type, antecedent rainfall and evaporation. In winter months and in very wet conditions, SMD will usually be close to zero, which represents saturation of the soil field capacity. SMD data are available in several forms for different periods. They can be obtained from the UK Met Office as daily estimated SMDs at synoptic weather stations. They can also be obtained as end-of-week or end-of-month areal averages over grass for 40 km × 40 km grid squares from the Met Office Rainfall and Evaporation Collection System (MORECS), which are usually adequate, unless the event is very localised.

API5 can be calculated using the procedure set out in Box 4.5:

Box 4.5 *API5 calculation procedure*

First determine the rainfall depths (in mm) for the 5 days prior to the event. The API5 value at 09:00 am on the day of the event is then defined by:

$(API5)_9 = (0.5)^{1/2} [P_{d-1} + (0.5) P_{d-2} + (0.5)^2 P_{d-3} + (0.5)^3 P_{d-4} + (0.5)^4 P_{d-5}]$

Where P_{d-1} refers to the rainfall total 1 day prior to the event

Finally, the API5 at the time of the event is given by:

$API5 = (API5)_9 \times 0.5^{(t-9)/24} + P_{t-9} \times 0.5^{(t-9)/48}$

Where t is the time (hours) of the beginning of the event
P_{t-9} = rainfall depth between time t and 09:00 am.

The percentage runoff values can either be applied to a total rainfall depth or can be recalculated incrementally for time periods during the design event.

Flood Estimation Handbook rainfall runoff method

This uses the FSSR 16 models for percentage runoff and a unit hydrograph approach, to predict runoff hydrographs from any given rainfall event. It recommends that the method should be calibrated to reflect statistical predictions from observed data from the catchment of interest or one that is "hydrologically similar".

The FEH is not considered appropriate for catchments of fewer than 200 ha, and the FEH manuals 1–5 (IH, 1999) should be referred to for detail of this method.

4.3 DEVELOPMENT RUNOFF

4.3.1 General concept

Runoff from paved areas is effectively instantaneous when compared to greenfield runoff. The runoff rate will reflect the intensity of the rainfall, with attenuation being provided by the filling of depression storage, surface runoff routing, pipe routing and SUDS. Design rainfall is processed using urban runoff models to determine both runoff rates and volumes.

4.3.2 Design rainfall

General concepts

Rainfall characteristics are extremely complex and, within the Flood Studies Report (FSR, IH, 1975) and more recently the Flood Estimation Handbook (FEH (IH, 1999)), simplified, generic profiles have been developed to represent design storms. These are then modified for different probabilities (return periods) and durations. They are used for application to greenfield and development drainage models from which flow hydrographs are then produced.

The FSR/FEH methods provide synthetic summer (peakier, with higher intensities) or winter (flatter, with lower intensities) rainfall profiles. The summer profiles should be used for sizing conveyance systems, particularly pipes. Winter profiles are generally used for sizing storages, not because the profile is “worse” than summer, but because runoff models for winter conditions usually have parameter values which generate more runoff and therefore result in greater storage requirements.

It should be noted that the FEH advises that these methods should not be used for event durations of fewer than 30 minutes. However as there are no alternatives for design rainfall hyetographs, 15 minute events are also used in practice.

For greenfield sites, the critical duration is generally not relevant and the prediction of the peak rate of runoff using IH124 does not require consideration of storm duration. However, if a runoff model is used to generate a flow hydrograph, the rainfall event duration needs to be found which generates the highest rate of runoff. For the developed site, the critical storm duration for key points in the drainage system will need to be determined. This may require the drainage system to be tested for a range of storm durations for each return period, from 30 minutes up to and possibly exceeding 48 hours.

The FSR/FEH methods are described in the following sections.

Flood Studies Report (FSR)

Although FSR is generally regarded as having been superseded by FEH, it is still widely used partly due to its ease of use. The rainfall analysis provided in the Flood Studies Report (IH, 1975) is based on data from 1941 to 1970 within the British Isles. The FSR provides a method for deriving design rainfall events for any point in the UK or Ireland using two rainfall parameters for any location.

These parameters are:

M5-60	1 in 5 year return period depth of rainfall for 60 minutes
r	ratio of the M5-60 minute rainfall depth and the M5-2 day rainfall depth

These two values can be obtained from figures given in Volume 4 of the FSR or Volume 5 of the Wallingford Procedure.

From these values, look-up tables are used to derive rainfall depths for any return period and any duration. In addition, an areal reduction factor (ARF) table is available to reduce the rainfall depth to take account of the spatial reduction of the average rainfall over the whole area.

Flood Estimation Handbook (FEH)

The FEH added significant additional rainfall datasets to that used in the FSR research work and also developed and used new statistical analytical procedures. Rainfall depths obtained using FEH show significant differences from those obtained from FSR in some parts of the country. Figure 4.5 illustrates the differences in FSR/FEH rainfall depth ratios for the 1 hour, 100 year event. For other durations, refer to UKWIR, 2004 – Climate change and the hydraulic design of sewerage systems (HR Wallingford *et al*, 2004).

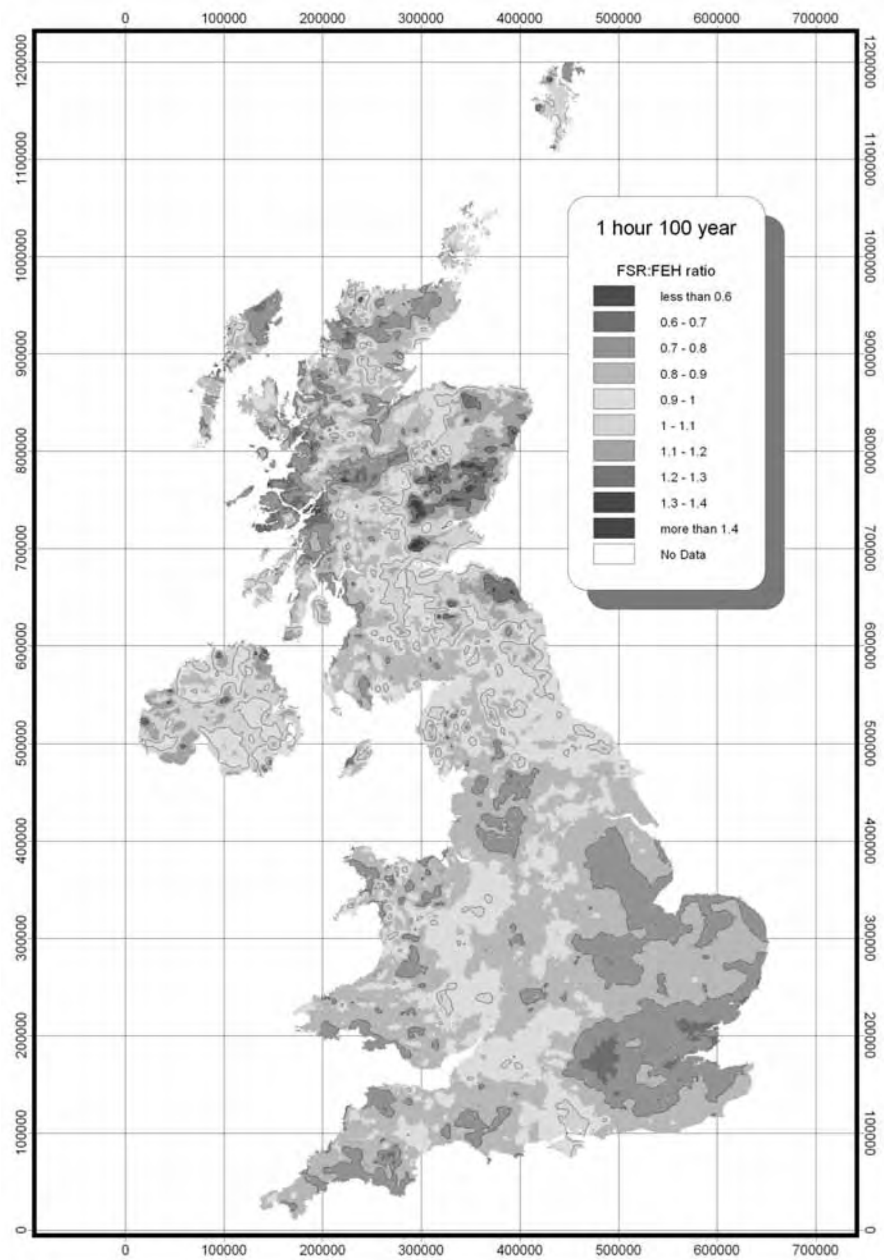

Figure 4.5 *FSR / FEH rainfall depth ratios for the 1 hour, 100 year event (courtesy of UKWIR, 2004)*

Climate change

Current guidance used by the EA *Preliminary rainfall runoff for developments* (Kellagher, 2004) is that climate change should be taken into account by increasing the rainfall depth by 10 per cent when computing storage volumes. Other rainfall depth factors are available from the UKWIR climate change project (HR Wallingford *et al*, 2004) which gives maps for predicted rainfall change across the UK. To apply this increase in rainfall depth, the hyetograph rainfall intensity values for the design storm events should be increased by 10 per cent. As work on climate change continues, recommendations on the likely change to future rainfall will be revised. However, it should be noted that storage volumes will increase by the square of the rainfall factor. This means that a 10 per cent increase in rainfall will result in a 20 per cent increase in storage, while a 40 per cent increase could double the storage. It is therefore recommended that a high factor is applied only where there is strong justification.

4.3.3 Initial assessments of development runoff rates and volumes

An initial assessment of the runoff rates from a development site can be made using the simple "Modified Rational" approach, described below. It can be assumed that there is 100 per cent runoff from paved areas and 0 per cent runoff from pervious areas, though others recommend 80 to 85 per cent for the paved runoff component and the fixed PR value for the proportion of the pervious surface which is likely to drain to the drainage system. Either approach is considered appropriate and the result is usually fairly similar for high density developments. Runoff from impermeable surfaces served by infiltration systems is normally assumed not to contribute though these units are usually only designed to a 10 year return period. Hydrograph methods are required for volume assessments.

Rational Method/Modified Rational Method

Peak runoff rate is estimated using the equation given in Box 4.6.

Box 4.6 *Rational Method/Lloyd-Davies equation to determine peak pipe flows*

$$Q = 2.78\ C\ i\ A$$

Where:

Q	=	design peak runoff (l/s)
C	=	non-dimensional runoff coefficient which is dependent on the catchment characteristics
i	=	rainfall intensity for the design return period (in mm/hr) and for a duration equal to the "time of concentration" of the catchment
A	=	total catchment area being drained (ha)

Increased understanding of the rainfall-runoff process has led to further development of the Rational Method into the Modified Rational Method, which is recommended for catchments up to 150 ha in size. In this approach, the runoff process is disaggregated from the routing process, and the runoff coefficient C is considered to consist of two components where

$$C = C_V C_R$$

Where C_V = volumetric runoff coefficient
C_R = dimensionless routing coefficient

The value of C_V depends on whether the whole site is being considered, or just the impervious areas alone. Assuming the latter:

$$C_V = \frac{PR}{PIMP}$$

Where PR is calculated using the equations in Boxes 4.7 and 4.8, and PIMP is the percentage imperviousness and represents the degree of urban extent.

$$PIMP = (Ai/A) \times 100$$

Where A_i = impervious area (ie roofs and paved areas) and A = total drainage area

Under summer rainfall conditions, CV ranges from 0.6–0.9, with the lower values representative of rapidly draining soils and the higher values of heavy clay soils. The routing coefficient CR varies between 1 and 2 and accounts for the effect of rainfall characteristics and catchment shape on the peak runoff magnitude. A fixed value for CR of 1.30 is recommended for design.

This gives:

$$Q_p = 3.61CViAi$$

where A_i = the impervious area (ha)

For this method to be used for design purposes, the rainfall intensity that causes the catchment to operate at steady state needs to be known. This gives the maximum flow rate for the catchment. The Rational Method states that a catchment just reaches steady state when the duration of the storm (and hence intensity i) is equal to the time of concentration of the area ie when the whole catchment contributes together.

The time of concentration can be defined as the time required for rain falling at the farthest point of the catchment to flow to the catchment outlet where the peak flow is to be calculated. The Rational Method assumes that the rainfall intensity, i, is constant during the time of concentration and that all the rainfall falling over the catchment contributes to the flow.

For an initial design of a pipe network (for pipe full flow), a constant rainfall intensity of 35 mm/hr can be assumed (or 50 mm/hr for a more conservative solution). Otherwise the rainfall intensity can be calculated for the estimated time of concentration for the required return period from rainfall-duration-frequency curves. These curves can be generated using the Flood Studies Report, Flood Estimation Handbook, or from gauged autographic rainfall data.

A variety of empirical equations have been produced to derive times of concentration. It is suggested that only the FSR and FEH methods are used for large catchments. Detailed design of urban drainage usually uses a time of entry of three to five minutes to which the time taken to travel from the furthest point in the catchment at an appropriate average velocity is added. Advice on this is provided in the Modified Rational Method in Volume 4 of the Wallingford Procedure.

Hydrograph methods

The principal difference between the Rational Method and hydrograph methods (such as the Wallingford Procedure) is the use of rainfall in the form of hyetographs in place of intensity-duration-frequency data. Hydrograph methods will generally be applied using proprietary software (see Section 4.7 and 4.9). These are usually used to check designs produced using the Rational Method as to the environmental regulator will often require demonstration of compliance that the system does not produce significant flooding for the 30 year event.

4.3.4 Detailed design approaches for the assessment of development runoff rates and volumes

The two methods used in predicting runoff from urban areas for detailed design purposes are:

1. Fixed Wallingford Procedure UK runoff model.
2. Variable Wallingford Procedure UK runoff model (New PR equation).

Both models are still used by the water industry although the variable runoff model, which was developed to address some of the limitations of the fixed runoff model, is generally favoured. Details of these two runoff models are given in the following sections. Details on the modelling approach are given in Section 4.7.

Fixed Wallingford Procedure UK runoff model

The fixed Wallingford Procedure UK runoff model is a statistically based regression equation that was calibrated against a large number of events recorded in the UK. It is given by the equation in Box 4.7.

Box 4.7 *Wallingford Procedure UK runoff model*

$$PR = 0.829PIMP + 25SOIL + 0.078UCWI - 20.7$$

Where:

PR	=	percentage runoff
PIMP	=	percentage impermeability (0 to 100) obtained by dividing the total directly connected impervious area (both roofs and roads) by the total contributing area
SOIL	=	an index of the water holding capacity of the soil (0.15 to 0.50), based on the FSR WRAP parameter, obtained from FSR (IH, 1975) or Wallingford Procedure mapping
UCWI	=	Urban Catchment Wetness Index, which is a composite of two antecedent wetness parameters and is given by: $UCWI = 125 + 8API_5 - SMD$ Where API5 = 5-day antecedent precipitation index (mm) SMD = soil moisture deficit (mm)

The value for UCWI is calculated from these parameters for specific events, but design values are provided by referring to a figure relating UCWI to the annual average rainfall for that location (see Figure 4.6 below).

For specific events, API5 is calculated using the procedure given in Box 4.5.

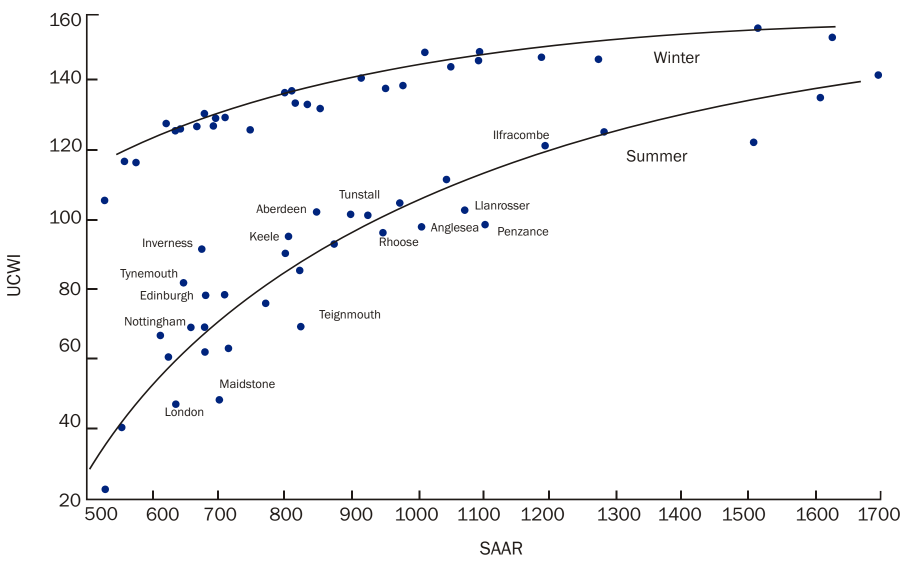

Figure 4.6 *Seasonal UCWI relationship with Standard Average Annual Rainfall (SAAR)*

The value of PR for the catchment is then apportioned to the paved and pervious surfaces using a weighting factor of 10 to 1 (see Wallingford Procedure for Europe (Kellagher, 2000)). Where values of PIMP, SOIL and UCWI are small, low or even negative values of PR can be calculated. It is recommended that a minimum value of PR of 20 per cent is used for impervious surfaces.

Variable Wallingford Procedure UK runoff model

This model was introduced by the Institute of Hydrology as a replacement to the original Wallingford Procedure model. It is used for predicting runoff in an urban environment and is often referred to as the "New PR" equation.

This model provides a variable percentage runoff during a rainfall event to take account of changes to the catchment wetness as the storm progresses.

This aspect is particularly important for long duration events where losses reduce as the pervious surfaces become saturated. The model takes the form set out in Box 4.8.

Box 4.8 *Variable Wallingford Procedure UK Runoff Model*

$$PR = IF*PIMP+(100-IF*PIMP)*\frac{NAPI}{PF}$$

Where:

PR	=	percentage runoff
IF	=	effective paved area factor
PF	=	soil moisture depth (mm)
PIMP	=	percentage impermeability (0 to 100)
NAPI	=	30 day antecedent precipitation index (depends upon the soil type)

This equation divides PR into two elements. First, the impervious area runoff is obtained by using an effective contributing area, IF. After initial losses on impervious surfaces, remaining losses are therefore given as a constant fraction of rainfall volume. Recommended values of IF are indicated in Table 4.4.

Table 4.4 *Recommended values of IF*

Surface condition	Effective impervious area factor, IF
Poor	0.45
Fair	0.60
Good	0.75

The losses on pervious surfaces and also non-effective impervious areas are represented by the second term of the equation. The first part of this term represents the total percentage of the catchment occupied by pervious and non-effective impervious areas. The losses from this area are dependent on the function NAPI/PF. NAPI is defined as a 30-day API with evapotranspiration and initial losses subtracted from rainfall. As for API5, API30 is given by a decay function equation equivalent to that set out in Box 4.4, but for 30 days and with the decay coefficient, C (equal to 0.5 in the equations in Box 4.5) related to soil type as shown in Table 4.5.

Table 4.5 *Relationship between SOIL types and decay coefficient C*

Soil types	C
1	0.1
2	0.5
3	0.7
4	0.9
5	0.99

The moisture depth parameter, PF, should normally be set at 200 mm.

Guidance on the use of the runoff models can be found in the *Wallingford procedure for Europe*, (Kellagher, 2000) and also the expert users guidance web site www.WaPUG.org

4.4 CONVEYANCE DESIGN

4.4.1 Initial sizing of pipe networks

Pipes are still commonly used to provide the conveyance and drainage connectivity for a site. The reason for doing an initial design for a pipe network is to show the general connectivity arrangement and to check on pipe sizes and depths for the system. The initial sizing of the stormwater network is typically carried out using runoff rates calculated for the development, and subsequently checked using hydrograph methods (using simple drainage models).

Simple rules of thumb exist for pipe diameters and gradients. Pipes must be at least 150 mm in diameter and these should not be laid flatter than 1 in 150. As larger pipes are required, pipes can be laid at gradients using the inverse of the pipe diameter, so a 225 mm pipe can be laid at 1 in 225 or steeper and a 300 mm pipe at 1 in 300 or steeper. For pipes larger than 500 mm, gradients should not generally be flatter than 1 in 500 due to construction tolerances. Tables for the capacity of pipes at all gradients are available from HR Wallingford (Barr and HR Wallingford, 2006). All pipe networks to be adopted should conform to Sewers for Adoption 6th edition (WRc, 2006) or Sewers for Scotland 2nd edition (Scottish Water, in preparation).

There is one aspect which needs to be highlighted with regard to SUDS. Any SUDS pipework that is to be adopted by the sewerage undertaker will need to be designed on the basis that all hard surfaces contribute runoff at the normal rate even if it is attenuated or reduced in volume by the SUDS components. This is a precaution which is currently being taken to ensure that long-term failure or change of drainage practice in the future will not result in flooding due to pipe capacities being overloaded, which will require future modification of the network. Exceptions to this rule will need to be agreed specifically with the adopting authority.

4.4.2 Initial sizing of SUDS conveyance units

Some SUDS units such as swales are designed predominantly as conveyance units. A simple estimate of the flow rate from such a conveyance unit can be calculated using Manning's equation. This calculates the flow in any channel of a given shape and roughness, and is given by the equation in Box 4.9.

Box 4.9 *Manning's Conveyance Equation*

$$Q = \frac{(1)}{n} AR2/3S1/2$$

Where:

Q = Flow rate (m^3/s)
n = Manning's coefficient, a roughness coefficient dependent upon the channel characteristics ($m^{-1/3}s$)
S = Overall slope of the channel (m/m)
R = Hydraulic radius (=A/P where A is the cross sectional area and P is the wetted perimeter)

Values of Manning's coefficient "n" can be obtained from many standard textbooks. Recommended values for grass channels are presented in Chapter 10 (Swales), Section 10.3.

Where the outflow from the SUDS unit is constrained or when the flow from the unit is to be incorporated into a larger network, then detailed modelling of the drainage system is likely to be required (see Section 4.6).

4.5 STORAGE DESIGN

4.5.1 General concepts

Storage of runoff within a SUDS system is essential for providing the extended detention of flows for water quality treatment, as well as for peak flow attenuation of larger flows for flood protection downstream of the site. Runoff storage can be provided within an on-site system through the use of structural controls and/or non-structural features and landscaped areas. Occasionally attenuation storage is provided in the river rather than in the development. However this is rarely cost effective for a developer as the volumes of storage required to affect peak flows in the river tend to be very much larger. It is also not in keeping with best practice environmental principles. Site storage effectively ensures that the developer is managing only the impact of his development.

Where a site is part of a major development area, it is often important to review the drainage requirements on a regional scale so that opportunities for regional storage as the final component in the SUDS management train for a number of sites, can be considered.

Figures 4.7 and 4.8 illustrate various storage options.

Attenuation storage is used to store runoff to enable a reduction in the peak discharge from the site. Attenuation volumes are designed to completely drain at a rate dictated by the outlet structure. Generally, attenuation storage is not considered as contributing to improvement of the runoff water quality, although it may often deliver benefits.

Retention storage facilities are designed to contain a permanent pool of water (in stormwater ponds and wetlands) which are used to provide water quality treatment.

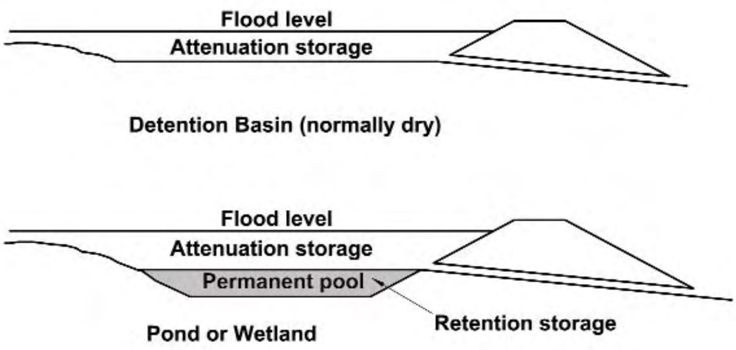

Figure 4.7 *Ponds and basins for temporary stormwater storage*

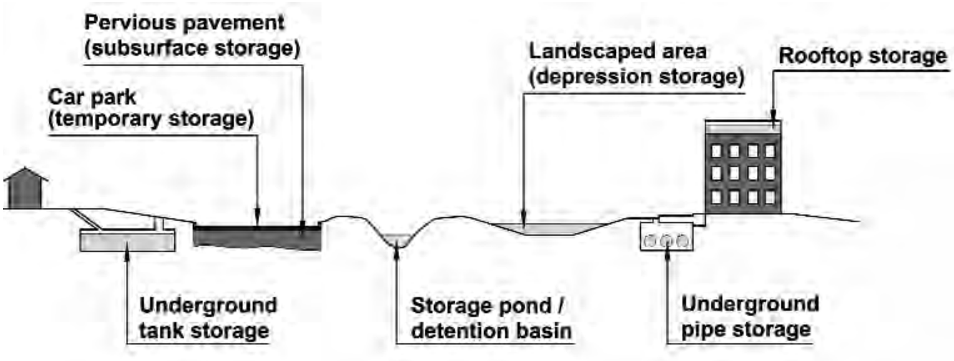

Figure 4.8 *Examples of other temporary storage locations*

Other storage concepts are presented below:

Site storage v regional storage

Storage facilities are often classified on the basis of their location and size. On-site storage is constructed on individual development sites and could include, for example, sub-pavement storage, soakaways, basins and ponds. Regional storage is designed to manage stormwater runoff from very large or multiple developments. Large basins, ponds or wetlands are more common for these areas.

On-line v off-line storage

Storage can be categorised as on-line or off-line. On-line storage uses a structural control facility that intercepts flows directly within a conveyance system or stream. Off-line storage is a separate storage facility to which flow is diverted from the conveyance system when flow rates or levels exceed a threshold. Figure 4.9 illustrates on-line versus off-line storage. The advantage of off-line storage is that the volume of storage provided is minimised as the pass-forward flow rate is maximised before the storage starts coming into effect. Water quality benefits cannot generally be achieved using off-line storage (as frequent events will bypass the facility and discharge directly downstream), unless a combination is applied in which the frequent events are stored on-line, with larger events being dealt with using a bypass. This will achieve minimum storage volume and provide treatment, but may be constrained by associated head losses.

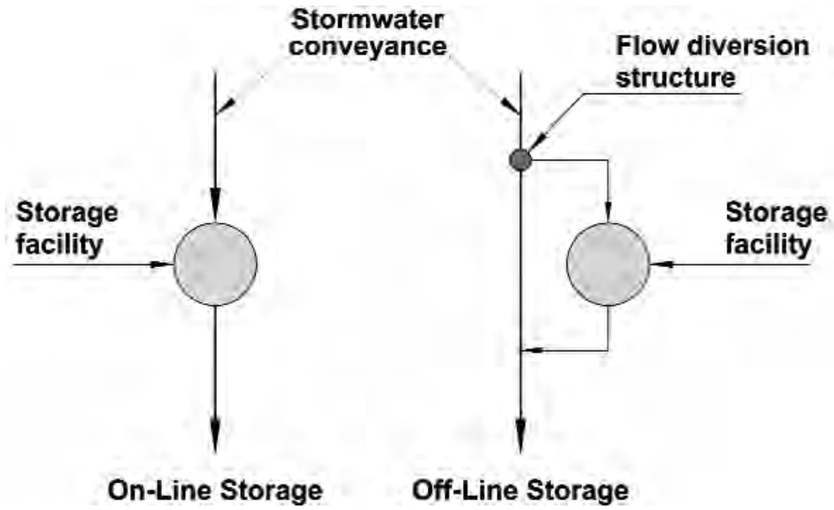

Figure 4.9 *On-line vs. off-line storage*

4.5.2 Stage-storage relationships

A stage-storage curve defines the relationship between the depth of water and storage volume in a storage facility (see Figure 4.10 for an example).

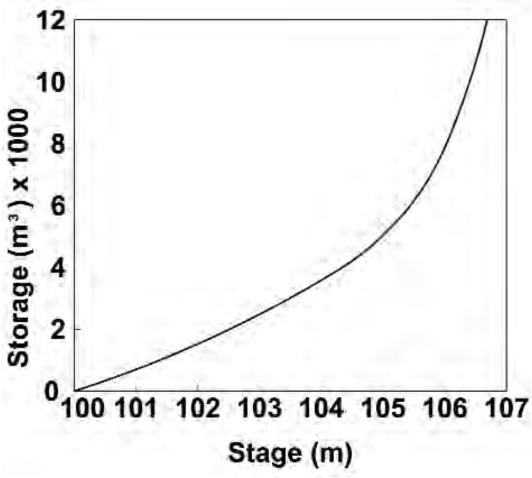

Figure 4.10 *Stage-storage curve example*

The storage volume for natural basins may be evaluated using a topographic map and integrating the depth-area relationship of the storage unit. The storage can then be estimated by averaging the areas for each increment of elevation over the full storage depth of the unit, as illustrated by the equation given in Box 4.10.

Box 4.10 *Calculation of storage volume from depth/area relationships*

> V 1,2 = [(A1 + A2)/2]d
>
> Where:
>
> V1,2 = storage volume (m^3) between elevations 1 and 2
>
> A1 = surface area at elevation 1 (m^2)
>
> A2 = surface area at elevation 2 (m^2)
>
> d = change in elevation between points 1 and 2 (m)

4.5.3 Stage (head)-discharge relationships

Simple outlet structures will not discharge their maximum discharge rate throughout an event. A stage-discharge curve defines the relationship between the depth of water and the discharge or outflow from a storage facility (see Figure 4.11). For simple assessments of storage requirements this relationship can be accounted for by including a 25 per cent additional storage allowance. The relationship can be modelled explicitly using detailed models.

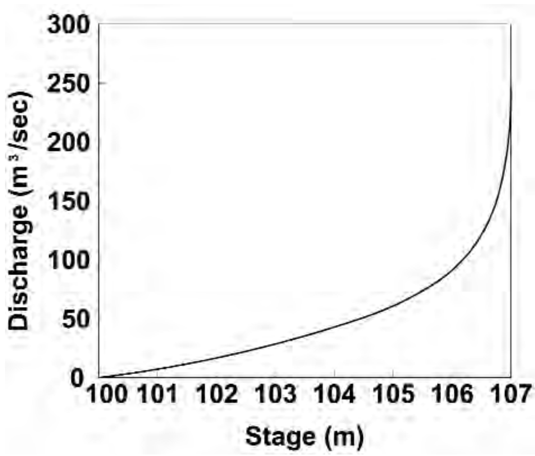

Figure 4.11 *Stage (head)-discharge curve example*

A typical storage facility often has two outlets or spillways: a primary outlet and a secondary (or emergency) overflow. The primary outlet is usually designed with a capacity sufficient to convey the design flows without allowing flow to enter the emergency spillway. A pipe, weir, orifice plate or other appropriate outlet can be used for the principal outlet. The emergency spillway is sized to provide a bypass for floodwater during a flood that exceeds the design capacity of the primary outlet, and is sometimes based on the assumption that the primary outlet is blocked. This spillway capacity should be designed taking into account the level of protection that is needed to be provided to the structure, particularly if failure of the storage facility is possible (eg via an embankment breach). The implications and routing of the emergency spill flow downstream must be considered. Chapter 19 provides detail on inlet/outlet design.

4.5.4 Attenuation storage

Attenuation storage aims to limit the peak rate of runoff from the development to the receiving watercourse to the corresponding greenfield runoff rate (or other agreed rate in the case of brownfield sites) for a range of annual flow rate probabilities.

Initial assessment

A method to give an initial estimate of storage volume is provided in the EA/Defra R&D Technical Report W5-074/A *Preliminary rainfall runoff management for developments* (Kellagher, 2004). The methodology for the initial estimation of attenuation storage has two conditions where compliance with greenfield runoff rates is not required. They are discussed here briefly.

The first condition is in areas of SOIL type 1 where, due to the very low greenfield runoff rates, the calculated storage volumes become very large and required throttle rates become very low. Infiltration should be an appropriate solution for such sites. However, where infiltration is constrained due to groundwater vulnerability, this may make some developments impractical. Where QBAR values are lower than 1 l/s/ha, a minimum of 1 l/s/ha should be used. Discharge rates for a development should be agreed with the environmental regulator in advance of preliminary design calculations.

The second condition is the need to adjust the limiting discharge rate to take into account of a minimum practical orifice size (where an orifice is proposed as the method of hydraulic control). The minimum size of opening in an orifice plate or vortex flow control to provide an acceptable risk of blockage is often accepted to be 75 mm diameter, unless the outfall is downstream of a filtration device such as a permeable pavement that will reduce the risk of blockage significantly. Sewerage undertakers usually insist on a minimum orifice of 150 mm.

An alternative to the EA/Defra approach is to develop a simple lumped model of storage system with a limiting discharge throttle and an overflow. The volume passing over the overflow is then the storage required for that specific event and throttle. A range of different storm durations will be required to determine the maximum spill volume. This method will under-predict the actual volume of storage needed as the head-discharge relationship for the hydraulic control is not being considered. An additional allowance of 25 per cent should be applied to the first estimate of storage to allow for this approximation.

Detailed assessment

For most sites, a detailed model of the drainage system should be run at detailed design stage, with the depth-storage relationship and other details represented accurately to check that adequate storage has been provided and the discharge criteria have been met. Details of the recommended modelling approach are given in Section 4.7.

4.5.5 Long-term storage

Long-term storage (see Section 3.3.3) aims specifically to address the additional volume of runoff caused by the development. This is particularly critical for catchments that are susceptible to flooding downstream of the proposed development. The basis for sizing this storage is the 100 year, 6 hour rainfall event. Although this is a relatively arbitrary value, the intention is to quantify the additional runoff generated by the construction of the development and to ensure that the drainage solution takes this into account.

The intention of long-term storage is to allow the volume equal to the greenfield runoff to discharge at greenfield rates, while retaining the rest of the runoff to discharge as infiltration or very low rates (usually 2 l/s/ha or less). The objective is to protect the river during times of extreme flooding, and it therefore needs to come into effect for such events, and not necessarily for frequent and high intensity short duration rainfall.

Initial assessment

A simple assessment is based on the rainfall depth of the 100 year, 6 hour event, taking the difference in runoff proportion between the pre- and post-development condition, values of which have been described earlier. Assuming that no runoff takes place from pervious areas after development (which can be achieved by appropriate design), and based on 80 per cent runoff rates for a 70 per cent level of impermeability, the following approximate values can be used:

Table 4.6 *Long term storage volumes for a typical development*

SOIL type	Storage volume (m^3/ha)
1	320
2	180
3	130
4	60
5	20

Calculation of long-term storage is simple, but requires a decision as to whether the unpaved areas are assumed to contribute runoff or not. The following formula allows assumptions to be made as to whether some or all of the paved and pervious areas contribute runoff. The formula assumes that only 80 per cent runoff occurs from paved areas, but 100 per cent runoff can be assumed if it is felt that a more conservative assumption is needed.

Box 4.11 *Long-term storage formula*

$$Vol = RD.A.10\left[\frac{PIMP}{100}(\alpha 0.8) + \left(1 - \frac{PIMP}{100}\right)(\beta .SPR) - SPR\right]$$

where:

Vol_{XS}	=	the extra runoff volume (m^3) of development runoff over Greenfield runoff
RD	=	the rainfall depth for the 100 year, 6 hour event (mm)
PIMP	=	the impermeable area as a percentage of the total area
A	=	the area of the site (ha)
SPR	=	the "SPR" index for the FSR SOIL type
α	=	the proportion of paved area draining to the network or directly to the river (values from 0 to1) with 80 per cent runoff
β	=	the proportion of pervious area draining to the network or directly to the river (values from 0 to1)

If all the paved area is assumed to drain to the network, and all the pervious areas are landscaped so that they do not to enter the drainage system or river, this formula simplifies to:

$$Vol = RD.A.10\left(0.8\frac{PIMP}{100} - SPR\right)$$

But where all pervious areas are assumed to continue to drain to the river or network, the formula becomes:

$$Vol = RD.A.10\left(0.8\frac{PIMP}{100} - \frac{PIMP}{100}.SPR\right)$$

Detailed assessment

Detailed modelling of the storage provided within a development site will be required to demonstrate compliance of the long-term storage provision if it is provided as temporary flood storage.

Consideration should be given to ownership and clean up responsibilities as well as the hydraulic drainage mechanisms. Under-drainage should be provided to ensure a relatively rapid return to its original state if public open space is flooded. Details of a recommended modelling approach are given in Section 4.6.

4.5.6 Permanent pond volume (water quality treatment volume)

The aim of the treatment volume is to retain and treat the most polluted water from the rainfall-runoff from all events, and to retain the full volume from most events. The treatment volume may be managed by splitting it between several components in series (see Chapter 3, Section 3.3.3).

An empirical formula to calculate an appropriate treatment volume was developed for Scotland before the publication of previous SUDS design guidance (Martin *et al*, 2000) and is linked to the rainfall depth for the area, as defined by M5-60 (see Box 4.12). In Scotland, this gives reasonable volumes, equivalent to approximately 10–15 mm rainfall depths, but for England and Wales where M5-60 values are higher, a fixed rainfall depth approach is generally applied.

Variable rainfall depth method (Scotland)

The treatment volume aims to provide sufficient storage, which is equal to or greater than the runoff from 90 per cent of all rainfall events.

Box 4.12 *V_t calculation using variable rainfall depths (for Scotland)*

$$V_t\ (m^3/ha) = 9.D.[SOIL/2+(1 - SOIL/2).I]$$

Where:

Vt	=	Water Quality Treatment Volume (as a function of the total development area)
SOIL	=	Soil classification (from Flood Studies or Wallingford Procedure WRAP map)
I	=	Fraction of the area which is impervious (eg 30 per cent impermeable area = 0.3)
D	=	M5 – 60 minute rainfall depth (ie 5-year return period, 60 minute duration storm depth determined from the Wallingford Procedure)

V_t is thus a function of local hydrological characteristics, soil type and the level of impermeability of the catchment. Depending on the values used, the equivalent rainfall depths range from 10 to 20 mm.

Fixed rainfall depth

Experience with the use of V_t has resulted in a pragmatic design rule of using a fixed rainfall depth. Typical values range from 11 to 15 mm and these depths should be applied to the impermeable area of the catchment only. This provides a very simple method for determining the treatment volume needed.

4.5.7 Designing for exceedance

Rainfall with intensities of up to 150 mm/hr can occur for short periods. Pipe networks can absorb rainfall in the region of 30–50 mm/hr, but rainfall above this level results in overland flow and local flooding. There will also be a contribution from permeable surfaces (which are effectively impermeable under these conditions). Generally runoff from pervious surfaces will be significantly delayed compared to those from hard surfaces, and it is suggested that no allowance need be made specifically for this aspect for these short duration events. However, where it can be seen that a significant contribution from pervious surfaces is likely (eg due to the steepness of the area and its size), some allowance for additional runoff should be made.

When gullies are overloaded the storm water runs down roads to low points. It is therefore important to consider this effect and make suitable provision at these locations together with suitably protecting adjacent dwellings. Although it is relatively easy to spot flood risk areas by examining the site contours and layout, the magnitude of flood ponding will be significantly influenced by the characteristics of the network serving the area. At the stage of initial evaluation, identifying the extent of flooding at these locations is difficult and they can only be effectively determined during detailed design using computer models. Flooding across roads is possible and care should be taken to determine all possible flood flow paths.

Sites are particularly at risk during the construction period as areas stripped of topsoil can effectively act in a similar manner to paved surfaces and are likely to deliver very high rates of runoff as well as high levels of suspended solids. This has implications for the need to provide temporary bunding of stormwater runoff and phasing of housing construction.

Detail on designing for stormwater exceedance can be found in CIRIA publication C635 *Designing for exceedance in urban drainage – good practice* (Balmforth *et al*, 2006).

4.6 DRAINAGE SYSTEM SIZING: FINAL ASSESSMENT AND MODELLING

By implementing a treatment/management train approach, stormwater storage should be provided as a range of distributed units rather than a single storage unit at the downstream end of the catchment. To establish compliance of the development proposals with the consent requirements for stormwater discharge, all elements of the drainage system will generally need to be modelled, together with an accurate representation of the land use of the areas served.

Figure 4.12 illustrates an appropriate approach for modelling of drainage systems at detailed design stage.

In refining the design, there are opportunities to vary:

- storage volumes
- conveyance systems slopes and capacity
- hydraulic control structure characteristics
- the methods used to meet long-term storage requirements.

It should be noted that a control structure designed to meet complex flow control criteria could result in a plethora of orifices or variable weir profiles being provided at various levels. However it is important to ensure the final design is practical as well as effective, and there should be some tolerance provided to achieving compliance with discharge requirements across all return periods.

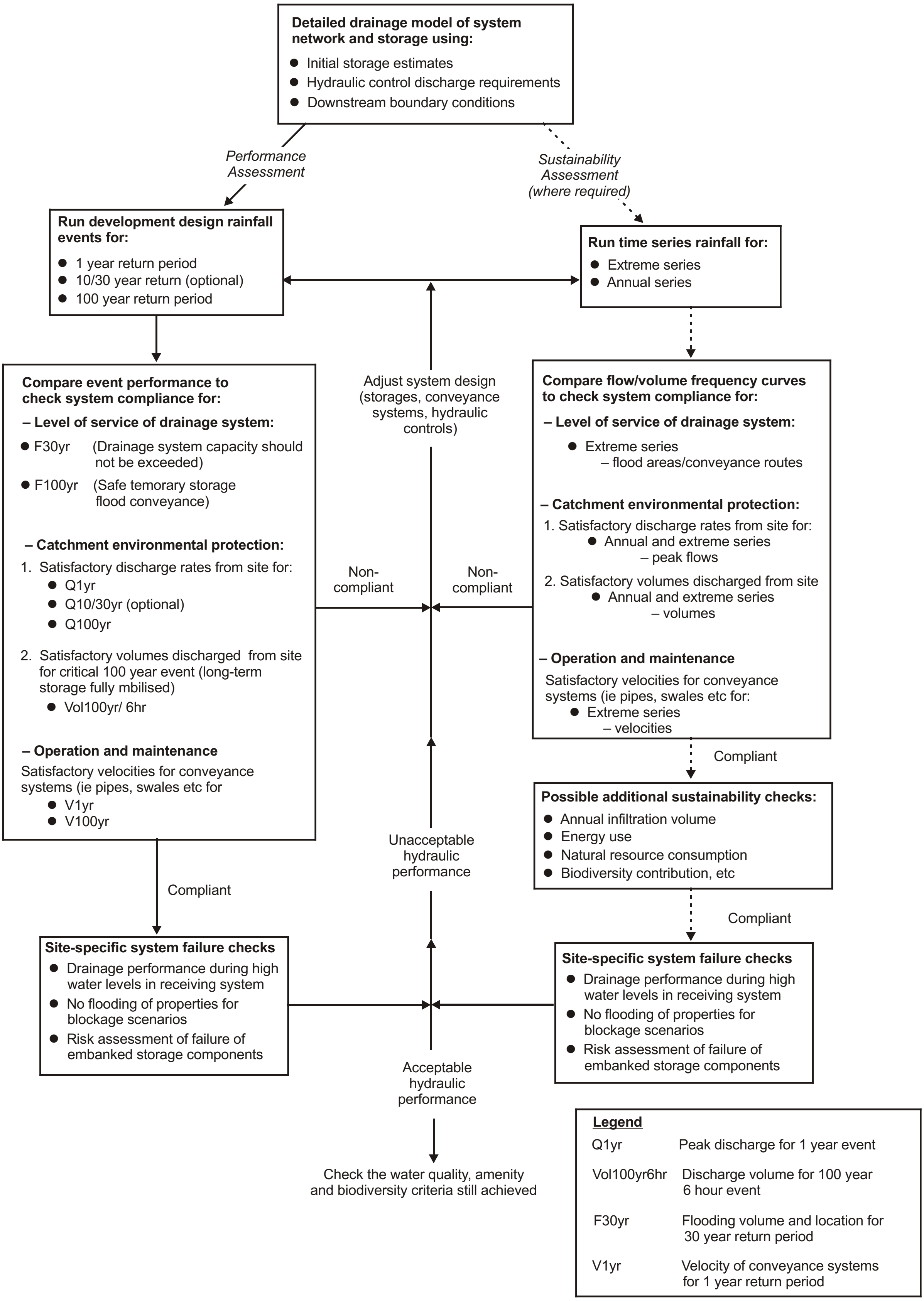

Figure 4.12 *The detailed drainage design process*

4.7 INFILTRATION DESIGN

4.7.1 General concepts

Infiltration can be used as a technique to dispose of stormwater. Infiltration systems allow stormwater to infiltrate into the ground over a period and also reduce the volume of stormwater runoff during the storm event. Therefore they reduce attenuation storage volume requirements and contribute to long-term storage criteria in trying to replicate greenfield conditions.

There are situations where infiltration drainage is not appropriate:

- where poor runoff water quality may pose a pollution threat to groundwater resources
- where the infiltration capacity of the ground is low
- where groundwater levels are high
- where the stability of foundations may be at risk.

For a soil to be suitable for accepting enhanced infiltration it must therefore be:

a) permeable

b) unsaturated.

In addition, it must be of sufficient thickness and extent to disperse the water effectively. Figure 4.13 is a schematic of a typical infiltration system.

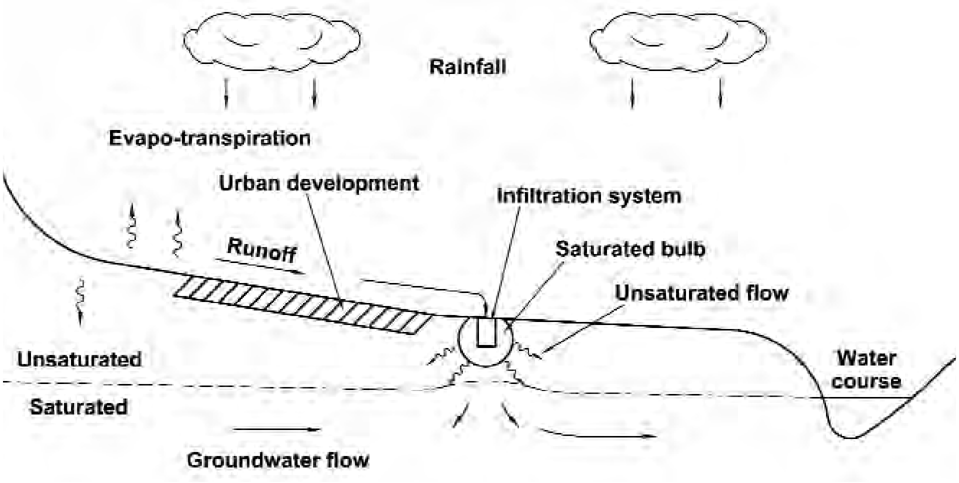

Figure 4.13 *Typical infiltration system for stormwater disposal*

4.7.2 Infiltration criteria

There are several key criteria that will determine both the suitability of a site for infiltration systems, and also the *in-situ* performance of the system. These are:

1. The performance of infiltration systems will depend on the properties of the soil in which they are constructed. The capacity of a soil to infiltrate water can be described by using an infiltration coefficient. This is the long-term infiltration rate into the soil divided by the area of infiltration. The infiltration rate is related to a soil's permeability. This will be high for coarse grained soils such as sands and gravels and low for fine soils such as silts and clays. Table 4.7 gives typical infiltration coefficients for different soil textures.

Table 4.7 *Typical infiltration coefficients based on soil texture*

Soil type	Typical infiltration coefficients (m/h)
Good infiltration media	
Gravel	10-1000
Sand	0.1-100
Loamy sand	0.01-1
Sandy loam	0.05-0.5
Loam	0.001-0.1
Silt loam	0.0005-0.05
Chalk	0.001-100
Sandy clay loam	0.001-0.1
Poor infiltration media	
Silty clay loam	0.00005-0.005
Clay	<0.0001
Till	0.00001-0.01
Rock	0.00001-0.1

2. The above figures provide a useful first indicator of the magnitude of the infiltration capacity but the high ranges reported illustrate the importance of factors such as soil packing, soil structure, swelling clay content and the presence of fissures in rock which will significantly affect the infiltration capacity. Field tests should, therefore, always be undertaken to determine infiltration coefficients for design purposes. It should be particularly noted that construction activities can severely affect infiltration rates if care is not taken to protection against compaction or blockage from fines.
3. If the stormwater runoff is polluted, there is a risk that infiltration systems may introduce pollutants into the soil and ultimately into the groundwater. Pre-treatment options can reduce this risk (see Chapter 7). However, the quality of the runoff must be appropriate for infiltration purposes and any requirements for groundwater discharge consents must be checked.
4. Infiltration should not be used in areas where the ground is contaminated.
5. Geotechnical advice should be taken and geotechnical properties of surrounding soils should be checked to ensure that the infiltration of water will not cause problems.
6. Groundwater levels must be checked to ensure that the infiltration surface is at least 1 m above the maximum anticipated level. Infiltration systems require an unsaturated soil to provide effective pollution protection.
7. The soil surrounding an infiltration system can become blinded through ingress of silt, and the infiltration capacity reduced as a result. All infiltration system designs should, therefore, include appropriate pre-treatment (ie silt/sediment removal systems). Systems should be monitored to check the extent of long-term silt deposition. Some blinding can be simply removed but in other cases, eg deep soakaways, blinding can render the system useless in time.

4.7.3 Geotechnical assessment

Infiltration systems introduce water into the surrounding soil. In many cases this will have no significant effect on the soil and the system will work satisfactorily. In some cases, however, the introduction of water into the soil may have serious implications for the stability of nearby services, foundations and slopes.

A geotechnical investigation is likely to be required to ensure that the ground conditions are suitable and to check the likely performance of the infiltration device. Figure 4.14 provides a decision tree for the use of infiltration units.

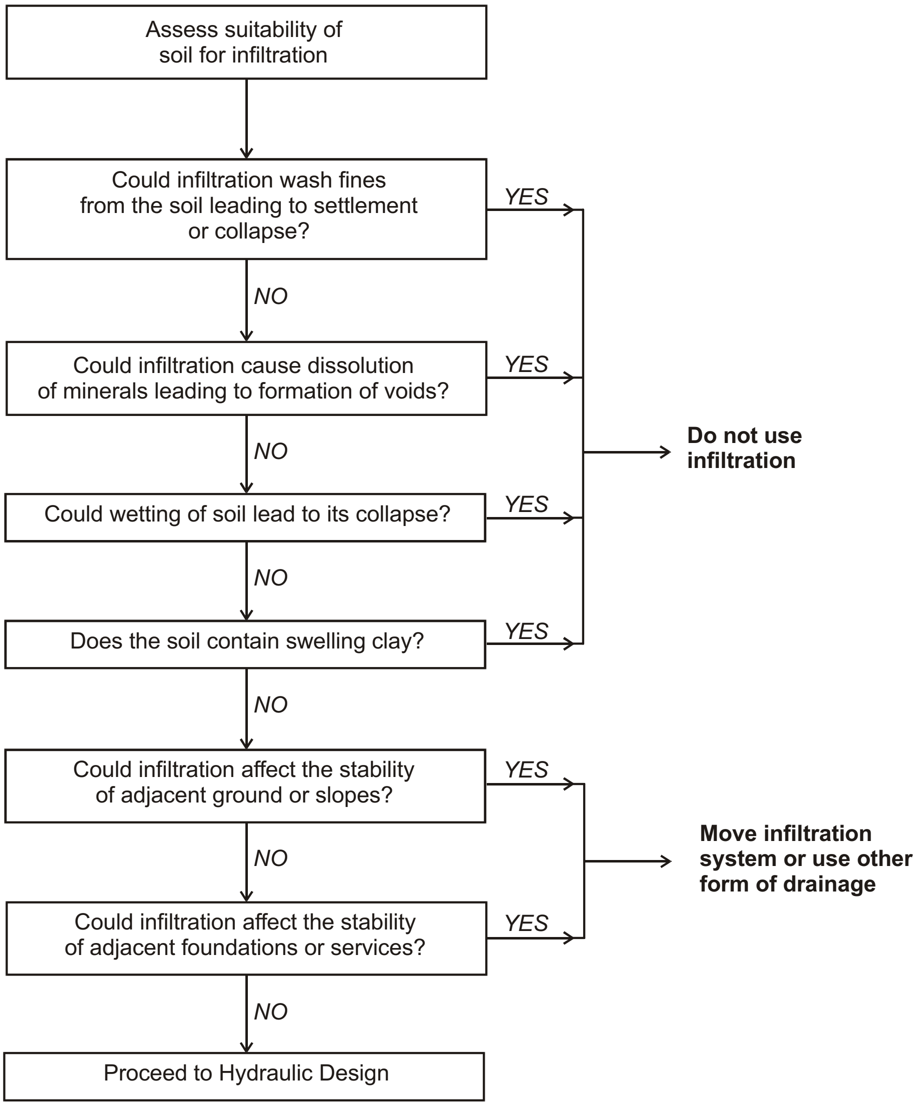

Figure 4.14 *Decision guide for the use of infiltration systems*

For further information on geotechnical issues relating to infiltration reference should be made to the CIRIA publication R156 *Infiltration drainage* (Bettess, 1996).

4.7.4 Hydraulic design

In most circumstances, the areas of the infiltration system will be considerably smaller than the impermeable area being drained. Except for the most permeable of soils, the inflow rate to the infiltration system (product of the rainfall intensity and drained area) will exceed the outflow rate (product of the infiltration coefficient of the soil and the infiltration area). It is, therefore, necessary to store the water on site or in the infiltration unit to allow time for it to soak away.

Provision of sufficient storage capacity is essential for an infiltration system to perform properly. If the infiltration system is incorrectly designed, the outflow rate may not be sufficient and flooding may occur.

The purpose of hydraulic design is to select dimensions for the infiltration system that are sufficient to dispose of the runoff from the design storm. The procedure is set out in Figure 4.15.

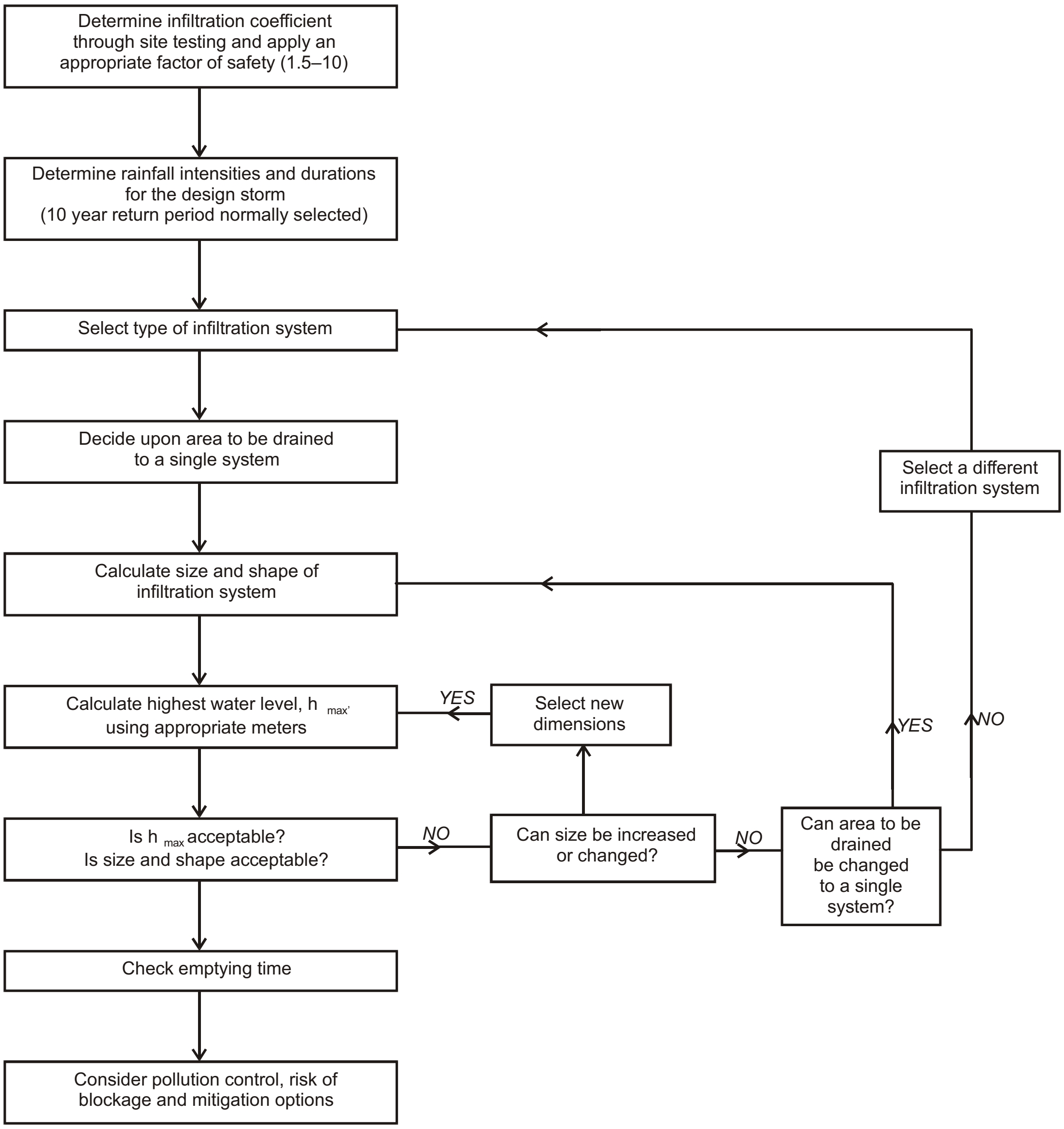

Figure 4.15 *Hydraulic design process*

A 10 per cent annual probability (1 in 10 year return period) event is commonly used for soakaways serving individual properties. Communal soakaways are generally avoided due to the concentration of flood risk at one location.

One of the largest uncertainties in the design of infiltration systems is the infiltration coefficient as this may reduce over time, particularly if effective pre-treatment is not included within the design and/or system maintenance is poor. To account for this, a factor of safety is introduced into the design procedure which reduces the observed value of the infiltration coefficient. The factor used depends upon the consequences of failure and engineering judgement is required to determine the factor to be used. Factors are suggested in Table 4.8 to account for possible loss of infiltration capacity through the design life of a system, although the figures are not based on actual observations of performance loss.

Table 4.8 *Suggested factors of safety, F, for use in hydraulic design of infiltration systems*

Size of area to be drained	Consequences of failure		
	No damage or inconvenience	Minor inconvenience (eg surface water on car parking)	Damage to buildings or structures, or major inconvenience (eg flooding of roads)
<100 m	1.5	2	10
100-1000 m^2	1.5	2	10
>1000 m^2	1.5	2	10

The following sections describe the calculation methods for infiltration system sizing.

Plane infiltration systems

For a given rainfall event discharging to an infiltration system of a particular size, the hydraulic equations can be solved to give the maximum depth of water, h_{max}. The equation for h_{max} is given in Box 4.13.

The procedure set out in Box 4.14 will ensure that stormwater will be able to infiltrate through the lower surface of the system into the soil at the required rate. For systems such as infiltration pavements which have a surface made of porous macadam or concrete blocks, a separate issue is the rate at which water can percolate through the surface. In such systems failure may occur because of poor surface infiltration and not due to poor infiltration into the surrounding soil. A designer should seek information to confirm the infiltration capacity of the selected surface material.

Box 4.13 *Determination of maximum depth of water for plane infiltration systems*

$$h = \frac{D}{n}(Ri - q)$$

Where:

- *R* ratio of the drained area to the infiltration area, $R = A_D/A_b$
- *q* infiltration coefficient, from percolation test (m/h), adjusted by the appropriate factor of safety
- *i,D* intensity and duration of rainfall events with the required return period at the site location (m/h, h)
- A_b base area of infiltration system (m^2)
- A_D area to be drained (m^2)
- *n* porosity of fill material (voids volume/total volume)

This may be obtained from laboratory tests or else the guide values provided in the following table may be used.

Material	Porosity, *n*
Geocellular systems	0.9 – 0.95
Clean stone	0.4 – 0.5
Uniform gravel	0.3 – 0.4
Graded sand or gravel	0.2 – 0.3

A perforated concrete ring soakaway may be installed in a square or rectangular plan excavation and the gap between the rings and the soil filled with clean stone. Under these circumstances an effective porosity, *n´*, applies.

$$n' = \frac{\pi r'^2 + n(WL - \pi r'^2)}{WL}$$

where *r´* is the radius of the ring sections (m)
W is the width of the excavation (m)
L is the length of the excavation (m)

Box 4.14 *Procedure for design of plane infiltration systems*

Procedure

1. Obtain the infiltration coefficient, q, (m/h) by dividing the infiltration rate found from field tests by the appropriate factor of safety.
2. Find the porosity of granular fill material
3. (i) Decide on the area to be drained, A_D,(m^2) and the infiltration surface area, Ab (m2)

   (ii) Calculate the drainage ratio, R, where $R = \frac{A_D}{A_b}$
4. (i) Select a storm duration, D (h).

   (ii) Determine the corresponding rainfall intensity, i (m/h).
5. (i) Check whether q exceeds Ri. If so then the rate of infiltration exceeds the potential rate of runoff, in which case $h_{max} = 0$.

   (ii) Otherwise, calculate the value of h_{max} (m)
6. Repeat steps 4 and 5 for a range of rainfall durations, constructing a spreadsheet or table of results.
7. Select the largest value of h_{max}

For an infiltration pavement, $R = 1$, step 3 is omitted and the maximum depth of water is given by:

$$h_{max} = \frac{D}{n}(i - q)$$

For an infiltration pavement where no subgrade material is provided to allow short-term storage of water, ie open lattice blockwork, storage occurs on open ground above the infiltration surface. In this case R = 1, n = 1, steps 2 and 3 are omitted and the maximum depth of water is given by:

$$h_{max} = D(i - q)$$

Alternatively, for an infiltration blanket the maximum depth h_{max} may be fixed and the designer may wish to know the base area of the infiltration system that will be required to ensure that the depth of water does not exceed h_{max}, in which case the procedure given in Box 4.15 should be followed.

Box 4.15 *Procedure for design of infiltration blankets*

Procedure to determine the base area required for a given maximum depth.

The equation for the base area A_b (m^2) is given by :

$$A_b = \frac{A_D\, i\, D}{nh_{max} + qD}$$

1. Obtain the infiltration coefficient, q, by dividing the infiltration rate found from field tests by the appropriate factor of safety.

   $$h_{max} = \frac{D}{n}(Ri - q),$$

   where R is the ratio of the drained area to the infiltration area, $R = A_D/A_b$
2. Find the porosity of granular fill material
3. (i) Decide on the area to be drained, A_D (m^2).

   (ii) Decide on the maximum allowable water level, hmax (m)
4. (i) Select a storm duration, D (h).

   (ii) Determine the corresponding rainfall intensity, I (m/h).
5. (i) Calculate $A_D.i.D$, n.hmax, and $q.D$.

   (ii) Calculate A_b (m^2).
6. Repeat steps 4 and 5 for a range of durations constructing a spreadsheet or a table of results.
7. (i) Find the largest infiltration surface area required.

   (ii) If this area is unacceptably large then increase h_{max} or decrease A_D and repeat from step 3.

3-D infiltration systems

For a given rainfall event discharging to an infiltration system of a particular size, the hydraulic equations can be solved to give the maximum depth of water, h_{max}. The approach used depends on whether the facility has vertical or sloping sides.

Vertical-sided structures

This procedure can be applied to soakaways and infiltration trenches. The maximum water depth h_{max} in the infiltration system is given by the equations given in Box 4.16 and the procedure in Box 4.17

Box 4.16 *Determination of maximum depth of water for 3D infiltration systems*

$$h_{max} = a\left(e^{(-bD)} - 1\right)$$

where

$$a = \frac{A_b}{P} - \frac{iA_D}{Pq},$$

$$b = \frac{Pq}{nA_b},$$

and P is the perimeter of the infiltration system (m).

These equations can be solved computationally, or graphically using Figure 4.16.

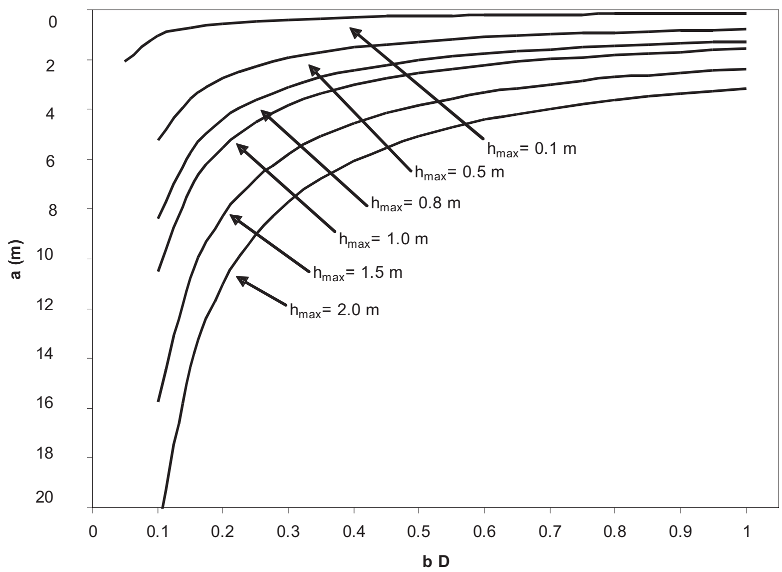

Figure 4.16 *Graph to determine maximum depth for 3-D infiltration systems*

Box 4.17 *Procedure to determine maximum depth for 3 D infiltration systems*

1. Obtain the infiltration coefficient, q, by dividing the infiltration rate found from field tests by the appropriate factor of safety.
2. Find the porosity of granular fill material. If the structure is open, $n = 1$. If it is part-filled with gravel then the effective porosity, n', is used
3. (i) Decide on the area to be drained, A_D.
   (ii) Choose the type and shape of infiltration system, ie cylindrical soakaway, infiltration trench.
4. (i) Select the proposed dimensions for the infiltration system, ie the radius of a cylindrical soakaway, the width and length of a rectangular plan system.
   (ii) Calculate the base area, A_b, and the perimeter, P, from the proposed dimensions.
   (iii) Determine the value of b from $b = \dfrac{Pq}{A_b n}$
5. (i) Select a storm duration, D.
   (ii) Determine the corresponding rainstorm intensity, i.
6. Determine the value of a from $a = \dfrac{A_b}{P} - \dfrac{A_D i}{Pq}$
7. Either calculate h_{max} or read off the value of h_{max} from Figure 4.15.
8. Repeat steps 5 to 7 for a range of rainstorm durations
9. (i) Find the largest value of hmax.
   (ii) If hmax is unacceptably high, return to step 4 and increase the dimensions.
   (iii) If h_{max} is still unacceptably high, either:
   (a) return to step 3 (i) and reduce the area drained to an individual system
   Or
   (b) return to step 3 (ii) and choose a different type of system.

Sloping-sided structures

For sloping-sided structures there is no simple analytical method for calculating the maximum water depth. A numerical procedure for calculating the depth is given in Bettess (1996). It is recommended that sloping-sided structures are approximated by a vertical-sided structure or that the method described in this publication is used.

Time for emptying

The hydraulic equations take both storage and infiltration into account and, if the infiltration rate is small, will ensure that the system incorporates sufficient storage. If infiltration is too small, however, there is the possibility that the system will not have emptied following one rainfall event before the next rainfall starts. It has been suggested that, to ensure the system's readiness to deal with a rainfall event, the infiltration rate from the system should be sufficient to half-empty the storage in 24 hours. For a given geometry of system, this effectively imposes a minimum acceptable infiltration rate. The relevant equations are given in Box 4.18.

Box 4.18 *Equations to calculate time to empty of an infiltration system*

1. (1) Time for half-emptying a plane infiltration system:

$$\frac{n\,h_{max}}{2q}$$

If the time for half-emptying is stipulated to be less than 24 hours and q is measured in m/h, then an acceptable infiltration coefficient is determined by:

$$q \geq \frac{n\,h_{max}}{48}$$

2. Time for half-emptying a 3-D infiltration system.

$$\frac{nA_b}{9P}\log_e\left[\frac{h_{max}+\frac{A_b}{P}}{\frac{h_{max}}{2}+\frac{A_b}{P}}\right]$$

If the time for half-emptying is stipulated to be less than 24 hours and q is measured in m/h, then an acceptable infiltration coefficient is given by:

$$q > \frac{n}{24}\frac{A_b}{P}\log_e\left(\frac{h_{max}+\frac{A_b}{P}}{\frac{h_{max}}{2}+\frac{A_b}{P}}\right)$$

For additional detail on the hydraulic design of infiltration systems CIRIA publication R156, *Infiltration drainage – manual of good practice* should be referred to (Bettess, 1996).

4.7.5 Pollution control and mitigation

Water that enters an infiltration system may carry pollutants. Wherever possible, dissolved and particulate pollutants should be prevented from reaching the soil surrounding the system through the use of upstream pre-treatment techniques (see Chapter 6).

The general procedure for assessing whether such measures may be required is set out in Figure 4.17.

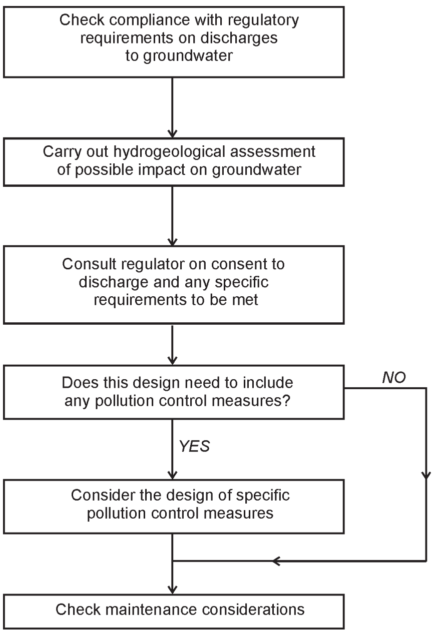

Figure 4.17 *Pollution control and mitigation process*

However, the environmental regulators often have published guidance on the acceptability of infiltration systems for particular types of site. These documents are discussed in detail in Chapter 2, Section 2.5.

4.8 DRAINAGE SOFTWARE: USE AND LIMITATIONS

4.8.1 Use of software models

The use of the phrase "the Wallingford Procedure" applied to the design of drainage systems is widespread, but its meaning is not always understood. The original suite of programs, which included a simulation program, was developed in 1981 and is now obsolete. The simulation program used hydrographic pipe routing, but also took into account surcharge effects in the network and used a new rainfall-runoff model that was calibrated against recorded runoff information. This runoff model has evolved over the years since 1981.

Therefore when authorities ask for the Wallingford Procedure to be applied, this is now generally taken to mean the use of a computational hydraulic simulation tool together with the use of the UK calibrated runoff model. Current simulation software is effectively applying the same technique to network design and analysis and so is still viewed as providing compliance with the "Wallingford Procedure" method.

4.8.2 Current software limitations

Commercial computational drainage software has developed since 1980 and is able to analyse pipe-based systems with great capability and accuracy. However, as with all software, users should satisfy themselves that the program meets their needs. It is important to understand the assumptions and limitations of any tool in being able to predict all aspects of the actual performance of the system. The following comments are currently pertinent to some software systems, but clarification on any issue should be sought from software suppliers.

Gully capacity

The linkage between overland runoff and receiving networks is generally via conceptual routing models that do not represent the actual physical processes. Thus runoff just "enters" the pipe system with a suitable delay to account for the flow time above ground. This is perfectly reasonable in most circumstances and has been proven in practice to provide accurate results for predicting system performance.

However, the ability of gullies to convey water into the drainage network is limited for extreme events, so where models predict all the water passing into the pipework, in practice, it often passes on down to the road. Thus, there may be situations where flooding can take place that are not predicted by the model. Some software packages cater for explicit modelling of gully capacities.

Overland flow

A consideration of overland flow in designing drainage systems has only recently become a stated requirement. Overland flood flow modelling has been carried out for a number of years by representing the road network as a secondary drainage system. Although the roads can be represented with reasonable accuracy, the issues related to model stability require very careful attention. In addition, the representation of flood storage depths at low points in the catchment, may not relate to the topography that actually exists and tend to be poor.

The use of 2D models to look at overland flow is rare at present and this is currently a major area of software development. It is, however, important to be aware of the possibility of flows passing across roads rather than being constrained within them.

SUDS units representation

In general, most software packages do not explicitly represent the actual performance of many SUDS units, particularly vegetated systems, although this is likely to be addressed in time. This constraint does not prevent a reasonable approximation of the system, particularly as many drainage elements can be replicated well.

It must be recognised that the use of vegetated systems has introduced uncertainty into the prediction of the hydraulic performance of systems which is not a function of a lack of modelling facility.

A number of runoff models have already been described in this chapter. However, even the variable UK runoff model, generally regarded as the best at present, is considered to be deficient for application to SUDS, where soil saturation is an important element of the performance.

4.9 DOWNSTREAM HYDROLOGIC ASSESSMENT

Where the proposed development will contribute a significant proportion of the flow within the receiving watercourse downstream of the point of discharge, then a flood risk assessment including a catchment impact assessment tends to be a regulatory requirement. This is likely to involve developing a routing model of the catchment, both with and without the proposed development, to verify the impact on downstream flood flows and levels.

Current guidance and procedures include the EA/Defra research document FD2320 *Flood risk assessment guidance for new developments* (Udale-Clarke, 2005), produced by HR Wallingford. This has guidance notes and references the procedures such as RASP, CFMPs and MDSF, all aspects which relate to catchment flood assessments.

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SUDS selection

5

Contents

SUDS selection

5

This chapter presents the process by which appropriate SUDS options may be selected for a site. The proposed flow chart and selection matrices should be used in conjunction with Section 2.4 (The development process) and Chapter 3 (Design criteria).

5.1 INTRODUCTION

There are many different SUDS components that can be used on a site. Each site will have unique characteristics and these should guide the selection of the most appropriate set of SUDS techniques. Not all SUDS techniques will be suitable for all sites and therefore it is important that the opportunities and constraints are identified at an early stage in the design process. SUDS selection is a key part of the planning and design of the development, described in detail in Chapter 2, and should be undertaken in conjunction with all stakeholders. Justification of the preferred options will form part of any drainage assessment (see Section 2.4.4) that may be required for the site.

When selecting SUDS it is important firstly to define the design criteria which are described in Chapter 3. There is unlikely to be a single "correct" answer; several options may meet the set criteria and judgement will be needed as to the appropriate solution for the development site. The ideal solution to drainage design will comprise a number of SUDS components linked together to form a SUDS management train. This is presented in Sections 1.3.2 and 3.3.3 and is a critical element of SUDS design philosophy.

A good first assessment of the suitability of different SUDS components can be achieved by reviewing the techniques set out in Table 1.7 of this document (Capability of different SUDS techniques). This will allow techniques to be selected for prevention, conveyance, pre-treatment, source control, site control and regional control. This chapter presents a more detailed series of matrices that can be used as a screening process to select the best group of SUDS for a development site. The matrices can be used to screen SUDS techniques using a step-by-step approach.

5.2 SUDS SELECTION CRITERIA

SUDS selection criteria are presented in Box 5.1.

Box 5.1 *SUDS selection criteria*

1. Land use characteristics.
2. Site characteristics.
3. Catchment characteristics.
4. Quantity and quality performance requirements.
5. Amenity and environmental requirements.

5.2.1 Land use characteristics

It is important to determine which SUDS techniques are best suited to the proposed land use of the area draining to the system. The different land use types are discussed in Table 5.1. The associated selection matrix is given as Table 5.2.

Table 5.1 *Influence of land use on SUDS selection*

Land use	Required drainage system characteristics
1. Very low density development areas	These areas are likely to have lower pollution levels and, providing they have a fully vegetated surface, lower sediment loadings compared to equivalent impervious surfaces. A full treatment train is unlikely to be necessary and a single stage should be sufficient.
2. Roofs	Roof runoff is unlikely to carry significant pollution loads and a single treatment stage (with appropriate pre-treatment) is likely to be sufficient.
3. Roads/ highways	The design criteria for road drainage systems, set out at the outline planning stage, will depend on: • the sensitivity of the receiving water • the traffic conditions (traffic flow and types of vehicles). If the receiving water is not particularly sensitive and the road has low traffic flows (eg residential roads), the quality criteria are likely to be similar to those for a commercial site. Where traffic loadings are higher, a specific assessment – as described in The Design Manual for Roads and Bridges (Highways Agency *et al*, 2005) – may be necessary to determine the requirements for treatment. Drainage near roads should ensure not only that the road surface can shed water quickly, but also that the ground around the road and paths will not become saturated. Lack of free draining ground under the road can lead to loss of ground strength and frost heave. If drainage runs alongside roads, the carriageway will need to be defined and measures taken to avoid over-running or parking on verges. Permeable paving systems may not be suitable for adoptable roads and any proposals should be discussed in detail with the adopting authority.
4. Commercial development (including shops, schools and offices)	Some small areas within these sites, such as fuel tanks or rubbish skips, should be treated as industrial (hotspot) sub-catchments. Unless the receiving water is particularly sensitive, two levels of treatment will typically be required. This might consist of source control followed by site or regional controls.
5. Industrial development /hotspot areas	Industrial areas pose a greater threat to the environment than other land uses. Runoff from these areas may include highly polluted runoff. Extra stages of runoff treatment are therefore required, especially for sensitive receiving waters. Pollution prevention measures are essential, eg the use of containment systems such as bunds will allow any spills to be controlled in high-risk areas. Roofing over areas such as garage forecourts will allow rainfall to be directed to the drainage system without being polluted. The area subject to spills can be drained separately without having to cater for the entire volume from rainfall runoff. For further details, see *Design of containment systems for the prevention of water pollution from industrial incidents* (Mason and Amies, 1997) and Chapter 6 of this document. Even if potentially polluting areas are contained, the risk of pollution is still relatively high, so the drainage from the whole industrial site should pass through at least three treatment stages. The following areas should be connected to the foul sewer, subject to the agreement of the water authority: • permanent skip areas • yard areas where chemicals and oils may be spilled • delivery bays where there is a high risk of spillage • designated pressure washing areas • fuelling areas. These areas should be clearly defined and kept to a minimum to limit the volume of water discharged to the foul sewer. Discharges of trade effluent must be in accordance with consents issued under the relevant UK legislation (see Chapter 2 for details).

Table 5.1 *Influence of land use on SUDS selection (continued)*

Land use	Required drainage system characteristics
6. Construction sites	During construction of a development, additional temporary drainage measures may be required. These should be discussed with the regulatory authorities on a site-by-site basis (see *Control of water pollution from construction sites*, CIRIA document SP156, Murnane *et al*, 2002). Temporary pre-treatment may be needed before the runoff enters the drainage system. If infiltration measures or permeable surfaces are to form part of the final drainage system, these will have to be protected from the large quantities of silt that arise during construction. If vegetated areas are to be used, eg swales, these will also have to be protected from erosion until the plants have had time to establish. Chapter 21 of this document deals with construction of SUDS, together with the associated Construction Handbook.
7. Brownfield sites	On uncontaminated brownfield sites, the water quality design criteria will depend on the existing sewerage infrastructure. If the water is discharged to a separate surface water sewer or directly to a watercourse, the site should be treated as an undeveloped site and the quality criteria will relate to the proposed land use. If the site drains to a combined sewer that is unlikely to be converted to a separate system, the surface water should be treated with a single stage of treatment to remove grit and coarse solids. Foul sewage should be drained separately within the site. An important criterion for all sites is the quantity of runoff. Storm flows can trigger combined sewer overflows, causing foul pollution and they can also overload wastewater treatment works, reducing treatment efficiencies. In exceptional circumstances the water authority might request that the runoff is detained completely and released only at night.
8. Contaminated land	Where a contaminated land site is proposed for redevelopment, SUDS may be used for the surface water drainage. However, the design of the drainage system will be site-specific and dependent upon the contaminants at the site, the remediation strategy and the risks posed by any residual contamination, in addition to normal design considerations. The developer will need to consult with the planning authority and demonstrate that the proposed drainage system will not cause re-mobilisation of contaminants resulting in exposure to the wider environment. Infiltration systems may not be appropriate without remedial measures, and most techniques will require the use of liners. Remediation and redevelopment of contaminated land is a complex subject that requires specialist knowledge. The CIRIA publication *Remedial treatment for contaminated land*, SP164 (Harris *et al*, 1998) should be referred to for further information.

Table 5.2 *Land use selection matrix*

SUDS group	Technique	Low density	Residential	Local roads	Commercial	Hotspots	Construction site	Brownfield	Contaminated land
Retention	Retention pond	Y	Y	Y[1]	Y[2]	Y[2]	Y[3]	Y	Y[2]
	Subsurface storage	Y	Y	Y	Y	Y	Y[3]	Y	Y
Wetland	Shallow wetland	Y	Y	Y[1]	Y[2]	Y[2]	N	Y	Y[2]
	Extended detention wetland	Y	Y	Y[1]	Y[2]	Y[2]	N	Y	Y[2]
	Pond/wetland	Y	Y	Y[1]	Y[2]	Y[2]	N	Y	Y[2]
	Pocket wetland	Y	Y	Y[1]	Y[2]	Y[2]	N	Y	Y[2]
	Submerged gravel wetland	Y	Y	Y[1]	Y[2]	Y[2]	N	Y	Y[2]
	Wetland channel	Y	Y	Y[1]	Y[2]	Y[2]	N	Y	Y[2]
Infiltration	Infiltration trench	Y	Y	Y[1]	Y[2]	N	N	Y	Y[4]
	Infiltration basin	Y	Y	Y[1]	Y[2]	N	N	Y	Y[4]
	Soakaway	Y	Y	Y[1]	Y[2]	N	N	Y	Y[4]
Filtration	Surface sand filter	N	Y	Y[1]	Y[2]	Y[2]	N	Y	Y[2]
	Sub-surface sand filter	N	Y	Y[1]	Y[2]	Y[2]	N	Y	Y[2]
	Perimeter sand filter	N	N	Y[1]	Y[2]	Y[2]	N	Y	Y[2]
	Bioretention/filter strip	Y	Y	Y[1]	Y[2]	Y[2]	N	Y	Y[2]
	Filter trench	Y	Y	Y[1]	Y[2]	Y[2]	N	Y	Y[2]
Detention	Detention basin	Y	Y	Y[1]	Y[2]	Y[1,2]	Y[3]	Y	Y[2]
Open channels	Conveyance swale	Y	Y	Y[1]	Y[2]	Y[2]	Y[3]	Y	Y[2]
	Enhanced dry swale	Y	Y	Y[1]	Y[2]	Y[2]	Y[3]	Y	Y[2]
	Enhanced wet swale	Y	Y	Y[1]	Y[2]	Y[1]	Y[3]	Y	Y[2]
Source control	Green roof	Y	Y	N	Y[2]	Y	N	Y	Y
	Rain water harvesting	Y	Y	N	Y[2]	N	N	Y	Y
	Pervious pavements	Y	Y	N	Y[2]	Y[1]	N	Y	Y[2]

Y: Yes N: No

[1] may require two treatment train stages, depending on type and intensity of road use and receiving water sensitivity

[2] may require three treatment train stages, depending on receiving watercourse sensitivity

[3] will require draw-down and rehabilitation following construction activities, prior to use as a permanent drainage system

[4] providing designs prevent mobilisation of contamination

5.2.2 Site characteristics

It is important to determine whether there are any site characteristics that may restrict or preclude the use of a particular SUDS technique. The site characteristics that can influence SUDS selection are discussed in the following table (Table 5.3). The associated selection matrix is given as Table 5.4.

Table 5.3 *Influence of site characteristics on SUDS selection*

Site characteristic	Required drainage system characteristics
1. Soils	The function of different SUDS is very dependent on the underlying soils. More permeable soils can enhance the operation of some practices, but adversely affect others, eg wet ponds or wetlands rely on a pool of water or saturated sub-soils to provide the basis for water quality treatment. Permeable soils will prevent the retention of a pool of water unless a liner is installed. Infiltration practices rely on the passage of water through the soil profile and more permeable soils transmit more water.
2. Groundwater: minimum depth to seasonally high water table	Infiltration devices will require at least 1 m of soil depth between the base of the device and the maximum expected groundwater level. This is to ensure that the system operates efficiently during periods of exceptional wet weather and that the risk of system flooding from high groundwater levels is minimised.
3. Area draining to a single SUDS component	Practices that rely on vegetative or media filtering of runoff tend to be more appropriate for smaller catchment areas, as large flows may overwhelm their ability to treat the runoff. Ponds can be appropriate for larger catchment areas although, by using effective source control and SUDS management trains, ponds will most usually feature at the bottom of a train of upstream components. It should be rare that areas >2 ha drain to a single SUDS component.
4. Slope of contributing drainage area	Steeper slopes may eliminate the use of some practices, may require other practices to be modified, but may have little impact on others. Depending on the design, it is usually more difficult to achieve higher pond/basin storage volumes on sloping sites. Swales may be adapted for steeper slopes if the swales are placed along the contours rather than up or down the slope. Biofiltration and filter strips require residence times that are generally only possible with gentler slopes. Infiltration practices are also limited to gentle slopes as they must provide storage of water until the water can soak into the ground. In addition, infiltration of water into a slope may cause saturation further down which could cause slope instability or re-emergence of stormwater.
5. Head	Elevation differences are needed from inflow to outflow to allow certain SUDS techniques to operate under gravity. If sufficient head is not naturally available, it can often be artificially created by excavation or by using embankments.
6. Availability of space	Some techniques require more land take than others, though this is not necessarily a barrier. In England and Wales, PPG 3 (DETR, 2000) calls for higher density housing developments, but also requires all developments to provide sufficient provision for open space and playing fields where such spaces are not already adequately provided within easy access of the new housing. A pond could be included in such an area, or the area could be used for extreme flood management, being designed to flood on rare occasions and for a short time during and after extreme storm events. In some instances, ponds have been located outside the development site on adjacent land.

Table 5.4 *Site characteristics selection matrix*

SUDS group	Technique	Soils		Area draining to a single SUDS component		Minimum depth to water table		Site slope		Available head		Available space	
		Impermeable	Permeable	0 – 2 ha	> 2 ha	0 – 1 m	> 1 m	0 – 5 %	> 5 %	0 – 1 m	1 – 2 m	Low	High
Retention	Retention pond	Y	Y[1]	Y	Y[5]	Y	Y	Y	Y	Y	Y	N	Y
	Subsurface storage	Y	Y	Y	Y[5]	Y	Y	Y	Y	Y	Y	Y	Y
Wetland	Shallow wetland	Y[2]	Y[4]	Y[4]	Y[6]	Y[2]	Y[2]	Y	N	Y	Y	N	Y
	Extended detention wetland	Y[2]	Y[4]	Y[4]	Y[6]	Y[2]	Y[2]	Y	N	Y	Y	N	Y
	Pond/wetland	Y[2]	Y[4]	Y[4]	Y[6]	Y[2]	Y[2]	Y	N	Y	Y	N	Y
	Pocket wetland	Y[2]	Y[4]	Y[4]	N	Y[2]	Y[2]	Y	N	Y	Y	Y	Y
	Submerged gravel wetland	Y[2]	Y[4]	Y[4]	Y[6]	Y[2]	Y[2]	Y	N	Y	Y	N	Y
	Wetland channel	Y[2]	Y[4]	Y[4]	Y[6]	Y[2]	Y[2]	Y	N	Y	Y	N	Y
Infiltration	Infiltration trench	N	Y	Y	N	N	Y	Y	Y	Y	N	Y	Y
	Infiltration basin	N	Y	Y	Y[5]	N	Y	Y	Y	Y	N	N	Y
	Soakaway	N	Y	Y	N	N	Y	Y	Y	Y	N	Y	Y
Filtration	Surface sand filter	Y	Y	Y	Y[5]	N	Y	Y	N	N	Y	N	Y
	Sub-surface sand filter	Y	Y	Y	N	N	Y	Y	N	N	Y	Y	Y
	Perimeter sand filter	Y	Y	Y	N	N	Y	Y	N	Y	Y	Y	Y
	Bioretention/filter strips	Y	Y	Y	N	N	Y	Y	N	Y	Y	N	Y
	Filter trench	Y	Y[1]	Y	N	N	Y	Y	N	Y	Y	Y	Y
Detention	Detention basin	Y	Y[1]	Y	Y[5]	N	Y	Y	Y	N	Y	N	Y
Open channels	Conveyance swale	Y	Y	Y	N	N	Y	Y	N[3]	Y	N	N	Y
	Enhanced dry swale	Y	Y	Y	N	N	Y	Y	N[3]	Y	N	N	Y
	Enhanced wet swale	Y[2]	Y[4]	Y	N	Y	Y	Y	N[3]	Y	N	N	Y
Source control	Green roof	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
	Rain water harvesting	Y	Y	Y	N	Y	Y	Y	Y	Y			
	Permeable pavement	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y

=Y: Yes N: No
[1] with liner
[2] with surface baseflow
[3] unless follows contours
[4] with liner and constant surface baseflow, or high ground water table
[5] possible, but not recommended (implies appropriate management train not in place)
[6] where high flows are diverted around SUDS component.

5.2.3 Catchment characteristics

It is important to determine whether there are any regulatory criteria that may restrict or preclude the use of a particular SUDS technique, or that may impose additional requirements on the performance of a particular system. The design of the SUDS may for example be influenced by the characteristics of the downstream water body that will receive the stormwater discharge. In some cases, high pollutant removal or environmental performance will be needed to fully protect aquatic resources and/or human health. These scenarios are discussed in Table 5.5.

Table 5.5 *Influence of catchment characteristic on performance requirements*

Catchment characteristic	Potential issues
1. Freshwater fisheries, sites with an ecological designation eg SSSIs, SACs	There will be a need to maintain habitat quality by maintaining natural recharge, preventing bank and channel erosion, preventing blanketing by silt, preserving the natural riparian corridor, preventing pollution, and by controlling stream warming.
2. Aquifers used for public water supply	In areas that recharge existing public water supply wells, SUDS designs will need to prevent possible groundwater contamination by preventing infiltration of contaminated runoff. At the same time, recharge will need to be retained. Groundwater protection zones are important considerations and the risk posed by infiltration techniques to groundwater needs careful evaluation. The legislation and regulation of discharges to groundwater is set out in Section 2.5.
3. Surface waters used for public water supply	Depending on the treatment available at the public water supply intake, it may be necessary to achieve a high level of pollutant removal of bacteria pathogens, nutrients, sediments and metals.
4. Coastal/ estuarial waters	Discharge to coastal or estuarial waters will not generally require peak flow or volume control as there will be no deterioration in flood risk as a result of increased runoff. Due to the high dilution available, surface water discharges to coastal waters are generally considered low risk. The main risk is from the faecal coliforms, oil and metals which are all present in urban runoff affecting bathing and shellfish waters, and here higher levels of treatment may be required.
5. Receiving waters that act as formal recreational/ amenity facilities	Removal of bacteria pathogens, nutrients, sediments and metals will be especially important for sites discharging to these watercourses and higher treatment levels may be required.
6. Requirement for sustainable water management /water conservation measures	Certain SUDS techniques/design adaptations will be more appropriate for implementation as part of rainwater harvesting/rainwater use schemes. SUDS criteria will depend on the intended type of use and the level of treatment implemented as part of the water supply system. The volume of storage will also depend on system demand.
7. Habitat-dependent flow regime	There may be a need to retain or adapt a particular drainage regime as a result of local habitat requirements.
8 Flood risk	Stringent constraints may be required for outfall flow regimes for development runoff that influences an area of high flood risk. For all locations, regulators are likely to request that volume and flow rate are constrained to the greenfield equivalent.
9 Discharges to the sewerage network	In this scenario, hydrologic criteria must be agreed with the water authority. The allowable discharge rate will depend on the headroom available in the downstream network. Sediment control is also likely to be of concern due to ongoing maintenance requirements.

There is no selection matrix for catchment characteristics as it is generally the number of components in the treatment train that will lower the risk of poor water quality treatment performance, ie additional treatment capacity can be achieved by passing surface water runoff through several stages in a treatment train. However, some components will be more effective than others in removing, for example, nutrients or metals and this should be considered when developing the drainage design (see individual component summary sheets at the start of each component chapter for details). Table 5.6 (a repeat of the earlier Table 3.3) gives an **indication** of the **minimum** number of components that are likely to be appropriate for different contributing and receiving catchment characteristics. It is stressed, however, that for larger sites, an increased number of components will generally be required to meet all design criteria. It is recommended that areas much greater than 2 ha do not drain to a single component, but that the catchment is split into subcatchments and several smaller features are included that drain to a final site control.

Table 5.6 *Number of treatment train components (assuming effective pre-treatment is in place)*

Receiving water sensitivity → / Runoff catchment characteristic ↓	Low	Medium	High
Roofs only	1	1	1
Residential roads, parking areas, commercial zones	2	2	3
Refuse collection/ industrial areas/ loading bays/lorry parks/highways	3	3	4

5.2.4 Quantity and quality performance

It is important to determine which SUDS techniques are suited to meeting the required hydraulic and water quality design criteria. These criteria are discussed in detail in Chapter 3. One technique may not meet all the criteria and a combination of practices may be needed.

The water quality treatment volume may be managed within a single SUDS technique or within a series of techniques, forming part of the treatment train. Each technique has a different removal efficiency for each pollutant of concern. However for most sites general water quality improvement is required across the suite of urban pollutants. Where there are particular pollutants of concern, the selected techniques must be appropriate for their management to acceptable levels.

Hydraulic criteria will require peak flow and volume control for a range of return periods (or probabilities). Flow rates are likely to be a function of the extent of structural hydraulic control at the system outfall, together with the size of attenuation storage provided in the system design. Significant volume control will be possible only through the use of infiltration systems, although extended detention (eg in basins, or beneath pavements) can promote significant losses through evaporation. Some systems are not appropriate for managing extreme flood events, eg filtration systems will be designed for maximum flow rates and high through-flows may damage their operational performance. In such cases, high flows should be diverted upstream of the SUDS technique.

The relevant selection matrix is presented as Table 5.7.

Table 5.7 *Quantity and quality performance selection matrix*

SUDS group	Technique	Water quality treatment potential					Hydraulic control			
		Total suspended solids removal	Heavy metals removal	Nutrient (phosphorous, nitrogen) removal	Bacteria removal (*)	Capacity to treat fine suspended sediments and dissolved pollutants	Runoff volume reduction	Suitability for flow rate control (probability)		
								0.5 (1/2 yr)	0.1 – 0.3 (10/30 yr)	0.01 (100 yr)
Retention	Retention pond	H	M	M	M	H	L	H	H	H
	Subsurface storage	L	L	L	L	L	L	H	H	H
Wetland	Shallow wetland	H	M	H	M	H	L	H	M	L
	Extended detention wetland	H	M	H	M	H	L	H	M	L
	Pond / wetland	H	M	H	M	H	L	H	M	L
	Pocket wetland	H	M	H	M	H	L	H	M	L
	Submerged gravel wetland	H	M	H	M	H	L	H	M	L
	Wetland channel	H	M	H	M	H	L	H	M	L
Infiltration	Infiltration trench	H	H	H	M	H	H	H	H	L
	Infiltration basin	H	H	H	M	H	H	H	H	H
	Soakaway	H	H	H	M	H	H	H	H	L
Filtration	Surface sand filter	H	H	H	M	H	L	H	M	L
	Sub-surface sand filter	H	H	H	M	H	L	H	M	L
	Perimeter sand filter	H	H	H	M	H	L	H	M	L
	Bioretention/filter strips	H	H	H	M	H	L	H	M	L
	Filter trench	H	H	H	M	H	L	H	H	L
Detention	Detention basin	M	M	L	L	L	L	H	H	H
Open channels	Conveyance swale	H	M	M	M	H	M	H	H	H
	Enhanced dry swale	H	H	H	M	H	M	H	H	H
	Enhanced wet swale	H	H	M	H	H	L	H	H	H
Source control	Green roof	n/a	n/a	n/a	n/a	H	H	H	H	L
	Rain water harvesting	M	L	L	L	n/a	M	M	H	L
	Permeable pavement	H	H	H	H	H	H	H	H	L

* limited data available

n/a: non applicable

H = high potential
M = medium potential
L = low potential

5.2.5 Community, environmental and amenity performance

It is important to determine whether the proposed SUDS components meet all the community and environmental requirements at the site. Adaptations to the proposed solutions that may enhance the benefits of the system should also be considered. The primary community and environmental issues of concern are discussed in the following table (Table 5.8), although this list is not exhaustive and site-specific issues require identification. The relevant selection matrix is presented in Table 5.9.

Table 5.8 *Influence of community and environmental factors on SUDS selection*

Community/ environmental factor	Influence on SUDS selection
1. Maintenance régime	The future management of the site can influence the choice of drainage system. At sites where ground staff are employed, grass mowing and other landscaping activities will take place regularly, so swales etc may be appropriate. At other sites, it may be preferable to contract out maintenance work with less regular, but at least annual maintenance on ponds, wetlands and pavements. A commitment to the long term maintenance of the drainage system should be established at early stages in the planning process by involving the owner of the proposed drainage system in the design process.
2. Community acceptability	Some SUDS techniques may not be acceptable in close proximity to property eg swales in gardens are not likely to be acceptable. Some ponds may only be acceptable providing a minimum level of operation and maintenance is ongoing, and providing the water quality is reasonable all year round. This may mean that additional treatment train components are required. Amenity considerations are site specific, but there may be opportunities to enhance/provide the following facilities for the local population: • additional recreational open space • opportunities for education • enhanced levels of landscape maintenance • improved visual impact (through integration of SUDS with local topography and site layout) • water features (including water bodies and conveyance channels). It should be noted that education campaigns can exert significant influence on community acceptance of sustainable drainage schemes (see Chapter 24 for additional details).
3. Cost	Construction and maintenance costs can vary widely between techniques and the long term costs of SUDS should be considered at an early stage. In selecting a design from a series of options, both capital and operational costs should be considered using a whole life costing approach (see Chapter 25 for details), and a cost-benefit analysis carried out. Benefits could include water quality, amenity and ecology improvements.
4. Public safety	Good design and education can help overcome concerns about safety (see Chapter 24). All drainage techniques have advantages and risks, and a balance must be struck. For example, culverts are confined spaces, whereas swales have sloping sides. The safest technique will depend on the site itself. Access to a water feature might be encouraged for education and recreation, and measures taken at particular areas to ensure this is safe. In other areas, access could be discouraged by the use of barrier planting, notices or low permanent fencing. Barrier planting has advantages over fencing as it has visual and wildlife value as well as being more of a deterrent than a challenge to unwanted visitors. Safety reviews should always be undertaken where open water systems are implemented. However, the risks associated with open water features can be minimised by community engagement and careful design – for example the use of shallow planted margins. It is recommended that RoSPA is consulted if there are specific safety concerns.
5. Habitat creation	SUDS can improve wildlife habitat. Ponds and wetlands offer the greatest opportunity, with aquatic and emergent vegetation providing a habitat for fish, insects, amphibians, reptiles, birds and mammals. Grassed surfaces in filter strips, swales and infiltration basins can be integrated into general landscaping, and can be used to create green corridors, linking to wildlife habitats elsewhere. Design of SUDS should try to maximise the species diversity; local grasses, flowers and wetland vegetation should always be used and invasive species avoided. Ecological benefits are maximised where SUDS features are sited in proximity to undisturbed, natural areas or where links to these are created.

Table 5.9 *Community and environmental factors selection matrix*

SUDS Group	Technique	Maintenance	Community acceptability	Cost	Habitat creation potential
Retention	Retention pond	M	H*	M	H
	Subsurface storage	L	H	M	L
Wetland	Shallow wetland	H	H*	H	H
	Extended detention wetland	H	H*	H	H
	Pond/wetland	H	H*	H	H
	Pocket wetland	H	M*	H	H
	Submerged gravel wetland	M	L	H	M
	Wetland channel	H	H*	H	H
Infiltration	Infiltration trench	L	M	L	L
	Infiltration basin	M	H*	L	M
	Soakaway	L	M	M	L
Filtration	Surface sand filter	M	L	H	M
	Sub-surface sand filter	M	L	H	L
	Perimeter sand filter	M	L	H	L
	Bioretention/filter strips	H	H	M	H
	Filter trench	M	M	M	L
Detention	Detention basin	L	H*	L	M
Open channels	Conveyance swale	L	M*	L	M
	Enhanced dry swale	L	M*	M	M
	Enhanced wet swale	M	M*	M	H
Source control	Green roof	H	H	H	H
	Rainwater harvesting	H	M*	H	L
	Permeable pavement	M	M	M	L

H: high
M: medium
L: low

* there may be some public safety concerns associated with open water that require addressing at design stage

5.3 Linking SUDS together to form a management train

The design of a SUDS scheme will normally require the use of two or more techniques that are linked together to provide the stormwater management train for the site (see Sections 1.3.2 and 3.3.3). Water quality treatment is critical for low flows, and stormwater attenuation and volume control is critical for high flows. Where possible, treatment components should be protected from extreme events that may damage their structure (eg filter strip/swale vegetation or filter trenches) and put their performance at risk. Flow diversion techniques are described in Chapter 19 (Inlets and Outlets), but flow control can often be achieved through effective landscaping and simple overtopping.

Each of the techniques selected will contribute in different ways to the management of the surface water runoff, and many of the techniques can be implemented:

- at different scales (by varying size)
- for different environmental conditions (by using containment liners)
- for different amenity requirements (by varying types and level of vegetation, and extent of its maintenance).

The number of components in the management train will depend upon:

- the size of the upstream catchment area
- the likely concentration of pollutants in the inflow; and
- the sensitivity of the receiving environment.

Table 5.10 gives some examples of possible treatment train options. This is not a complete list and a train should be developed that meets design criteria and suits site constraints. Components with a higher treatment capacity can always be substituted, and pre-treatment must always be implemented.

Table 5.10 *Examples of SUDS treatment trains*

	Example	Infiltration	Permeable pavement	Vegetative filtering and detention	Granular filtering and detention	Retention (permanent pond)	Wetland/sand filter	Proprietary oil/silt/debris traps
Number of components:1								
Component sequence	A	1	1	1	1	1	1	
Number of components:2								
Component sequence	A	2	1	1	1			1
	B		1	2		2		2
	C			1	1	2		
Number of components:3								
Component sequence	A		1	3	1	2		
	B		1	1	1	2 + 3		
	C			1	2	3	3	
Number of components:4								
Component sequence	A			1	2	3	4	
	B			4	1	2 + 3		

A number (1) indicates that the system could feature as the first component in the management train for that particular example. If several components are labelled with a (1), this implies that any one of them would be suitable for this position.

5.4 THE SUDS SELECTION PROCESS

5.4.1 Summary

The SUDS selection process is summarised in the following flow chart.

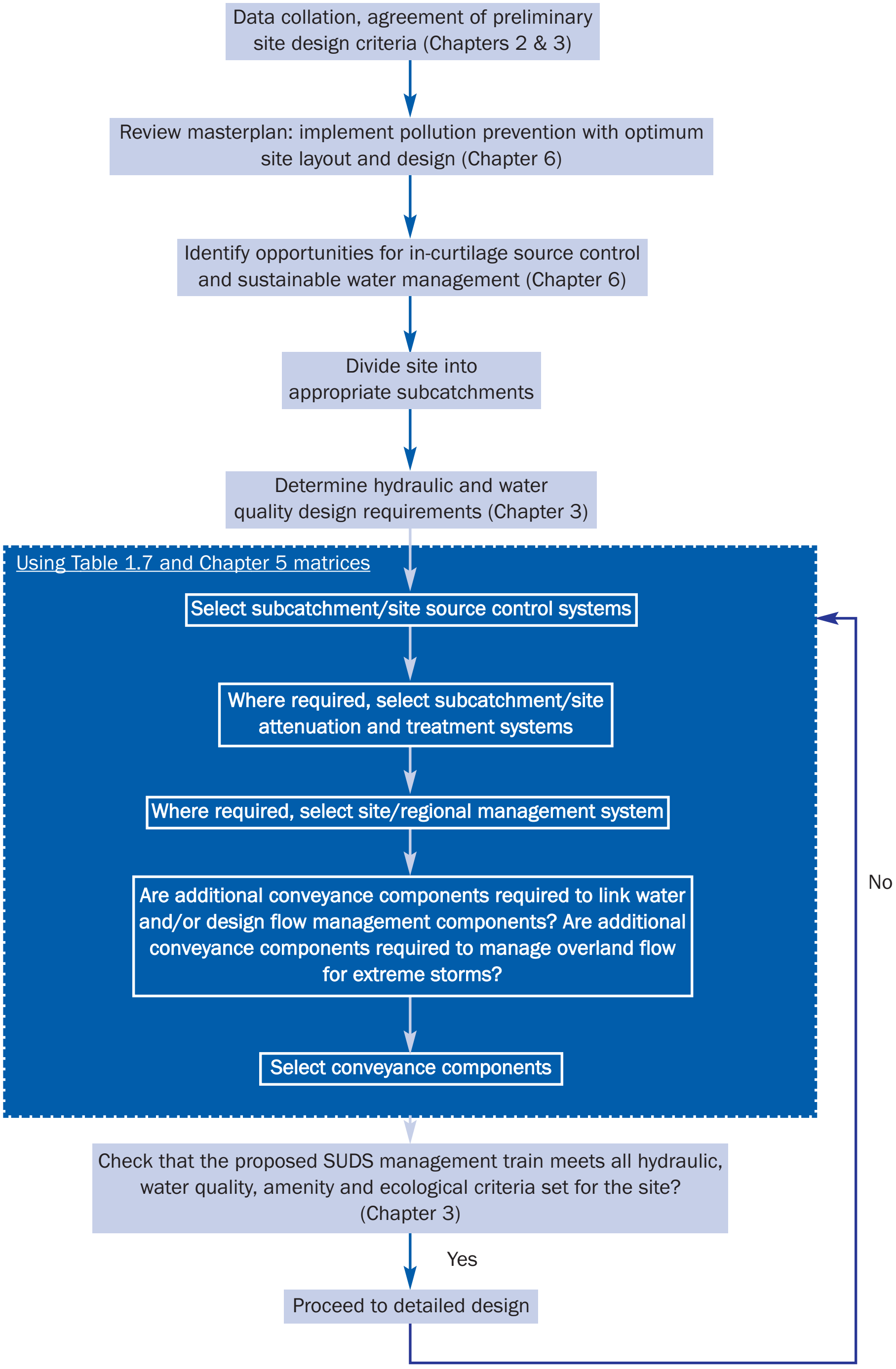

Figure 5.1 *SUDS selection flowchart*

5.4.2 Detail

Step 1: Data collation, agreement of preliminary site design criteria

Before the drainage techniques can be selected and designed, data is needed of the site and the planned development principles. The information will be needed to:

a) Evaluate existing conditions.

b) State the concepts of the proposed development.

c) Allow the impact of the proposals to be assessed.

d) Enable the design criteria to be developed.

The basic initial data requirements are presented in Table 5.11.

Table 5.11 *Initial data requirements*

Data type	Data description
Original drainage pattern	The natural drainage pattern of the site is a good starting point for the drainage system. One of the main design criteria for water quantity management should be to minimise changes to the flow regime of the local area. There are exceptions: • if an industrial site is built on permeable soils that would normally allow free infiltration, pollution in the runoff might contaminate the groundwater – in such cases, runoff might have to be treated to remove pollutants before infiltration can be considered • at a contaminated land site, infiltration techniques may not be appropriate due to the risk of contaminant mobilisation.
Catchment topography, soils and groundwater characteristics	These will influence the choice of drainage methods and provide basic information to calculate runoff characteristics. If infiltration is likely to be an option, an initial assessment of the soil characteristics will need to be made via site infiltration tests, as described in Chapter 4 and Appendix B. A general indication of whether the area is suitable for infiltration can be obtained by reference to the latest regulatory guidance on groundwater protection (see Section 2.5).
Location of discharge and status of receiving watercourse	Discharge may be to a surface water body (either directly or via a surface water sewer), to a combined sewer or to land. Ideally, surface water should be returned to the environment as close to the source as possible and in as many locations as possible, thus spreading the impact on receiving waters. The status of the receiving water may influence the regulatory requirements for quantity or quality control.
Development characteristics	One item of primary importance will be the proposed pattern of land use. In particular, it will be useful to know if potentially polluting activities are grouped together or scattered throughout the development. Areas of open space, roads and car-parking areas will also be important considerations.
Community/ environmental influences	There may be specific habitat requirements as a result of local biodiversity action plans (BAPs) or other environmental objectives. Consultation could identify specific community preferences.

Table 5.12 can be used as a guide to the data collation process.

Table 5.12 *Design information checklist*

Description	Details for the particular project	Consultees and sources of information
Site characteristics		
Topography		Site survey or inspection.
Areas of catchment		Site survey.
Soil type		Site investigation.
Infiltration potential of soil & seasonal groundwater levels		Site investigation.
Structural properties of soil – CBR, stiffness		Site investigation and laboratory testing.
Former land use		Local authority, Ordnance Survey maps, local library.
Hydraulic		
Hydrology of catchment		Site inspection and observations.
Flood risk		Environment Agency/SEPA/DoE (NI)/local authority.
Rainfall data		Meteorological Office or Wallingford Procedure.
Discharge design criteria – quantity		Environment Agency/SEPA/DoE (NI) or water service company.
Discharge design criteria – quality		Environment Agency/SEPA/DoE (NI) or water service company.
Acceptable overland flows/surface flooding		Owner/operator/Environment Agency/SEPA/DoE (NI).
Storage capacity and permeability of materials		Laboratory testing and test section or manufacturers' specifications.
Environmental		
Contamination of ground below site		Local authority, Ordnance Survey maps, local library and site investigation.
Details of receiving water/watercourse/aquifer		Environment Agency/SEPA/DoE (NI)or water service company.
Environmental sensitivity of site		Environment Agency/SEPA/DoE (NI)/local authority /English Nature(Countryside Council for Wales).
Groundwater vulnerability and source protection status		Environment Agency/SEPA/DoE (NI).
Design specific parameters		
Land use planning		
Development type and land use		Proposed development plans.
Potential areas for SUDS		Proposed development layout plan.
Structural		
Structural/hydraulic properties of materials		Laboratory testing and test sections or manufacturer's specifications.
Construction and design loads		Proposed development plans.
Health and safety		All affected parties.

Design criteria for quantity, quality, amenity and ecology including the level of treatment required for different land use types should be agreed with the environmental regular, the sewerage undertaker, the local authority, and the stakeholder to be responsible for the long-term operation and maintenance of the system. Chapter 2 discusses the planning of SUDS, and design criteria are presented in Chapter 3.

Step 2: Review development masterplan and implement pollution prevention and optimum site layout and design, wherever possible.

Site layout and site management practices can have an important impact on the quantity and quality of rainfall runoff. Best practice is discussed in detail in Chapter 6.

Step 3: Identify feasibility of within-curtilage source control and sustainable water management options, using Table 1.6 and Chapter 5 selection matrices.

Where water resources are under significant pressure, the sustainable management of water on any new development site is likely to be a high planning priority. Opportunities for harvesting and use of rainfall runoff should be discussed with the environmental regulator and local planning bodies to determine the extent to which measures might be appropriate or practicable on any site. Other "within curtilage" source control options (eg green roofs, soakaways, permeable pavements) and site management processes should be implemented as the first component in the SUDS management train.

Step 4: Divide site into subcatchments

For larger sites, the area to be drained should be divided into discrete subcatchments to enable local management of the runoff. By using source control for each sub-catchment, a large site can use the same drainage methods as an individual plot. If source control cannot be used, sub-catchments may have to be grouped together and the runoff managed at a site or regional level.

Step 5: Determine hydraulic and water quality design requirements (taking account of any benefits already accruing from Steps 2 & 3)

Initial source control and sub-catchment rainfall runoff management may mean that some of the hydraulic and water quality criteria have already been met.

Step 6: Identify feasibility of potential subcatchment/site source control options (eg infiltration trenches, infiltration swales, infiltration basins), using selection matrices (Tables 5.2, 5.4, 5.6, 5.8)

The following questions should be addressed:

1. Do subcatchment/site source control options require pre-treatment components?
2. Is subcatchment/site source control sufficient, or are additional downstream site controls required to meet criteria for all design events?
3. If subcatchment/site source control option feasibility is low, would alternative subcatchment/site controls be a preferred option?

Step 7: Identify feasibility of potential subcatchment/site detention/treatment options (eg detention basins, ponds, wetlands, filter trenches), using selection matrices (Tables 5.2, 5.4, 5.6, 5.8)

The following questions should be addressed:

1. Do subcatchment/site detention/treatment options require pre-treatment components?

2 Is subcatchment/site detention/treatment sufficient, or are additional downstream site controls required to meet criteria for all design events?

3 If subcatchment/site detention/treatment option feasibility is low, would alternative site/regional controls be a preferred option?

Step 8: Identify feasibility of potential site/regional control options (eg ponds, wetlands, basins etc), using selection matrices (Tables 5.2, 5.4, 5.6, 5.8)

The following questions should be addressed:

1 Do site/regional control options require pre-treatment components?

2 Is site/regional control sufficient, or are additional controls required to meet criteria for all design events?

Step 9: If there is more than one component in the treatment train, are additional conveyance components required to link techniques?

Are additional conveyance components required to manage overland flow for storm events in excess of design events?

Step 10: Identify feasibility of potential conveyance components (eg swales, infiltration / filter trenches, pipes, overland flood flow routes, wetland channels etc), using selection matrices

The following questions should be addressed:

1 Do conveyance components require pre-treatment?

2 Does the relative position of the drainage to roads, paths, driveways, street furniture, structures and public utilities impact on conveyance options?

Note: if the catchment contains piped surface water drainage, this should be considered in detail.

Step 11: Does the identified SUDS management train meet all hydraulic, water quality, amenity and ecological criteria set for the site?

If not, return to Step 6 and revise proposals.

5.5 REFERENCES

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Source control

6

Contents

Continued overleaf

Source control 6

6.1 INTRODUCTION

To reduce the impact of development on the natural hydrological state of a catchment, site design should aim to mimic the greenfield runoff response at source through the use of sustainable drainage and rainwater harvesting practices.

The inclusion of effective source control measures needs to begin with the site planning and design process. New development or re-development can be designed to reduce their impact on receiving watercourses through targeted conservation of natural areas, minimising the use of impervious surfaces, and optimum integration of stormwater treatment.

The goals of good site design should include:

- managing stormwater (quantity and quality) as close to source as possible
- preventing potential damaging impacts rather than mitigating them
- where possible, using simple, non-structural methods for runoff management (that are often lower cost and lower maintenance than structural controls).

The use of good site design for stormwater management can provide benefits including:

- reduced construction costs
- increased property values
- more open space
- more pedestrian-friendly developments
- more aesthetically pleasing and naturally attractive landscapes
- integration of biodiversity and habitat provision
- availability of rainwater for reuse.

Examples of relevant good site design practices and techniques relevant to source control are discussed in the following sections.

6.2 SITE DESIGN TECHNIQUES

6.2.1 Conservation of existing site features

A greenfield site contains natural features, including drainage networks – such as either ephemeral or perennial watercourses, depressions, floodplains, wetlands, vegetation, permeable areas, zones of high water table, and steep slopes. By identifying and integrating such features with the development, changes to the natural hydrological cycle can be minimised. Any undisturbed vegetated areas will promote soil stability, facilitate filtering and limit runoff through infiltration, interception and evapotranspiration.

New development should avoid floodplain areas in order to reduce the risks to human life and property damage, and to allow the natural stream corridor to accommodate flood flows and act as a wildlife corridor.

Porous soils, such as sands and gravels, provide opportunities for groundwater recharge of stormwater runoff and should, therefore, be utilised in the development of potential stormwater management options.

Creating unstable or easily erodible soils (including steep slopes) should be avoided due to the increased risk of erosion and sediment supply. Earthworks compaction gives rise to stable, high density soil with low permeability. This can significantly reduce infiltration and increase runoff, and such areas should be minimised wherever possible.

6.2.2 Site layout

The layout of roads and buildings on a site should follow natural landforms wherever possible. Natural drainage paths should be preserved by appropriate design of road layouts and buildings. Clearing and grading of the site should be kept to a minimum and filling or grading of natural depressions and ponding areas should be avoided. Open space should be maximised, and wherever possible, integrated with the drainage design.

6.2.3 Reduction of impervious surfaces

Impervious surfaces should be minimised as they prevent infiltration and increase runoff and pollutant loadings. Approaches to limiting impermeable surface areas include:

- reducing road lengths and widths
- minimising building footprints
- using green roofs
- locating buildings close to the main road network to minimise lengths of impervious access
- using grass swales for roadway drainage to encourage infiltration
- using porous pavements for driveways and parking areas
- placing footpaths on one side of the street only (if and where appropriate).

6.2.4 Structural measures

Source control practices are specific techniques that aim to manage the quantity and/or quality of the runoff at source. Structural measures include:

Quality only:

- physical structures (eg bunding of above ground oil or chemical storage tanks) (see Figure 6.1)
- containment or covering of runoff from stockpiles of soil and waste products
- containment of areas such as lorry washing or oil changing activities
- grass filter strips at the edge of car parks or carriageways.

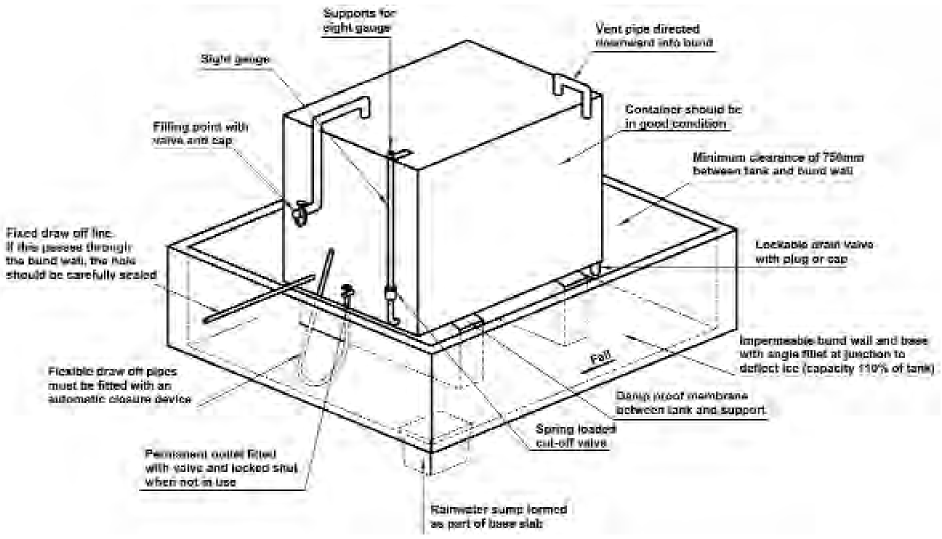


Figure 6.1 *Bunded oil tank*

Quantity and quality:

- green roofs
- soakaways
- infiltration trenches
- pervious surfaces
- bioretention
- appropriate rainwater harvesting systems.

Some UK sewerage undetakers allow customers to claim a reduction in their water charges where surface water runoff from their property does not drain into the sewerage network.

The following sections in this chapter address source control practices that are mainly concerned with the management, disposal and reuse of roof runoff (green roofs, soakaways and rainwater harvesting systems). Infiltration trenches, bioretention and pervious surfaces are covered in Chapters 9, 11 and 12 respectively.

6.3 SITE MANAGEMENT TECHNIQUES

Site management practices can make a significant contribution to minimising the urban pollutants that are washed off during rainfall. These include:

- frequent sweeping of impervious surfaces to reduce pollutant build-up
- minimising the application of de-icing products or use of alternative de-icing methods
- minimising the application of chemicals (eg fungicides) used on landscaped areas
- ensuring that adequate procedures are in place to deal quickly with spillage of materials using dry rather than wet techniques
- educating the public to reduce fertiliser application, minimise runoff from car or bin washing, and disposal of liquid waste to surface drains.

Green roofs 6.4

Description

Green roofs comprise a multi-layered system that covers the roof of a building or podium structure with vegetation cover/landscaping/permeable car parking, over a drainage layer. They are designed to intercept and retain precipitation, reducing the volume of runoff and attenuating peak flows.

KEY DESIGN CRITERIA

- design for interception storage
- minimum roof pitch of 1 in 80, maximum 1 in 3 (unless specific design features are included)
- structural roof strength must provide for the full additional load of saturated green roof elements
- hydraulic design should follow guidance in BSEN 12056-3 (BSI, 2000)
- multiple outlets to reduce risks from blockages
- lightweight soil medium and appropriate vegetation.

ADVANTAGES

- mimic predevelopment state of building footprint
- good removal capability of atmospherically deposited urban pollutants
- can be applied in high density developments
- can sometimes be retrofitted
- ecological, aesthetic and amenity benefits
- no additional land take
- improve air quality
- help retain higher humidity levels in city areas
- insulates buildings against temperature extremes
- reduces the expansion and contraction of roof membranes
- sound absorption.

DISADVANTAGES

- cost (compared to conventional runoff
- not appropriate for steep roofs
- opportunities for retrofitting may be limited by roof structure (strength, pitch etc)
- maintenance of roof vegetation
- any damage to waterproof membrane likely to be more critical since water is encouraged to remain on the roof.

PERFORMANCE

Peak flow reduction:	Medium
Volume reduction:	Medium
Water quality treatment:	Good
Amenity potential:	Good
Ecology potential:	Good

TREATMENT TRAIN SUITABILITY

Source control:	Yes
Conveyance:	No
Site system:	No
Regional system:	No

SITE SUITABILITY

Residential:	Yes
Commercial/industrial:	Yes
High density:	Yes
Retrofit:	Yes
Contaminated sites/sites above vulnerable groundwater	Yes

COST IMPLICATIONS

Land-take:	None
Capital cost: (depending on roof type and capacity)	Low-High
Maintenance burden:	Medium

POLLUTANT REMOVAL

Total suspended solids:	High
Nutrients:	Low
Heavy metals:	Medium

KEY MAINTENANCE REQUIREMENTS:

- irrigation during establishment of vegetation
- inspection for bare patches and replacement of plants
- litter removal (depending on setting and use).

6.4.1 General description

Green roofs can be used to reduce the volume and rate of runoff so that downstream SUDS and other drainage infrastructure can be reduced in size.

Typical green roof cross-sections are shown in Figure 6.2 (and discussed in detail in Section 6.2.4). It should be noted that root barriers tend to encourage root die-back, and can generally be avoided through the use of careful waterproofing and appropriate design.

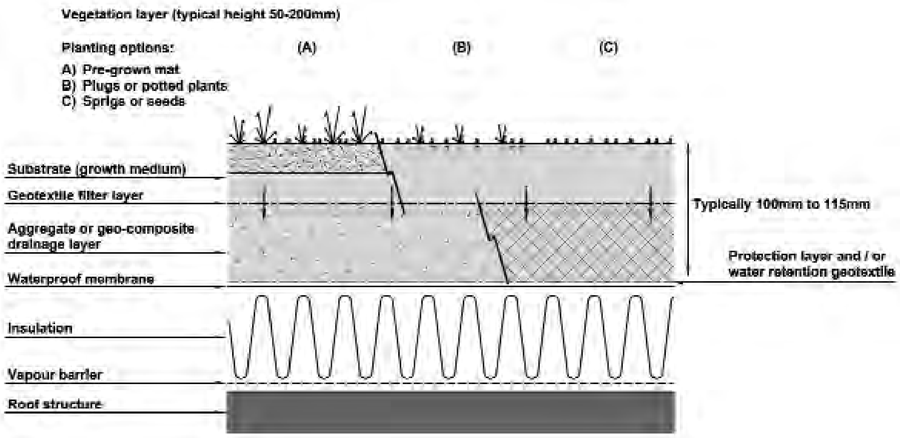


Figure 6.2 *Example details of a green roof (adapted from Tarr, 2002)*

There are three main types of green roof:

Extensive green roofs. These cover the entire roof area with low growing, low maintenance plants. They are only accessed for maintenance and can be flat or sloping. Extensive green roofs typically comprise a 25 mm to 125 mm thick growing medium in which a variety of hardy, drought tolerant, low-level plants are grown. Vegetation normally consists of mosses, succulents, herbs or grasses and is intended to be self-sustaining. They are lightweight and cost effective, and can be used in a wide variety of locations with minimal maintenance.

Intensive green roofs. These are landscaped environments with high amenity benefits, which include planters or trees and are usually accessible. They may also include water features and storage of rainwater for irrigation. Intensive roofs generally impose much greater loads on the roof structure and require significant ongoing maintenance.

Simple intensive green roofs. These are vegetated with lawns or ground covering plants. This vegetation requires regular maintenance, including irrigation, feeding and cutting. However, demands on building structures are moderate and the roof system will be less expensive. They are occasionally accessible, though more often designed to be overlooked.

There are also various combinations of green roof that combine both types in a single roof system. Extensive green roofs may be known as sedum roofs, eco-roofs, biodiverse, living roofs or vegetated roof covers; intensive roofs are also termed roof gardens. A comparison of the main differences between extensive and intensive green roof systems is given in Table 6.1. Another variety of alternative roofing system is termed a “brown” roof which incorporates a substrate (laid onto a flat roof, over a waterproof membrane) that is left to colonise naturally. Both green roofs and brown roofs are sometimes referred to as “alternative” roofs. Green roofs can be used on elevated buildings or at ground level above underground car parks or other subsurface structures (these are often called podium roofs).

Table 6.1 *Comparison of extensive and intensive green roof systems (edited from CMHC, 1998)*

Extensive green roof	Intensive green roof
Thin growing medium; little or no irrigation; Stressful conditions for plants; low plant diversity.	Deep soil; irrigation system; more favourable conditions for plants; high plant diversity; often designed for access.
Advantages: • lightweight; generally not requiring significant structural reinforcement • suitable for large areas • suitable for roofs with slope of up to 1 in 3 • low maintenance and long life • little or no need for irrigation and specialised drainage systems • less technical expertise required • often suitable for retrofits • vegetation self-management • relatively inexpensive • looks more natural • easier for planning authority to demand as a condition of planning • stormwater retention **Disadvantages:** • limited plant variety and ecological value • limited or negative aesthetic benefits (some people find such systems unattractive in winter).	**Advantages:** • greater diversity of plants and habitats • good insulation properties • can simulate a wildlife garden • can be made very attractive • often accessible, with opportunities for recreation and amenity benefits • high energy efficiency and good storm water retention capability. • longer membrane life. **Disadvantages:** • greater loading on roof structure • need for irrigation and drainage systems requiring energy, water, materials • higher capital & maintenance costs • frequent maintenance required • greater technical expertise required to implement and operate.

The successful design of a green roof will require collaboration between structural engineers, landscape architects, ecologists, horticulturists and drainage engineers. It also requires consideration of the maintenance that will be required. Access to undertake the construction and maintenance easily and safely is a high priority in design considerations. Additional, important design considerations include:

- the saturated weight of the system and the load bearing capacity of the underlying roof deck and structure
- imposed loads, including maintenance and snow cover
- the root penetration resistance of the waterproof membrane
- resistance to wind shear and negative (uplift) wind pressures
- management of drainage
- suitability of plant material.

Green roofs can be used to help achieve the targets set in biodiversity action plans by choosing appropriate layouts, designs and planting schemes that will provide the desired habitat for the species concerned. Compared to conventional roofing, the soil and vegetation on an alternative roof may reduce the risk of raised runoff temperatures. This is particularly important where the runoff is into water bodies that support salmonids.

6.4.2 Selection and siting of green roofs

Green roofs can be used on a variety of roof types and on any property size, although large areas of roof are generally more cost-effective. The following issues should be considered to ensure the suitability of green roofs at a particular site.

Table 6.2 *Considerations for using green roofs*

Space required	Green roofs put no additional space requirements on a development. They are, therefore, well suited to urban city centre settings where there is limited space for other techniques. Green roofs can be retrofitted easily providing there is sufficient structural capacity in the roof to support them. With careful choice of materials, lightweight systems can be designed to suit most buildings.
Siting	Green roofs are particularly suited for use on flat or gently sloping roofs on commercial buildings, sports centres, schools and other similar buildings. The environmental parameters at the location where a green roof is to be installed have to be considered in the design process. The height of the roof, its exposure to wind, the roof's orientation to the sun and shading by surrounding buildings during parts of the day will have an impact. The general climate of the area and the specific microclimate on the roof must also be considered. Views to and from the roof may also determine where certain elements are located for maximum effect.

6.4.3 Hydraulic and water quality design

Although green roofs absorb most of the rainfall that they receive during ordinary events, there is still the need to discharge excess water to the building's drainage system. This is because their hydraulic performance during extreme events tends to be fairly similar to standard roofs. The hydraulic design of green roof drainage should therefore follow the advice in BS EN 12056-3 (BSI, 2000) (although the standard relates to the design of normal roof drainage). Useful information is also provided in BS 6229: *Code of practice for flat roofs with continuously supported coverings* (BSI, 1982). Detailed guidelines for the planning, execution and upkeep of green roof sites have been developed in Germany by Forschungsgesellschaft Landschaftsentwicklung und Landschaftsbau (FLL, 2002)

Green roofs should attenuate storms up to a two-year return period event. Green roofs will contribute to attenuation of flows from larger storms and this should be taken into account when sizing downstream SUDS devices on a site where their hydraulic performance is known. Where snow accumulation is likely to be significant, snow melt will also require consideration in the roof drainage design.

Approximate water storage capacities of a range of green roof types are given in Figure 6.3. The maximum water capacity of vegetation substrates in their compacted or installed state is between 20 per cent by volume (for single-course construction, extensive roofs) to 45 per cent at intensive roof sites. In any case, the maximum water capacity should not exceed 65 per cent by volume in order to avoid waterlogging.

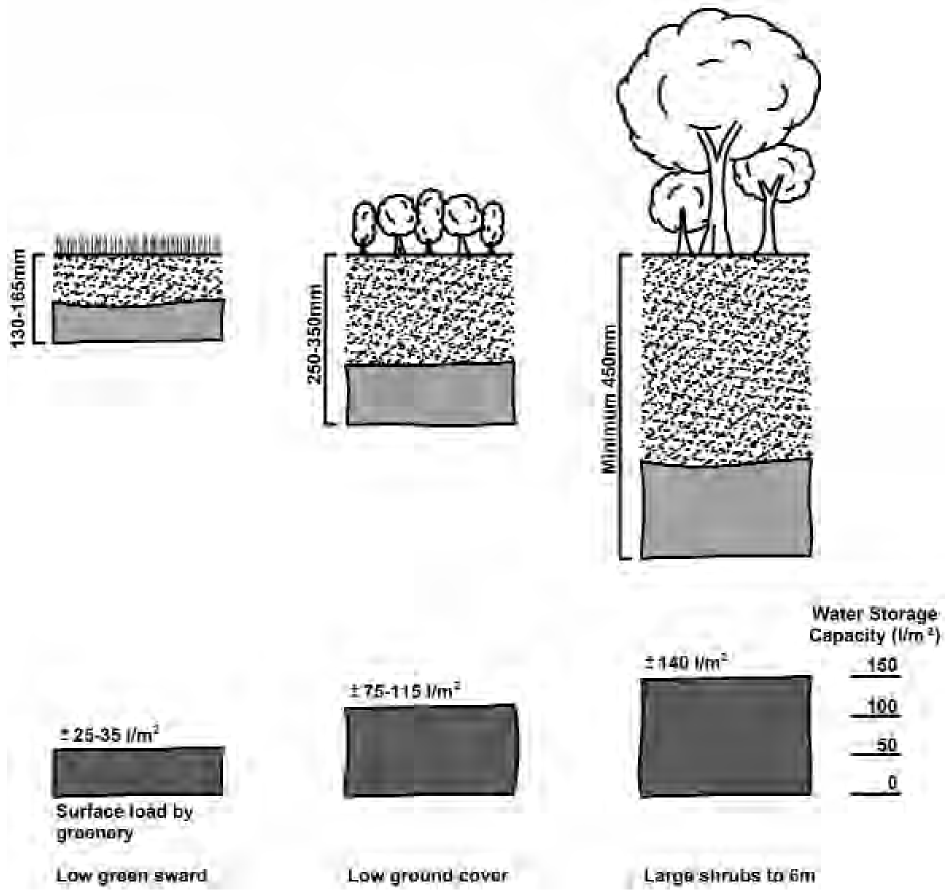


Figure 6.3 *Green roof water storage capacity (adapted from English Nature, 2003)*

6.4.4 Physical specifications

Fire resistance

The fire resistance of green roofs should be considered. All openings, vents etc should be protected or surrounded by non-vegetative materials such as pavers or other proprietary fire retardant products. The roofs must have adequate resistance to the external spread of fire as required by Building Regulation B4 (DTLR, 2002) or Standard 2.8 in Scotland (SSBA, 2004). To achieve this, a risk assessment should be undertaken, considering factors such as the organic content of the substrate, the vegetation type and the effects of these on the spread of fire (Wilson *et al*, 2004). German authorities only consider extensive roofs to be fire resistant if:

- the substrate/soil is >30 mm deep
- the substrate/soil contains less than 20% organic matter
- there is a 1 m wide gravel or slab fire break every 40 m
- travel strips are provided around all structures penetrating the roof (FLL, 2002).

Insulation

No additional insulation is required for the successful establishment of a green roof, but designers often use the roof as an opportunity to improve the thermal efficiency of the building. Green roofs may be "cold" where an air gap separates the membrane from the insulation beneath, or "warm" where insulation covers the waterproof layer.

Roof pitch

Good drainage is vital to the long-term performance of a flat roof. Water ponding on the roof surface or within the green roof construction on top of the water-proofing layer must be prevented. To ensure the minimum finished fall of 1 in 80 (recommended for flat roofs in BS 6229 (BSI, 1982)), falls should be designed to 1 in 40. Falls must be consistently graded, without deflections or depressions in which water may pond.

The construction effort and cost of green roofs tends to increase with roof pitch. For roofs steeper than 1 in 10, rapid runoff should be prevented by increasing the retention capacity of the substrate. For roofs steeper than 1 in 3, specific design advice should be sought to determine appropriate steps that are required to:

- prevent soil slippage and erosion
- provide additional support with cross battens
- provide a raised grid structure to secure the plant growing substrate.

Roof support

The additional load imposed on the underpinning roof structure varies with the type of green roof, but it is typically within a range of 0.7 to 5 kN/m^2. Intensive green roofs with trees together with an imposed "crowd" loading can impose loads of up to 10 kN/m^2. The distributed load should account for a saturated soil (and snow loadings, if appropriate), and live loadings should account for maintenance staff and equipment and visitors (if appropriate). Deeper planting beds can often be constructed over internal columns and walls where a higher overall loading capacity can be provided. The design of the supporting structure should only be undertaken by an experienced engineer.

Uplift pressures from wind are greatest at the corners of a roof and these may be designated as vegetation-free zones with pavers used to prevent damage. However, green roofs are no more vulnerable to this threat than conventional roofing. Trees may require shielding from the wind, or else anchoring. On tall buildings, higher wind speeds may increase water loss and/or damage plants through windburn, and may therefore prove a risk to the long-term survival or plant communities. Barriers (eg parapet walls) can be used to mitigate these effects.

Waterproofing

A high quality, robust waterproofing layer is required and is a vital component of the system. Two common types of membrane are:

1. Rubberised asphalt that is applied directly to roof as a hot liquid.
2. Single ply thermoplastic sheet membranes that are typically installed over a vapour barrier and insulating layer.

The water-proofing layer may need to be anchored to the roof to resist wind uplift forces if plastic sheeting is used. Waterproof membranes should be root resistant and should be adequately protected from temperature changes and mechanical damage to ensure that the integrity of the lower building fabric is retained. BS 6229 (BSI, 2003) should be referenced together with other relevant waterproofing specifications.

Care must be taken to ensure reliability of membranes, as repairs are difficult once the green roof is completed. It is therefore recommended that membranes are flood tested before the covering elements are installed.

The drainage layer

The drainage layer is located over the waterproofing layer and underlies the entire green roof. It keeps the growing medium aerated, holds some water for times of drought, and drains excess water. It connects to gutters and downpipes, typically via geocomposite/geocellular drainage systems that are lightweight and provide efficient drainage. The layer must have sufficient flow capacity to carry the necessary volume of water from the roof and to prevent ponding of water over the membrane. Flow capacity will depend on a number of factors, the principal ones being the hydraulic gradient and the confining pressure applied to the geocomposite. The relevant European Standards (BS EN 13252, BSI, 2001) require manufacturers of "geotextiles and geotextile related products" to declare the flow capacity at a hydraulic gradient of 1.0 (for green roofs, more appropriate gradients would be of the order of 0.01) and a confining pressure of 20 kPa (which is appropriate for green roof applications). Manufacturers should also be able to give the appropriate performance data for lower hydraulic gradients.

A shallow layer of gravel over a width of approximately 400 mm from the outside perimeter of the roof is recommended, providing additional drainage close to outlets, fire control and access to the roof for maintenance.

Geotextile filter layer

This prevents clogging of the drainage layer by separating it from the growth medium above. It should have zero breakthrough head (ie water discharges through it without building up on the upstream side) in order that it does not impede the passage of water. It is essential to mark the position of the roof outlets before installing the protection layer, so that they can be easily located and the filter layer cut accordingly. Reliable detailing at points where the filter layer is penetrated by eg pipework, and perimeter areas with durable protection is critical.

Soil/growth medium

This is kept as thin as the planting will allow. Typically 100 mm to 250 mm thickness is acceptable, although greater depths contribute to wind stability, offset high drying rates and protect the roots from frost damage. The depths appropriate for various types of vegetation are summarised in Table 6.3.

Low density soils with good water retention are required and mixtures of organic and mineral material (for example crushed pumice and expanded clay) are suitable. Appropriate materials need to be:

- water permeable
- water and air retentive
- resistant to rot, heat, frost and shrinkage
- high in nutrients
- a good rooting medium.

Normal topsoil is too heavy for use on green roof systems and the growth medium must be carefully formulated to provide for the oxygen, nutrient and moisture needs of plants. Detailed guidelines for the specification of soils for green roofs have been developed in Germany (FLL, 2002) and the specification for soil for use on extensive roofs is provided in Table 6.3.

Table 6.3 *Specification of soil cover for extensive roofs (FLL, 2002)*

Physical property	One layer system	Multi-layered system
Water retention	Min 20%	Min 35%
Water permeability	Min 60mm/min	Min 0.6mm/min
Air content (fully saturated)	Min 10%	Min 10%
Chemical property		
pH	6.5 to 9.5	6.5 to 8.0
Salt content of water extract	Max 1 g/l4 to 8% Max 80 mg/l Max 200 mg/l Max 700 mg/l Max 160 mg/l	
Initial organic matter content		
Nitrogen (N)		
Phosphorous (P_2O_5)		
Potassium (K_2O)		
Magnesium (Mg)		

Water storage/irrigation

Green roofs must be able to store water and not dry out too quickly. If this is not possible within the soil substrate, then additional forms of water storage (eg tanks or reservoirs), or irrigation may be necessary. Irrigation systems are not recommended due to the costs and resourcing associated with their implementation and management. If irrigation is required, base level irrigators that introduce water directly to the root zones via the drainage layer have the following advantages:

- roots are encouraged to grow down into the deepest part of the soil medium where temperature and moisture conditions are most stable
- a dry surface cover is maintained, thus discouraging the germination of weed seeds
- water losses due to evaporation are minimised.

Access

Stairways, perimeter barriers, safe paths and in some cases lighting and lifts, all built to the relevant standards, are required if the green roof is to be used by people. Full consideration must also be given to appropriate access required for maintenance.

6.4.5 Outlets

Multiple outlets should be provided to green roofs to minimise the risk of blockage which could have serious consequences. They should also be easily accessible for seasonal cleaning and in case of blockage. Detailed guidance on the capacity and location of rainwater gutters and outlets is given in BS 12056-3 (BSI, 2000). Rainwater outlets should accept runoff from both the drainage layer and the surface of the system.

Outlets should be separated from the growth medium as shown in Figure 6.4.

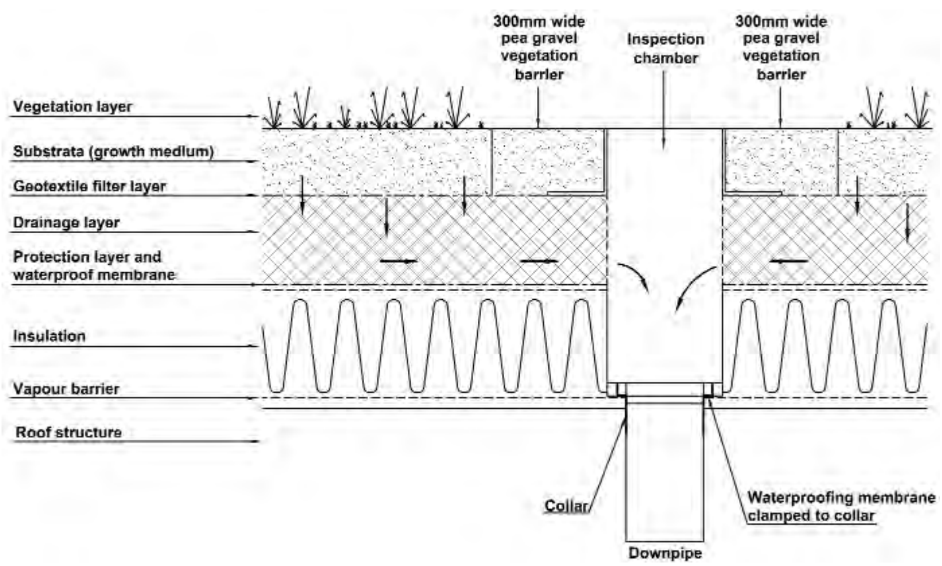


Figure 6.4 *Example detail of outlet from a green roof (adapted from Wilson* et al*, 2004)*

6.4.6 Landscaping and vegetation

The roof-top microclimate is a difficult environment for plants to survive, and the advice of a landscape architect or similar professional with experience of green roofs is essential. The vegetation has to deal with periodic rainfall alternating with hot and dry periods. Plants also have to contend with high winds and low winter temperatures (which is not ameliorated by the ambient heat stored in the ground).

To be able to survive vegetation should have the following attributes:

- perennial
- drought tolerant, requiring little or no irrigation after establishment
- preference for well-drained soils
- rapid colonisation
- self-sustaining, without the need for fertilisers, pesticides or herbicides
- ability to withstand heat, cold and high winds
- ability to tolerate poor soil and mildly acidic conditions
- low maintenance ie needing little or no mowing or pruning
- fire resistant.

The choice of plants also depends on the other layers in the roof design (and vice versa) and on sun and shade conditions. The plants chosen should be appropriate for the substrate used, its thickness and the environmental conditions. To meet these requirements, alpine or sub-alpine species are best suited to green roofs. Some sedum (*Sedum*) species are well adapted, as are sedge (*Carex*), fescue (*Festuca*) and feather grass (*Stipa*). Herbs, grasses, and other low ground covers may also be appropriate, however the advice of a specialist should be sought. In many cases there may be very good reasons to widen the range of plants, such as to improve water storage, enhance the aesthetics of the roof or encourage biodiversity. The use of a wider range of plants is dependent on other layers in the system and the accessibility or visibility of the roof. Suggestions for relevant plants with increasing depth of growth medium are given in Table 6.4.

Table 6.4 *Planting for green roofs (Dunnett, 2003)*

Depth of growth medium	Accessibility and visibility of roof			
	Inaccessible/not overlooked	Inaccessible/visible from a distance	Inaccessible/visible from a close distance	Accessible
0 to 50 mm	Simple sedum/moss communities.	Simple sedum/moss communities.	Simple sedum/moss communities.	Simple sedum/moss communities.
50 to 100 mm		Dry meadow communities/low growing drought tolerant perennials, grasses and alpines, small bulbs.	Dry meadow communities/low growing drought tolerant perennials, grasses and alpines, small bulbs.	Dry meadow communities/low growing drought tolerant perennials, grasses and alpines, small bulbs.
100 to 200 mm			Semi-extensive mixtures of low medium dry habitat perennials, grasses and annuals, small shrubs, lawn/turf grass.	Semi-extensive mixtures of low medium dry habitat perennials, grasses and annuals, hardy shrubs.
200 to 500 mm				Medium shrubs, edible plants, generalist perennials and grasses.
Greater than 500 mm				Small deciduous trees and conifers.

There are four basic methods of installing green roof vegetation:

- **Vegetation mats:** These are pre-germinated mats that provide immediate full plant coverage and erosion control. These have minimal weed problems, and require little maintenance or watering during the establishment period.
- **Plugs or potted plants:** These may provide more flexibility, but coverage takes longer, and erosion may be a risk. They will require watering and weeding during establishment.
- **Sprigs:** These have to be hand planted, and require weeding, erosion control and watering initially.
- **Seeds:** These have to be hand or machinery planted, and require weeding, erosion control and watering initially.

Intensive green roofs can be landscaped and managed to suit local aesthetic and community requirements. Extensive green roofs may not be universally welcomed as their appearance can be relatively untidy. In practice, green roofs in city centres are not obvious to most passers by, although they can be overlooked by high rise buildings. Use of green roofs in sub-urban areas tend to use pitched roofs which are more visible.

6.4.7 Operation and maintenance requirements

Intensive green roofs will require regular maintenance. Lawns will require mowing weekly or fortnightly, plant beds may require weeding on a weekly or fortnightly basis during the growing season, and wildflower meadows may require annual mowing with the cuttings removed. Extensive green roofs should normally only require bi-annual or annual visits to remove litter, check fire breaks and drains and, in some cases, remove unwanted colonising plants. The most maintenance is generally required in the first three years, and usually this should be made the responsibility of the green roof provider.

Operation and maintenance requirements for green roofs are described in Table 6.5.

Table 6.5 *Green roof operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Remove debris and litter to prevent clogging of inlet drains and interference with plant growth.	Six monthly/annually or as required.
	During establishment (ie year one), replace dead plants as required.	Monthly (but usually responsibility of manufacturer).
	Post establishment, replace dead plants as required.	Annually (in autumn).
	Remove fallen leaves and debris from deciduous plant foliage.	Six monthly or as required.
	Remove nuisance and invasive vegetation, including weeds.	Six monthly or as required.
	Mow grasses (if appropriate) as required. Clippings must be removed and not allowed to accumulate.	Six monthly or as required.
Occasional maintenance	-	-
Remedial actions	If erosion channels are evident, these should be stabilised with additional soil substrate similar to the original material. Sources of erosion damage must be identified and controlled.	As required.
	If drain inlet has settled, cracked or moved, investigate and repair as appropriate.	As required.
Monitoring	Inspect all components including soil substrate, vegetation, drains, irrigation systems (if applicable), membranes, and roof structure for proper operation, integrity of waterproofing and structural stability.	Annually/after severe storms.
	Inspect soil substrate for evidence of erosion channels and identify any sediment sources.	Annually/after severe storms.
	Inspect drain inlets to ensure unrestricted runoff from the drainage layer to the conveyance or roof drain system.	Annually/after severe storms.
	Inspect underside of roof for evidence of leakage	Annually/after severe storms.

If mechanical systems are located on the roof, then spill prevention measures must be exercised to ensure that roof runoff is not contaminated. The mechanical system area should be bunded and provided with separate drainage.

Training and guidance information on operating and maintaining the roof should be provided to all property owners and tenants. Safety fastenings will be required for personnel working on the roof.

Access routes to the roof should be designed and maintained to be safe and efficient and walkways should always be kept clear of obstructions.

Long-term maintenance responsibility for a green roof should always be placed with an appropriate organisation. Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken.

6.4.8 Construction

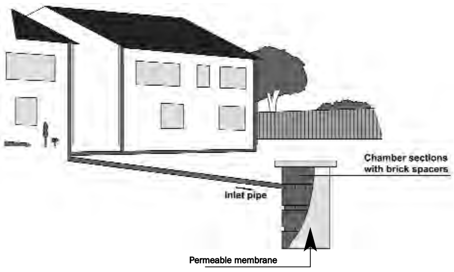
Correct application of the waterproof membrane is essential to the viability of the green roof. Quality control must be assured through the use of certified roofing procedures and a water test immediately following membrane application to ensure impermeability.

Temporary ballasting of individual components may be required during construction to prevent uplift due to wind.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Safe access is required for construction of the green roof, and also for all activities in areas beneath the roof. Ideally, in order to reduce the risk of damage, the roof should be installed when no follow-on trades need access to the roof after installation.

Additional information on construction and programming of construction activities is provided in Chapter 21.

Soakaways 6.5



Description

Soakaways are square or circular excavations, either filled with rubble or lined with brickwork, pre-cast concrete or polyethylene rings/perforated storage structures surrounded by granular backfill. They can be grouped and linked together to drain large areas including highways. The supporting structure and backfill can be substituted by modular, geocellular units (see Chapter 13). Soakaways provide stormwater attenuation, stormwater treatment and groundwater recharge.

KEY DESIGN CRITERIA

- design to meet site drainage standards – generally 1 in 10 or 1 in 30 year design event
- site infiltration rate assumed for design should be based on appropriate site investigations and should include an appropriate factor of safety
- appropriate pre-treatment is required
- if used, fill material should provide >30 per cent void space
- minimum distance of 1 m from the base to the seasonally high groundwater table
- minimum distance of 5 m from foundations.

ADVANTAGES

- minimal net land take
- provides groundwater recharge
- good volume reduction and peak flow attenuation
- good community acceptability
- easy to construct and operate
- can be retrofitted.

DISADVANTAGES

- not suitable for poor draining soils
- field investigations required to confirm infiltration rates
- not suitable for locations where infiltrating water may put structural foundations at risk, or where infiltrating water may adversely affect existing drainage patterns
- not appropriate for draining polluted runoff
- increased risk of groundwater pollution
- some uncertainty over long-term performance
- possible reduced performance during long wet periods
- where property owner responsible for operation and maintenance, performance difficult to guarantee.

PERFORMANCE

Peak flow reduction:	Good
Volume reduction:	Good
Water quality treatment:	Good
Amenity potential:	Poor
Ecology potential:	Poor

TREATMENT TRAIN SUITABILITY

Source control:	Yes
Conveyance:	No
Site system:	Yes
Regional system:	No

SITE SUITABILITY

Residential:	Yes
Commercial/industrial:	Yes
High density:	Yes
Retrofit:	Yes
Contaminated sites/sites above vulnerable groundwater	No

COST IMPLICATIONS

Land-take:	Low
Capital cost:	Low
Maintenance burden:	Low

POLLUTANT REMOVAL

Total suspended solids:	Medium
Nutrients:	Low
Heavy metals:	Medium

KEY MAINTENANCE REQUIREMENTS:

- removal of sediments/debris from pre-treatment device
- monitoring performance (using observation well).

6.5.1 General description

Soakaways are the most commonly used type of infiltration device in the UK. They store rapid runoff from a single house or from a development and allow its efficient infiltration into the surrounding soil. Drainage from individual properties are often connected to over-sized square or rectangular, rubble-filled voids sited beneath lawns without formal provision for access and inspection.

Where larger systems are required (eg for several buildings or commercial/highway areas), the device tends to be constructed of pre-formed polyethylene or pre-cast concrete rings of between 1 and 2.5 metres in diameter (or other suitable perforated void forming devices) that can be hollow, or filled with rubble, single-sized stone, or plastic high voids media. The hollow, or high voids fill, provides good storage capacity which allows the size of the structure to be minimised. Soakaways can reduce the volume of water that needs to be disposed of by downstream drainage and facilitates groundwater recharge. The time taken for stormwater to exfiltrate through the base and/or sides of the device will depend on the soakaway shape and size, and the infiltration characteristics of the surrounding soil. Modular, geocellular systems are described in detail in Chapter 13, and infiltration trenches, which are a linear soakaway with a high internal surface area are dealt with in Chapter 9.

In bypassing the upper soil layers and decreasing the distance to the water table, there is an increased risk of groundwater pollution. It is important that the source generates water with a low pollutant load or there is appropriate treatment in the system upstream of the soakaway. Depending on the characteristics of the sub-soil, pollution abatement will take place through processes of sedimentation, filtration, bio-degradation and volatilisation. Geotextile layers can also be used for additional trapping of stormwater particulates. Figure 6.5 shows the characteristics of a standard, lined soakaway and pre-treatment device for a typical larger system.

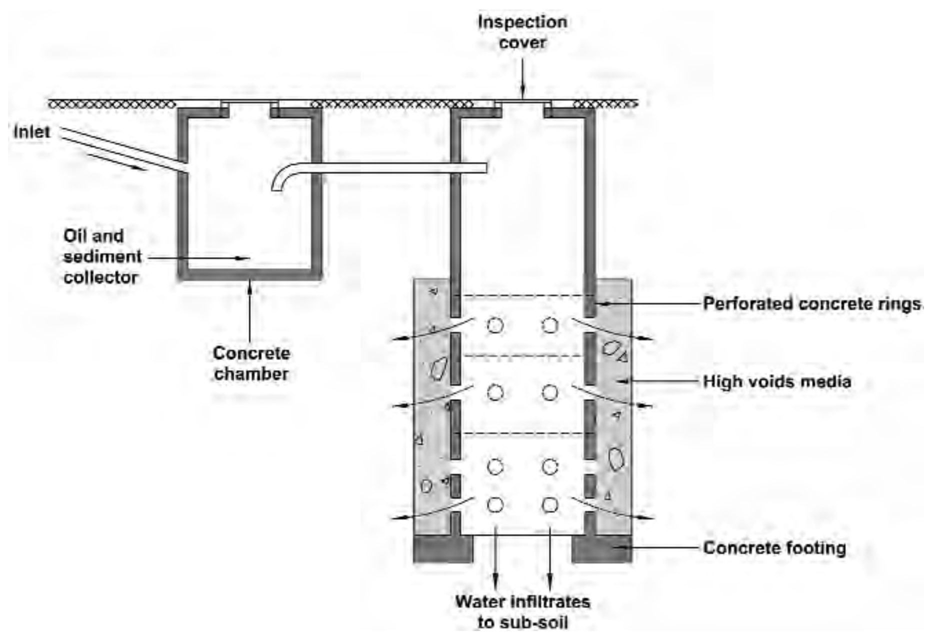


Figure 6.5 *Soakaway details (including a pre-treatment device)*

6.5.2 Selection and siting of soakaways

Soakaways are best-suited to the infiltration of stormwater runoff from small areas such as roofs of residential housing. Provided the runoff is appropriately pre-treated before entering the soakaway, the device can handle stormwater from any impervious residential and most commercial areas. In general, they are not suitable for draining runoff from pollution hotspots, and only pre-treated roof runoff should be considered for infiltration to sensitive groundwater resources.

The following issues should be considered to ensure the suitability of soakaways at a particular site.

Table 6.6 *Considerations for using soakaways*

Drainage area	Soakaways are often used to drain individual residential properties. However they can be applied as a single large unit or linked group of units to drain a group of houses. They may also be used to drain roads and parking areas (via linked soakaways or infiltration trenches), but greater care is needed to ensure that sediment and pollutant levels are reduced to acceptable levels before passing flow to the device. They can often be retrofitted into existing developments, for small areas such as private driveways and roof drainage. They can also be used to manage overflows from water butts and other rainwater collection systems.
Space required	As a sub-surface infiltration device, a soakaway requires no net land take. They can be built in many shapes and can often be accommodated within high-density urban developments.
Siting	Soakaways should not be used: • within 5 m of a building or road • in an area of unstable land without full consideration of the impact of the infiltrating water • in ground where the water table reaches a level within 1 m below the base of the soakaway at any time of the year • near any drainage field, drainage mound or other soakaway which would result in the overall soakage capacity of the ground being exceeded and the effectiveness of any drainage field impaired • where the risk of contamination in the runoff could result in pollution of groundwater. Soakaways should not be used to drain landscaped or similar areas due to risk of sediment blockage and clogging of the soils surrounding the device.
Site slope & stability	Soakaways should not be sited on unstable ground, and ground stability should be verified by assessing site soil and groundwater conditions. They should not be considered within or over waste fill materials, uncontrolled fill or non-engineered fill. On sloping sites, an assessment should also be made to ensure that infiltrating water will not cause raised groundwater levels and/or waterlogging of downhill areas, and that slopes are not made unstable.
Subsurface soils and groundwater	Where modular systems are designed for infiltration, the seasonally high groundwater table must be more than 1 m below the base of the facility and the design must comply with the environmental regulator's policy on infiltration and groundwater protection. Infiltration design methods are described in Chapter 4. In areas containing contaminated soils or contaminated groundwater, soakaways are not acceptable. Any excavation or earthmoving processes required must be assessed to ensure that mobilisation of contamination does not occur.

6.5.3 Hydraulic and water quality design

Soakaways should be designed to manage storms up to the standard of service required. This is generally the 1 in 10 or 1 in 30 year storm for a house, group of houses or commercial building. As discharge criteria from a development is usually based on a 100 year event, the performance of the soakaways under such conditions needs to be known. For ease of design, this may result in the soakaways being designed to the 100 year event. The impact of flooding in excess of the design event will need to be assessed and floodwater may need to be conveyed safely to downstream drainage components.

The soakaway should discharge from full to half-volume within 24 hours so that sufficient capacity is available to receive runoff from subsequent storms. The procedures outlined in Chapter 4 should be followed for the design of infiltration devices.

6.5.4 Physical specifications

Geometry

With adequate void support, soakaways can be designed to suit any available geometry. Deep soakaways (ie >4 m) will require approval by the environmental regulator.

Materials

Soakaways can be built as simple excavations that are backfilled with high voids media, or excavations supported by storage modules of pre-cast concrete or plastic with holes/perforations that maximise infiltration to the surrounding ground. If infiltration modules are used, these can remain hollow or be filled with high void space material.

Granular material can be separated from the surrounding soil through the use of a suitable geotextile to prevent migration of fines into the soakaway. The migration of fines can cause ground settlement around the soakaway and also cause risks of blockage. The top surface should be protected to prevent the ingress of backfill material during and after surface reinstatement. Characteristics of the geotextile should suit the surrounding soil particle size and permeability. The geotextile should be placed so that it can be cleaned or removed and replaced if it becomes blocked (ie not wrapped around the outside of ring units). Additional detail on suitable geotextile specifications is given in Appendix C.

Soakaways must be of sufficient strength to cater for the loads acting on them, especially where they are required to be traffic bearing.

Material sustainability principles are addressed in Section 3.6.

6.5.5 Design for maintenance and safety

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

Inspection of the soakaway should be possible. This can either be through an inspection well, where the internal space is filled, or through opening of a cover, where the internal space is left as a void. Inspection access should provide a clear view of the soakaway base (even if filled). For small, filled soakaways, a 225 mm perforated pipe is appropriate. The point of discharge of the drain to the soakaway should be visible, and the access should enable debris and sediments to be cleared from the pit. If pre-formed hollow space soakaways with covers are employed, the cover should either be lockable or only be accessible with special keys.

6.5.6 Pre-treatment/inlets

A sedimentation chamber or equivalent treatment device provided before the inlet to a soakaway will facilitate regular maintenance and reduce the risk of blockage.

6.5.7 Outlets

Overflow of excess stormwater can be via a piped outlet/overflow or through the top of the soakaway, if considered necessary. Provision should be made for storms in excess of the design event via overland flood routing or temporary local surface storage areas.

6.5.8 Landscaping and vegetation

Soakaways attract roots of plants that grow in their vicinity. This is, to a certain extent, an advantage as plant roots take up water from the facility and roots provide additional openings in the surrounding soil for water to infiltrate. However, too vigorous root intrusion into backfilled soakaways, especially from larger shrubs and trees, should be kept in check as they can fill a significant percentage of the void space of these devices and can cause structural damage.

6.5.9 Operation and maintenance requirements

The useful life and effective operation of a soakaway is related to the frequency of maintenance and the risk of sediment being introduced into the system. An easement should be considered where multiple properties discharge to a single soakaway, to ensure long-term access for maintenance purposes.

Operation and maintenance requirements for soakaways are described in Table 6.7.

Table 6.7 *Soakaway operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Remove sediment and debris from pre-treatment devices and floor of inspection tube or chamber.	Annually.
	Cleaning of gutters and any filters on downpipes.	Annually.
	Trimming any roots that may be causing blockages.	Annually (or as required).
Occasional maintenance	–	–
Remedial actions	Reconstruct soakaway and/or replace or clean void fill, if performance deteriorates or failure occurs.	As required.
	Replacement of clogged geotextile.	As required.
Monitoring	Inspect silt traps and note rate of sediment accumulation.	Monthly in the first year and then annually.
	Check soakaway to ensure emptying is occurring.	Annually.

Maintenance will usually be carried out manually, although a suction tanker can be used for sediment/debris removal for large systems or in public environments. If maintenance is not undertaken for long periods, deposits can become hard-packed and require considerable effort to remove.

Replacement of the void fill will be necessary if the device becomes blocked with silt. Monitoring will give information on changes in infiltration rate and provide a warning of potential failure in the long-term.

Roads and/or parking areas draining to soakaways should be regularly swept to prevent silt being washed off the surface. This will minimise the need for ongoing maintenance.

Maintenance responsibility should be placed with an appropriate organisation and maintenance schedules should be developed during the design phase. Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken.

6.5.10 Construction requirements

Soakaways should not be used for untreated drainage from construction sites, where runoff is likely to contain large amounts of silt, debris and other pollutants.

Perforated, pre-cast concrete ring soakaways should be installed within a square pit, with side dimensions about twice the selected ring diameter. The need to oversize the soakaway pit for purposes of 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 (BRE, 1991).

Some, otherwise permeable soils and soft rocks (eg chalk), can have their permeability significantly reduced by smearing of the surface during excavation, especially by mechanical diggers. It is recommended that the exposed surface of the soil is manually cleaned of any smearing before the geotextile and granular fill surrounding the chamber are installed.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Soakaways should always be constructed using safe construction methods. Additional information on construction and programming of construction activities is provided in Chapter 21.

Water butts 6.6

Description

Water butts are the most common means of harvesting rainwater for garden use. They are small, off-line storage devices that are designed to capture and store roof runoff. If stormwater management benefits are to be obtained, specific modification of these units is required. This chapter assumes the use of appropriately modified water butts.

KEY DESIGN CRITERIA

- overflow provision.

ADVANTAGES

- easy to construct, install and operate
- easy to retrofit
- inexpensive
- marginal stormwater management benefits
- provides water for non potable water uses, eg garden watering

DISADVANTAGES

- high risk of blockage of small throttles
- very limited water quality treatment benefits
- property owner responsible for operation and maintenance, therefore cannot be guaranteed

PERFORMANCE

Peak flow reduction:	Low
Volume reduction:	Low
Water quality treatment:	Low
Amenity potential:	Poor
Ecology potential:	Poor

TREATMENT TRAIN SUITABILITY

Source control:	Yes
Conveyance:	No
Site system:	No
Regional system:	No

SITE SUITABILITY

Residential:	Yes
Commercial/industrial:	Yes
High density:	Yes
Retrofit:	Yes
Contaminated sites/sites above vulnerable ground water	Yes

COST IMPLICATIONS

Land-take:	None
Capital cost:	Low
Maintenance burden:	Low

POLLUTANT REMOVAL

Total suspended solids:	Low
Nutrients:	Low
Heavy metals:	Low

KEY MAINTENANCE REQUIREMENTS:

- inspection of inlet and outlet for blockages
- silt and debris removal.

6.6.1 General description

In-curtilage storage includes techniques such as garden ponds, cisterns, rainwater tanks and water butts. Of these, water butts are the most widely applied and are normally off-the-shelf solutions. They are simple water conservation techniques that can contribute to sustainable water management for developed areas. Modifications to standard designs can provide some stormwater attenuation, however these are not commonly used or available. In general water butts do not provide water quality treatment.

A water butt collects rainwater runoff from roofs via an inlet that is connected to the roof down-pipe. The device is normally constructed from polyethylene, which is often sourced from recycled material. Water butts are manufactured in a wide variety of sizes and some models consist of inter-connectable units.

During wet periods, water butts are often full, resulting in little or no attenuation or reduction in outflow rates or volumes. However, water butts can be designed to attenuate runoff by using a throttled overflow system as shown in Figure 6.6.

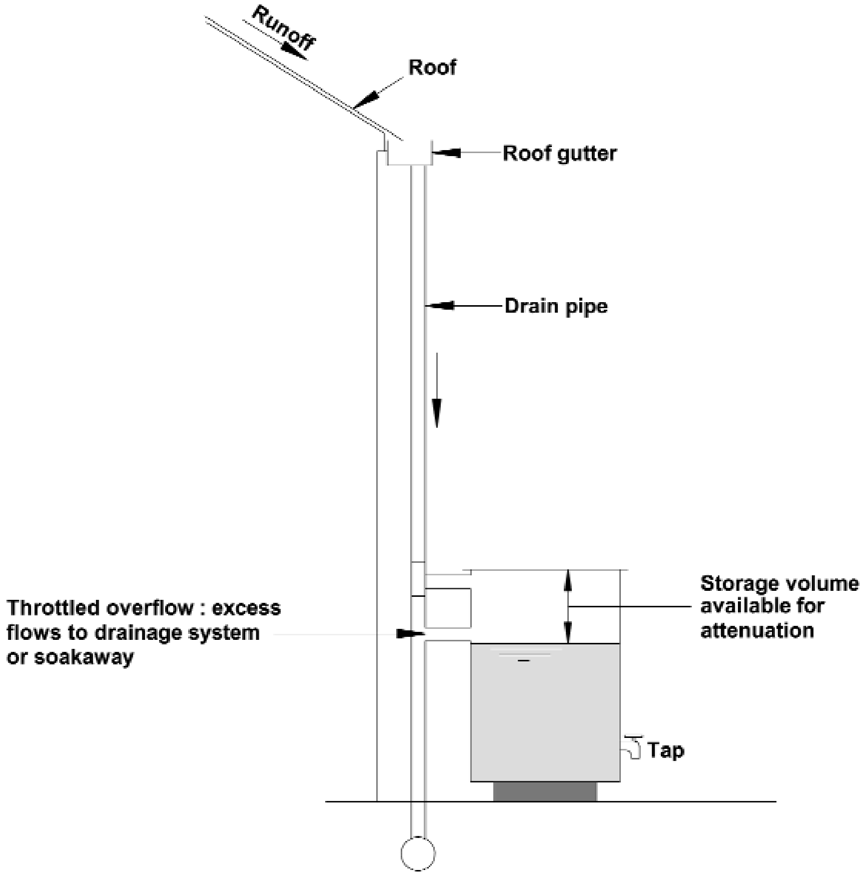


Figure 6.6 *Two-stage water butt schematic (designed for stormwater attenuation)*

6.6.2 Selection and siting of water butts

Water butts are best-suited to low and medium density residential housing, where rainwater is used for garden use on a regular basis. The following issues should be considered to ensure the suitability of water butts at a particular site.

Table 6.8 *Considerations for using water butts*

Drainage area	Their use is normally limited to roofs of individual residential properties and/or their ancillary buildings.
Space required	Individual water butt units require very little extra space and a 0.25 m^3 unit can be accommodated on 0.5 m^2 surface area.
Siting	The water butt should be placed as near as practical to the feeding roof downpipe. If the butt is placed on a stand, this facilitates the filling of watering cans.

6.6.3 Hydraulic and water quality design

Water butts are not generally designed to provide hydraulic benefits in terms of stormwater management. This is because the risks associated with their use and operation are too great to assume any significant storage is available for stormwater attenuation or volume reduction. If modifications to designs do allow attenuation during flood events then their contribution to stormwater management should be assessed and probably explicitly modelled as part of the site drainage system.

6.6.4 Physical specifications

Geometry

Water butts are usually relatively small devices, containing less than 0.5 m^3 of water.

Materials

Water butts should be durable and watertight and have a clean, smooth interior. Available tank materials include plastic, steel, concrete and fibreglass.

Material sustainability principles are presented in Section 3.6.

Design for maintenance and safety

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

A tight-fitting cover is essential to prevent insect breeding and to keep insects, rodents, birds and children from entering or falling into the tank. Water butts must have a firm base that is strong enough to withstand the weight of the full container and should be appropriately fixed to prevent it falling over. The water butt should be placed on a stand that is high enough to allow convenient water withdrawal. Water butts should be easily cleaned.

6.6.5 Pre-treatment/inlets

The inlet is normally through a water withdrawal valve from the roof downpipe. These should have a filter at the point of entry to keep out roof debris.

6.6.6 Outlets

Water butts need either an inlet valve that closes flow into the container when it is full, or an overflow arrangement that conveys excess stormwater away from the building without causing damage. Erosion protection measures for the overflow should be provided as necessary.

6.6.7 Operation and maintenance requirements

Water butts are low maintenance devices. The operation and maintenance requirements for water butts are described in Table 6.9.

Table 6.9 *Water butts operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Cleaning of tank, inlets, outlets, gutters, withdrawal devices and roof drain filters of silts and other debris.	Annually (or following poor performance).
Occasional maintenance	Replacement of any filters.	As required.
Remedial actions	Repair of erosion damage, or damage to tank.	As required.
Monitoring	Inspection of the tank for debris and sediment build up.	Annually (or following poor performance).
	Inspection of inlets, outlets and withdrawal devices.	Annually (or following poor performance).
	Inspection of areas receiving overflow, for evidence of erosion.	After extreme storms.
	Inspection of roof drain filters.	Annually (or following poor performance).

6.6.8 Construction requirements

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Water butts should be installed using safe construction methods, and manufacturers' guidelines should be followed in all cases.

Rainwater harvesting 6.7

Description

Rainwater from roofs and hard surfaces can be stored and used. If designed appropriately, the systems can also be used to reduce the rates and volumes of runoff.

KEY DESIGN CRITERIA

- design dependent on demand requirements, contributing surface area, stormwater management requirements, and seasonal rainfall characteristics
- first flush often diverted away from tank.

ADVANTAGES

- with careful design, can provide source control of stormwater runoff
- reduces demand on mains water.

DISADVANTAGES

- potential risks to public health
- systems can be complex and costly to install
- above ground tanks can be unsightly.

PERFORMANCE

Peak flow reduction:	High
Volume reduction:	High
Water quality treatment:	Poor
Amenity potential:	Poor
Ecology potential:	Poor

TREATMENT TRAIN SUITABILITY

Source control:	Yes
Conveyance:	No
Site system:	No
Regional system:	No

SITE SUITABILITY

Residential:	Yes
Commercial/Industrial:	Yes
High density:	Yes
Retrofit:	Yes
Contaminated sites/sites above vulnerable ground water	Yes

COST IMPLICATIONS

Land-take:	None
Capital cost:	High
Maintenance burden:	Medium

POLLUTANT REMOVAL

Total suspended solids:	High
Nutrients:	Low
Heavy metals:	Medium

KEY MAINTENANCE REQUIREMENTS:

- inspection and cleaning of collection systems, filters, throttle and valves, pumps.

6.7.1 General description

Rainwater from roofs and hard surfaces such as car parks can be stored and used in and around properties. The collected water can be used potentially for a range of non-potable purposes, such as flushing toilets, washing machines (which may require adaptation), and irrigation. Rainwater systems may be able to provide potable water, but this is likely to require sophisticated water treatment systems and monitoring to ensure compliance with the Private Water Supplies Regulations (DoE, 1991).

CIRIA publication *Rainwater and greywater use in buildings: best practice guidance,* C539 (Leggett *et al*, 2001) and the Environment Agency publication *Harvesting rainwater for domestic uses: an information guide* (EA, 2003) should be referred to for detail of components and for disinfection or physical/biological treatment requirements.

Typically, the stored water is held in off-line storage tanks and, where stormwater attenuation is important, the permanent storage volume required for reuse is provided in addition to the volume required to attenuate stormwater flows.

The three general concepts of rainwater harvesting systems are set out in Table 6.10.

Table 6.10 *Rainwater harvesting system types*

System type	System description
a) Direct system	Water runs off the roof through a coarse filter into the storage tank. The water is then pumped via a submersible pump direct to the applications in and around the building. If no rainwater is left in the tank, the mains water back up will supply mains water into the storage tank (switch point orientated external mains back up).
b) Gravity system	Water runs off the roof through a coarse filter into the storage tank. Then the water is pumped via a submersible pump into a header tank. From there the water is gravity fed to the applications. If no rainwater is left in the tank, the mains water back up will supply mains water into header tank (switch point orientated internal mains back).
c) Centralised system	Water runs off the roof through a coarse filter into the storage tank. The pump is located in the building. If there is need of water, it is sucked from the tank into the building and then supplied to the applications. If no rainwater is left in the tank, the mains water back up directly supply the mains water into the suction pipe of the pump. Most of the time the pump and the mains back up system are a single component.

Each system has different advantages and disadvantages in respect of operating safety, water efficiency, electrical efficiency, noise, easy maintenance, required space and supplied pressure to applications.

A conceptual rainwater harvesting system is presented in Figure 6.7.

Water use storage can be added on to other SUDS components, such as extra storage volume in a pond, storage under pervious pavements etc. Systems collecting runoff from the ground surface should incorporate a good filtration system or oil separator upstream of the rainwater tank.

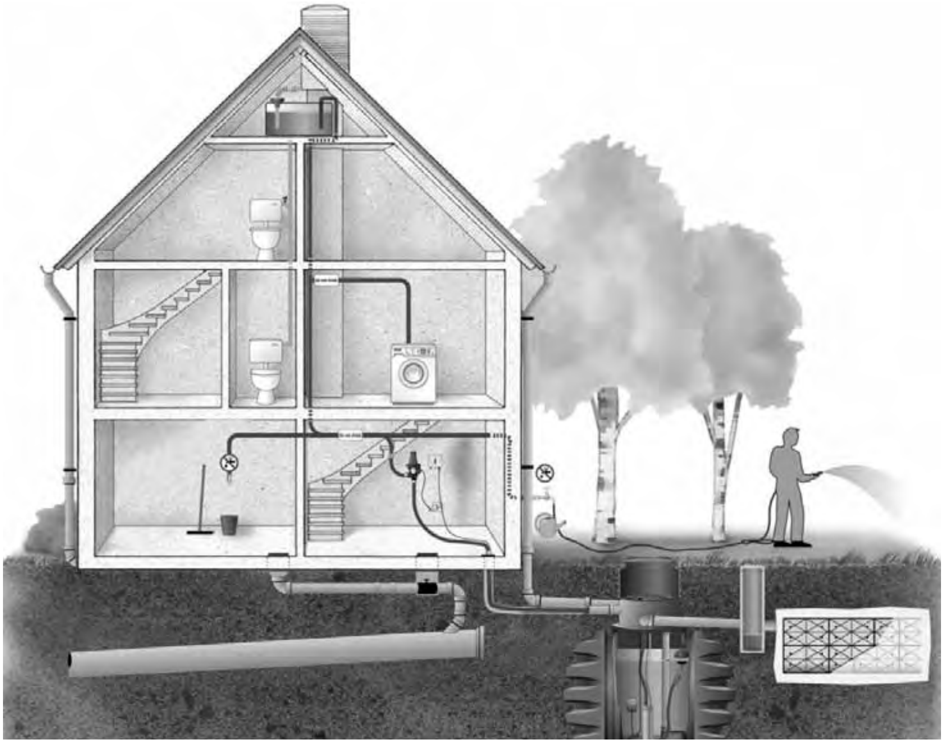


Figure 6.7 A conceptual rainwater harvesting system

6.7.2 Selection and siting of rainwater harvesting systems

Selection and siting of rainwater harvesting systems depends on local conditions and the intended use of the harvested rainwater. Water that is to be used for irrigation can be harvested from any surface, provided the runoff meets minimum water quality standards. If rainwater is to be used in buildings for purposes such as toilet flushing, washing, or in cooling systems, it needs to be of reasonably good quality, and runoff surfaces should be relatively free from debris and sediments.

The following issues should be considered to ensure the suitability of rainwater harvesting systems at a particular site.

Table 6.11 *Considerations for using rainwater harvesting systems*

Drainage area	The size of the surface area required depends on the volume of demand for rainwater reuse. It will also vary depending on the local seasonal rainfall characteristics.
Space required	Storage tanks for harvested rainwater can be underground structures that do not require surface space. Space requirements of surface tanks depend on their storage volume and design. Storage ponds require additional area to accommodate the demand for water, in addition to their stormwater attenuation volume.
Siting	Rainwater harvesting facilities should ideally be sited at or close to their catchment area and close to the place of the intended rainwater use. Technically they can be located almost anywhere in urban areas, for example on roofs, at the end of roof downpipes, under parking areas, beneath buildings, and as extra storage volume in ornamental ponds. Ideally a tank should be located in a place that will moderate water temperature, reducing bacterial growth in summer and frost damage in winter, eg underground.

6.7.3 Hydraulic and water quality design

The size of the storage tank for reuse purposes will be a function of the water demand together with the following factors:

- the catchment area
- the seasonal rainfall pattern
- the demand pattern
- the retention time (length of time the water will be stored in the tank)
- the cost.

The size of a storage tank to provide effective stormwater management as well as provision for reuse is dependent on the same factors, with additional storage provided based on the design storm to be served. An indicative volume for the stormwater component is 2 m^3 for a standard house. The effectiveness of the stormwater management will depend on all the factors above and therefore can only be assessed using a time series approach.

There is a need to provide an overflow to cater for excess inflows. In addition, a facility to flush out floating debris is useful.

The potential amount of rainwater that could be collected from a catchment area can be estimated using the method set out in Box 6.1:

Box 6.1 *Method to estimate annual collectable rainfall from rainwater harvesting device*

Annual collectable rainfall (l) = Average annual rainfall (mm) x total catchment area (m^2) x drainage coefficient x filter efficiency

Where:

Average annual rainfall = local meteorological data supplied by local Environment Agency or Meteorological Office.

Drainage coefficient = the proportion of the rainfall that runs off the catchment and reaches the collection tank. Light rainfall will only wet the roof and then evaporate; heavy rainfall can overflow from gutters and therefore be lost. The following figures are appropriate for use for different roof types:

Roof type	Drainage coefficient
Pitched roof, slate tiles	0.8
Flat roof	0.5
Flat roof, gravel	0.4
Extensive green roof *	0.3
Intensive green roof *	0.2

Filter efficiency = the proportion of the collected water that is available for use, following filtering. Most manufacturers recommend that a factor of 0.9 be used.

* *The use of green roofs and rainwater harvesting together can be challenging. This is due to both the hydraulic disadvantages as well as water quality issues of colour, sediment and bacteria.*

This formula will give an indication of the rainwater volume available for collection from a catchment area, which can then be compared with the estimated demand to establish the potential for water savings. However, there are many local factors that will influence actual water savings, such as the rainfall pattern and the pattern of demands.

A common rule of thumb for household water use is to size the tank at 5 per cent of the available rainwater supply, or of the annual demand, using the lower figure of the two.

In order to optimise the tank size for large systems, a more rigorous analysis is required using time series rainfall and a detailed knowledge of the seasonal water usage for the collected water.

There are four potential stages in the treatment of rainwater: pre-treatment, filtration, biological treatment and disinfection, as follows:

1. **Initial filtration (or pre-treatment)**
   This should remove debris, such as leaves, grit, moss and soil, which lead to degradation of water quality. Filters that do not require regular cleaning reduce maintenance and consumable costs.
2. **Filtration from the rainwater collection tank**
   Initial filtration is not a total barrier and it is good practice to filter water taken from the collection tank. (eg floating filters, cartridge filters, slow sand filters, rapid gravity filters etc).
3. **Biological treatment**
   The process uses naturally occurring bacteria to break down contaminants such as hydrocarbons, organic compounds, phosphates, nitrates and ammonia. This requires a medium "seeded" with these cleaning bacteria (eg permeable pavement gravel sub-base, reed bed treatment, membrane technology).
4. **Disinfection**
   Once the water has been filtered, it may require disinfection (physical or chemical) to kill off microbiological and bacterial activity. Systems that use rainwater solely for toilet flushing do not require this process.

In general, the water should be stored underground for the following reasons:

- the water will be cold, therefore hazardous bacteria should not develop
- cold water is able to store oxygen longer and therefore support (beneficial) aerobic development in the storage tank
- algal growth will be minimised due to the lack of sunlight.

If stored above ground or in a basement, the water should be kept cold and out of direct sunlight. CIRIA publication, C539 (Leggett et al, 2001) provides additional detail on treatment methods.

6.7.4 Physical specifications

Components

Rainwater systems are likely to include the components given in Table 6.12:

Table 6.12 *Rainwater system components*

Component	Description
Collection pipework	This delivers rainwater from sources (eg roof areas, hard-standings) to the collection tank or cistern.
Collection tank	This is where rainwater is stored before use. When the water in the tank reaches a certain level, an overflow trap allows floating materials to be skimmed off into the storm drain.
Treatment	Any treatment and disinfection devices required are dependent on the final use of the stored water. CIRIA publication C539 (CIRIA 2001) should be referred to.
Pump	Some rainwater systems store water collected from the roof at roof level and gravity feed this to the point of use. This means a pump is not necessary provided there is sufficient head of water. However, most rainwater and greywater systems use a collection tank below or at ground level and water is pumped into the building.
Cistern	The cistern provides temporary storage prior to domestic use. Backflow protection of the water supply mains is usually achieved at this location. The cistern should have a high level switch or other means to stop the collection tank pump when it is full, and a low level switch (or float valve) to enable makeup from the mains water supply when the collection tank is empty.
Distribution Pipework	This is required to link the different components listed above together.
Controls	Systems may be designed either with the operation controlled by mechanical float valves, or using electrical or electronic controls.

Materials

Most rainwater collection tanks are manufactured from plastics, but concrete, ferro cement, brick or steel could be used if they are protected against the corrosive effects of the stored water and any disinfectants used. The storage of rainwater does not have to be in a traditional tank; the void space in sub-base material of a permeable paving system or within geo-cellular modular units, encapsulated within a robust, weldable, geomembrane can also be used. Geotextile and geomembrane specifications are presented in Appendix C. Material sustainability principles are set out in Section 3.6.

Tanks must be designed to prevent ingress of groundwater. Underground tanks must be properly designed and installed to withstand groundwater, earth and/or backfill pressures, surcharge loads, vehicular loading and flotation.

Design for maintenance and safety

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

Tanks must be accessible for internal cleaning and maintenance and must be fitted with a close-fitting, removable cover to allow inspection. For additional requirements, see CIRIA publication C539 (Leggett *et al*, 2001) and C626 *Model agreements for rainwater and greywater systems* (Shaffer *et al*, 2004). All pumps should be fully maintainable.

6.7.5 Pre-treatment/inlets

When the runoff that is to be collected contains high sediment loads or is otherwise polluted, stormwater harvested water may only be viable for use with prior treatment.

Primary screening devices are used to prevent leaves and other debris from entering the tank. Typical devices are shown in Figure 6.8.

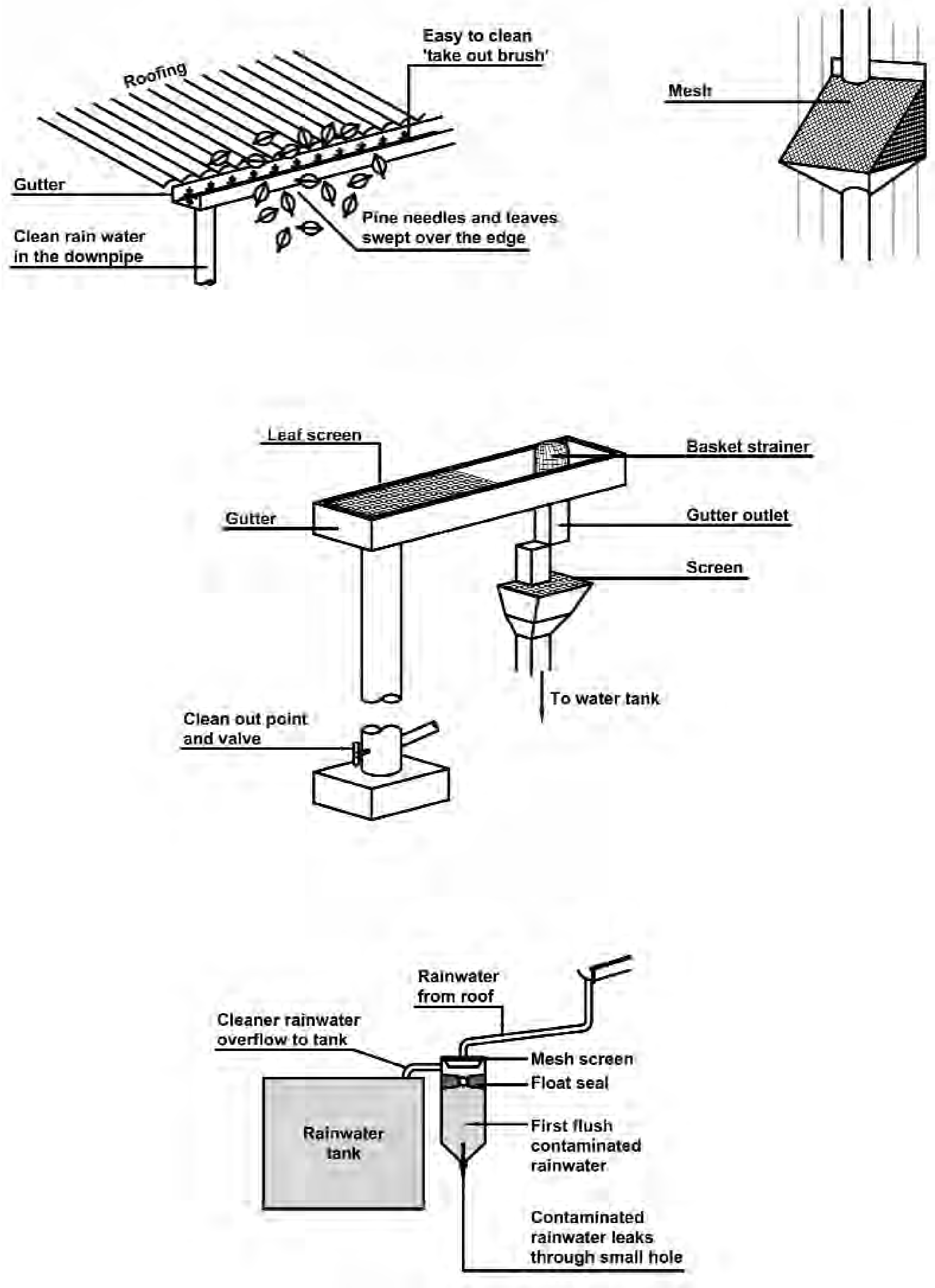


Figure 6.8 *Screening devices and first flush diversion*

Primary screening devices often have a wire mesh screen installed near the downspout. If there are trees nearby and leaves pose a problem, a leaf screen should be installed along the entire gutter length.

First flush devices are designed to divert the first part of the rainfall away from the main storage tank. The first flush picks up most of the dirt, debris, and contaminants (eg bird droppings) that collect on the roof. The system should therefore be designed so that at least the first 40 litres of roof runoff are diverted into a separate chamber for every 100 m^2 of roof area.

6.7.6 Operation and maintenance requirements

Rainwater systems should be designed so that use of the systems can be temporarily discontinued, for example if maintenance is required. Most systems require periodic checking and maintenance to ensure trouble-free and reliable operation. There are wide differences in the extent of maintenance required for different systems and manufacturer's guidelines should always be followed.

Table 6.13 *Rainwater harvesting for domestic use: operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Cleaning of tank, inlets, outlets, gutters, withdrawal devices and roof drain filters of silts and other debris.	Annually (or following poor performance).
Occasional maintenance	Replacement of any filters.	Three monthly.
Remedial actions	Repair of erosion damage, or damage to tank.	As required.
	Pump repairs.	As required.
Monitoring	Inspection of the tank for debris and sediment build up.	Annually (or following poor performance).
	Inspection of inlets, outlets and withdrawal devices.	Annually (or following poor performance).
	Inspection of areas receiving overflow, for evidence of erosion.	Annually (or following extreme events).
	Inspection of any pumps – check function and wiring.	Annually.
	Inspection of roof drain filters.	Annually (or following poor performance).

When buying a property, purchasers should be made aware that a rainwater system is installed. Maintenance and operational requirements must be made clear. This should preferably be in the form of a manual and system logbook, with initial instruction carried out in person. Such a manual and logbook should be incorporated into literature given to the new owner.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken.

6.7.7 Construction requirements

Care must be taken to avoid cross-connections, and pipe marking is essential (refer to Water Supply (Water Fittings) Regulations, DETR, 1999). Chapter 2 provides some material on legal issues and additional detail is provided in CIRIA C626 (Shaffer *et al*, 2004).

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Excavations for sub-surface storage tanks must be conducted safely and manufacturers' instructions for installation should always be followed.

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Pre-treatment

7

Contents

Pre-treatment

7

This chapter describes a range of pre-treatment devices that may be used to manage sediment and other debris upstream of SUDS components.

7.1 INTRODUCTION

The purpose of pre-treatment is to remove silt, sediment and debris from runoff before discharge to a downstream SUDS component. Pre-treatment options are intended to prevent clogging and reduce the need for maintenance of the downstream treatment facility. Easy access for maintenance equipment is required to remove the sediment that will be concentrated in the device.

If an appropriate SUDS management train is implemented for a site (see Sections 1.3.2 and 3.3.3), then source control or top of the train components should help fulfil the pre-treatment requirements of downstream systems. Wherever possible, sediment and debris should be managed in open, surface systems where build-up is obvious and removal is operationally simple. This reduces the risk of unseen blockages causing performance failure, particularly during extreme events. There are benefits to sediment treatment processes in their exposure to ultraviolet light and drying, which aid in breaking down pollutants. Dry silts and sediments are also considerably simpler to remove, as de-watering is not then required.

However, in some high density urban development locations where there is no alternative to sub-surface, piped systems, then more traditionally engineered silt trapping components may be required. Also, where amenity/aesthetic requirements mean that the build-up of sediments on the surface is unacceptable (eg for visual or possibly odour reasons), then collection in a small pond or forebay (ie below the water) may be the only option.

Pre-treatment is especially important for all infiltration practices. In order to ensure that pre-treatment mechanisms are as effective as possible, designs should ideally incorporate "multiple pre-treatment", using practices such as swales, sediment basins and filter strips in series upstream of the infiltration device.

Pre-treatment components may therefore take a range of forms, depending on catchment characteristics, the type of downstream system and the upstream drainage design. The most common types are listed in Table 7.1.

Table 7.1 *Pre-treatment components*

Pre-treatment component	Description
Vegetated buffers (filter strips)	These are vegetated strips of land over which flows are treated at low velocities. They are appropriate as pre-treatment devices for SUDS components receiving sheet flow from adjacent impervious areas, eg filter drains, swales, permeable pavements. Details of filter strips are provided in Chapter 8.
Dry swales	These are vegetated channels over which flows are treated at low velocities. They can be used as pre-treatment devices for SUDS components receiving point source inflows. Details of swales are provided in Chapter 10.

Table 7.1 *Pre-treatment components (continued)*

Pre-treatment component	Description
Detention basins	These remove settleable solids from runoff by gravitational processes. Runoff enters the basin via an energy dissipating inlet structure and is allowed to spread out. The water is then conveyed to the next treatment stage via a raised outlet pipe, or other conveyance method. Detention basins are also often used as temporary measures to minimise the escape of settleable solids from temporarily disturbed land such as construction sites or quarries. Details of detention basins are provided in Chapter 16.
Sediment sumps	These structures retain a permanent pool of water. They reduce flow velocities and allow larger particles to settle out, by gravitational separation. They may be located above or below ground and may be contained within the treatment facility or within a separate structure. Commonly used types of sediment sumps include forebays and sedimentation manholes. Details of these systems are given in Section 7.2.
Vortex separators	These structures promote settling and collection of sediments and other pollutants. With appropriate maintenance, they can demonstrate high removal rates for coarse material, but they do not remove fine particles. Details are given in Section 7.3 of this chapter.
Proprietary filtration systems	These systems filter water by passing it through various filter media. Their appropriateness and likely performance should be evaluated for site-specific applications. Maintenance requirements should be given full consideration in all circumstances. Details are given in Section 7.4 of this chapter.
Catch basin inserts	These systems can be inserted into standard curb or grate inlets and provide limited removal of sediments, debris, oil and grease from road runoff. Details are given in Section 7.5 of this chapter.
Oil separators	Oil/water separators are applicable for treating surface water runoff from areas where hydrocarbon products are handled (eg petrol stations, storage areas, lorry parks, airports etc), or where small oil spills regularly fall on paved surfaces exposed to rain. They require ongoing maintenance to ensure effective operation. Details are given in Section 7.6 of this chapter.

7.2 SEDIMENT SUMPS

Sediment sumps may be located above or below ground; they may be contained within the SUDS system, or stand as a separate structure. They should remove sediment from the stormwater runoff, must be easily maintainable, and must be safe to operate.

A sedimentation manhole is a manhole with an enlarged sediment sump that maintains a permanent water pool to promote settling of solids and to store settled sediments. It can also include a baffle to retain oils and floating debris. A typical schematic is shown in Figure 7.1. A sedimentation manhole will not achieve removal of dissolved pollutants or colloidal contaminants and fine silts and there tends to be a high potential for re-suspension of sediments. As a result, water quality treatment performance is limited. They may be appropriate as a cost-effective and simple solution to protection of downstream units where there is a high proportion of sands/coarse sediments in the study catchment.

Forebays are sumps contained within the same structure. The sedimentation cell is divided from the treatment cell by a berm, wall, or baffle. The dividing structure acts to retain sediment and to reduce and manage flow velocities and flow paths. Forebay details are provided in the individual SUDS component chapters, within the pre-treatment sections. Forebays constructed as part of the treatment cell should be sized for 10 per cent of the treatment volume. The system should have the capacity for the maximum flow delivered to the downstream system, unless appropriate flow diversion is provided upstream.

A staff gauge should be installed within a sediment sump to enable maintenance staff to determine the depth of accumulated sediment. All weather access for maintenance vehicles should be provided to the sump, to allow the required maintenance and monitoring activities to take place at all times.

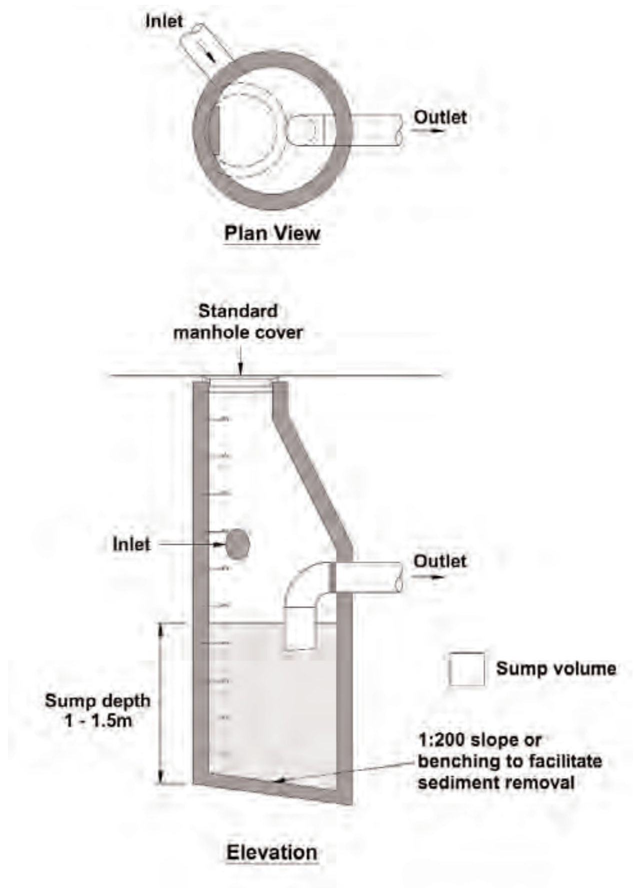


Figure 7.1 *Typical off-line sedimentation manhole*

7.3 HYDRODYNAMIC/VORTEX SEPARATORS

Hydrodynamic or vortex separators are vault structures, with a gravity settling or separation unit to remove sediments and other stormwater pollutants. The water moves in a centrifugal manner between inlet and outlet thus facilitating the sediment removal process within a small space. The centrifugal forces created by the circular motion cause suspended particles to move to the centre of the device where they settle to the bottom. They can either be designed to accommodate the full flow to be conveyed downstream, or can be installed downstream of a bypass structure, so that high flows are routed around the device. A possible layout is shown in Figure 7.2.

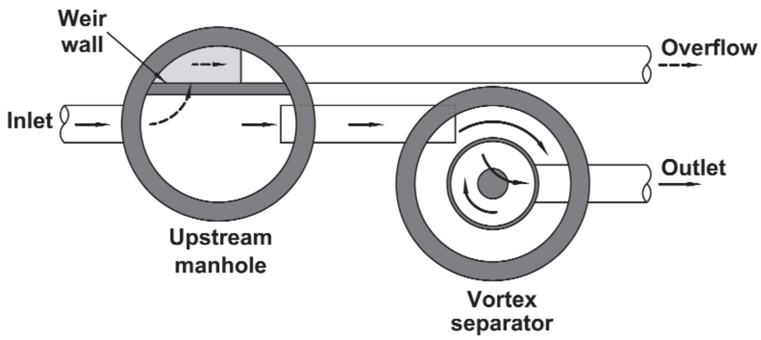


Figure 7.2 *Typical off-line layout for hydrodynamic separator unit*

Hydrodynamic separators are most effective where the materials to be removed from runoff are heavy particulates (which can be settled), or floatables (which can be captured), rather than solids with poor settleability, or dissolved pollutants.

If the facility is on-line, it should be sized to accommodate the peak flow of the maximum design event likely to be conveyed by the stormwater system. If the facility is off-line, it should be sized to accommodate the peak of the design water quality treatment storm event.

There are a wide variety of proprietary vortex separator units which vary considerably with respect to geometry, and the inclusion of radial baffles and internal circular chambers. In addition to the standard units, some manufacturers offer supplementary features to reduce the velocity of the flow entering the system (thus increasing the efficiency by allowing more sediment to settle out), reducing turbulence, or improving performance by the inclusion of static separator screens. The units are often prefabricated as a range of standard units, but they can often be customised for a specific site if required.

Hydrodynamic separators need regular maintenance to ensure continuing proper operation. They are usually hidden beneath the ground, and malfunctioning is not easy to detect and therefore often ignored. This can cause poor outflow water quality as a result of re-suspension of solids and anaerobic conditions developing within the device.

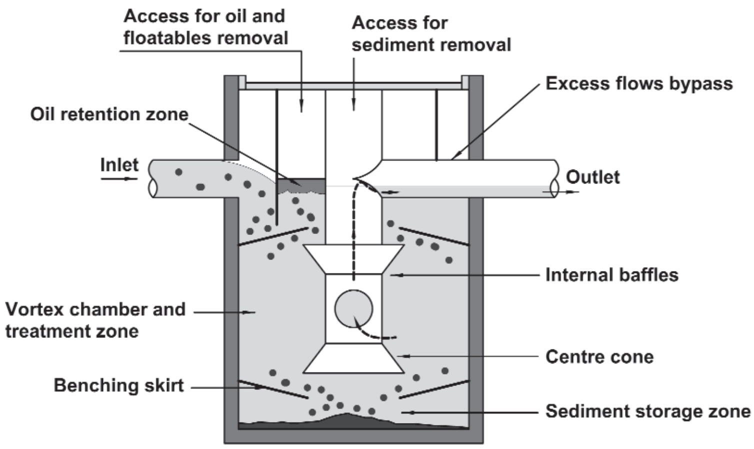


Figure 7.3 *Typical schematic of a hydrodynamic separator unit*

Hydrodynamic systems such as these typically consist of a standard concrete manhole with internal components made from either polypropylene or stainless steel. With regular maintenance, they should function effectively for a period in excess of 30 years.

7.4 PROPRIETARY FILTRATION SYSTEMS

Filtration systems for urban stormwater management evolved from conventional sand filter systems. During the early stages of development, a leaf compost medium was used in fixed beds, replacing sand. More recent systems usually hold filter media in cartridges and a wide array of filter media are available including leaf compost, pleated fabric, cellulose, activated charcoal, perlite, amended sand and perlite, and zeolite. Stormwater is routed through the filtering or sorbing medium, which traps particulates and/or soluble pollutants.

Filtration systems are offered by a variety of manufacturers and can be purchased as prefabricated standard units or custom-made to suit site conditions. Some of the techniques on the market combine vortex separation and on-line filtration in one system. Figure 7.4 shows a generalised schematic of a combined concentration/ filtration system.

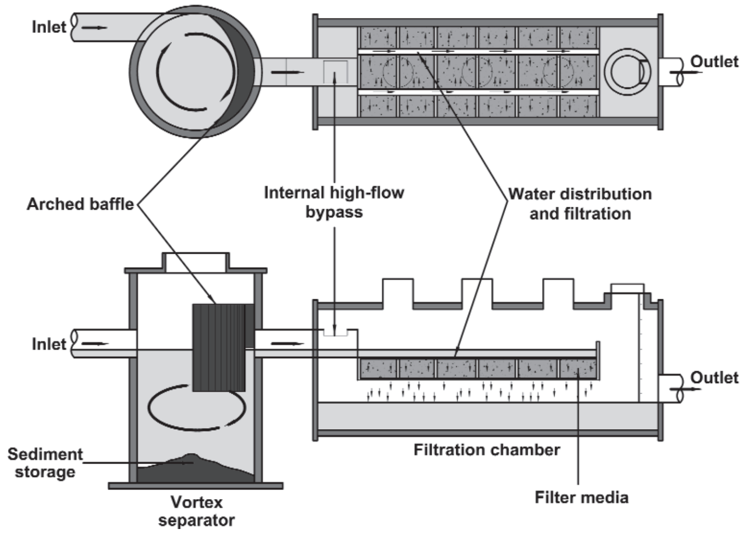


Figure 7.4 *Schematic of a vortex-enhanced sedimentation and media filtration system*

In the above system, the water quality treatment storm is treated within the filtration chamber. Less frequent events are treated in the vortex separator with the peak flow partially bypassing the filter media beneath the filter bed, so avoiding the need for external diversion chambers.

7.5 CATCH BASIN MODIFICATIONS

Modifications to conventional catch basin systems can provide some removal of sediments, floating debris, oil and grease from stormwater. They should not be used as standalone facilities, but should comprise the source control component within a SUDS treatment train. Systems can comprise one or more of the following:

- sump and baffle configurations that promote settling of sediments
- treatment systems that provide additional filtration by the inclusion of filter media within the catch pit (catch basin "inserts")
- infiltration surfaces.

A typical catch basin sump is shown in Figure 7.5.

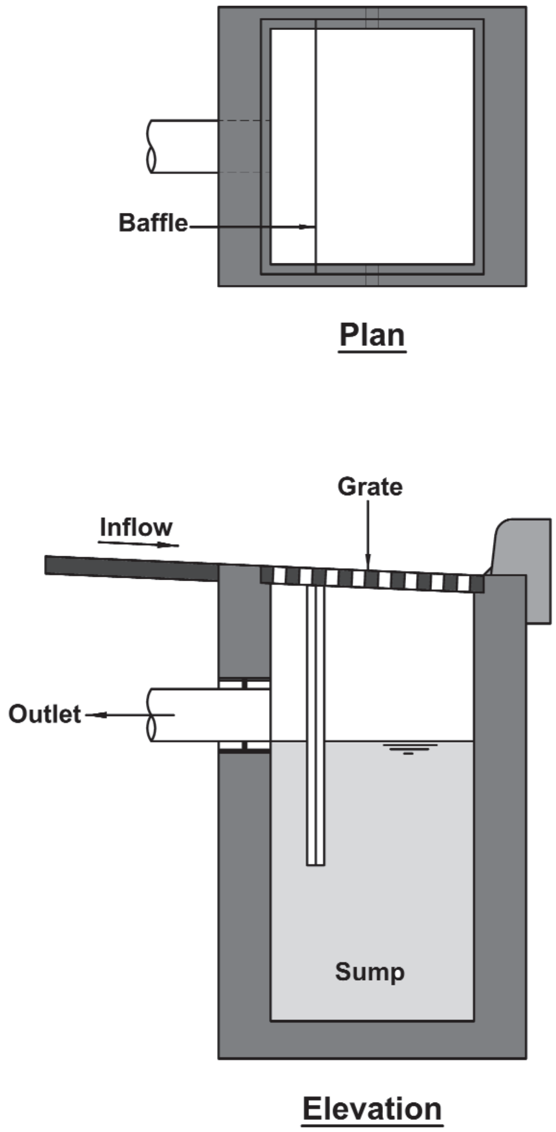


Figure 7.5 *Typical catch basin sump schematic*

Filter media can either be suspended within the catch pit from a drain-inlet frame or else inserted well below the drain inlet in the sump area. There are two basic types of catch basin inserts. One insert option consists of a series of trays, with the top tray serving as an initial sediment trap, and the underlying trays comprising media filters. Another option uses filter fabric to remove pollutants from stormwater runoff. These devices have a very small volume compared to the volume of the catch basin sump, and require very frequent sediment removal.

Catch basin inserts should be designed with a high-flow bypass to prevent re-suspension and washout. In some catchment basin inserts, the overflow outlet is not a true bypass because excess water still contacts the treatment area prior to overflow. In these catchment basin inserts, stormwater treatment may be compromised at higher flow rates due to the very short contact time and potential for flushing of previously trapped materials.

An adaptation of the standard catch basin is to incorporate infiltration through the catch basin bottom. Two challenges are associated with this design. The first is the potential groundwater impacts, and the second is the potential for clogging, preventing infiltration. Infiltrating catch basins should not be used in commercial or industrial areas, due to possible groundwater contamination. While it is difficult to prevent clogging at the bottom of the catch basin, it may be possible to incorporate some pre-treatment into the design.

As a general rule, catch basin inserts should be designed to perform acceptably for a design storm, for example the 2-year rainfall event, based on hydrologic characteristics and the degree of imperviousness of the site. They must not interfere with required drainage design for larger rainfall events and appropriate overflows must be included within any design. They are not appropriate for use on sites where sediment loads may put the hydraulic and water quality performance of the systems at risk (eg industrial sites, construction sites etc). Outlet from a catch basin insert is typically through holes or slots in the tray that is the filter or holds the filter media. The outflow drops normally into a conventional manhole or pipe from where it is ideally conveyed to the next treatment stage.

Catch basin inserts have good retrofit capability. The ease of retrofitting depends on the type of device to be fitted. Some systems may not be appropriate in areas where leaves and sand could cause a problem for maintenance. However, existing catch basins are typically designed to provide efficient removal of water from a roadway. Catch basin inserts containing filter media may have the potential, particularly in retrofit situations when not previously included in flow calculations, to slow water flow and reduce overall capacity. Therefore, revised hydraulic calculations may be required to check suitability.

7.6 OIL SEPARATORS

Oil/water (or gravity) separators are widely used to prevent hazardous chemical and petroleum products from entering watercourses and public sewers. They should be installed close to the potential pollution source to minimise emulsification of oils and/or their coating of sediments. A photograph of a typical oil/water separator is shown in Figure 7.6.

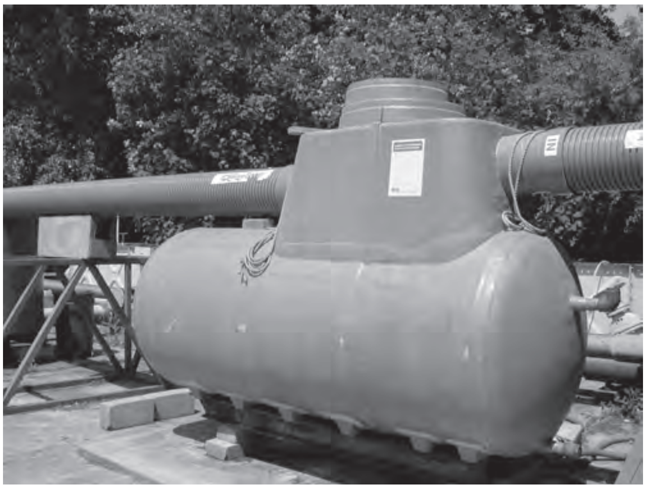


Figure 7.6 *A typical oil separator*

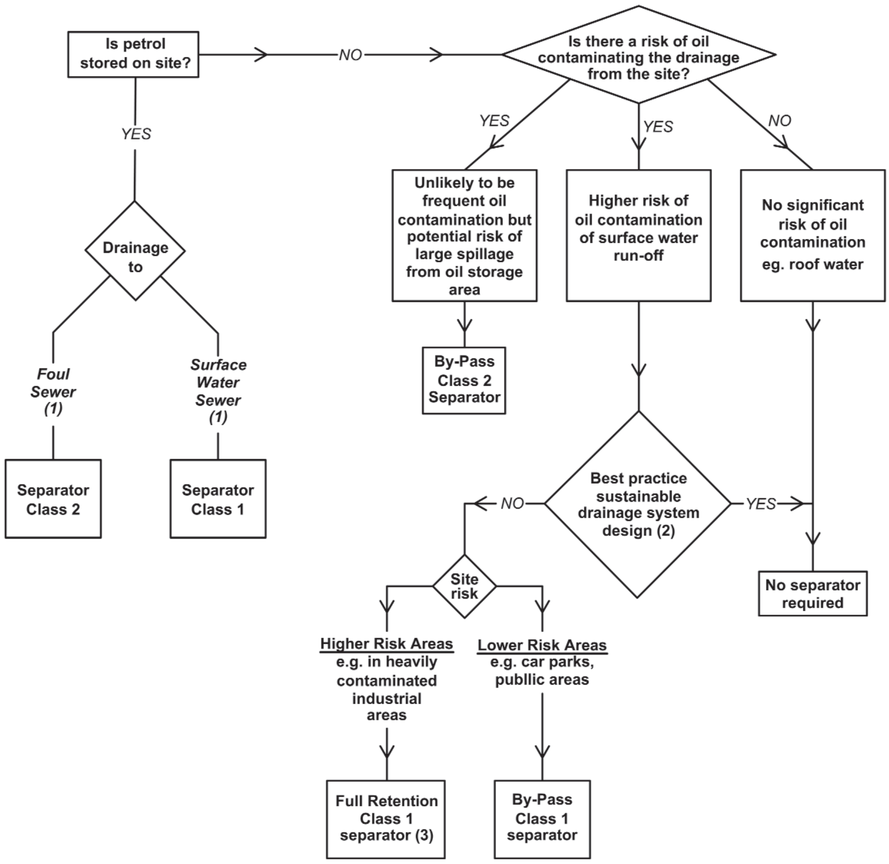
Separator designs are almost all based on the principal of separation by flotation. Globules of lower density oil or grease in clean non-turbulent water will, if given adequate time, rise by gravity. Once on the surface they can be effectively removed by skimming/pumping etc. Gravity separators cannot be used for the removal of dissolved or emulsified oils and pollutants such as coolants, soluble lubricants, glycols and alcohols. Since re-suspension of accumulated sediments is possible during heavy storm events, separator units are typically installed off-line.

Gravity separators are available as prefabricated proprietary systems from a number of different commercial vendors, but can also be built *in-situ*. The facilities should be designed in accordance with BS EN 858-1, *Separator systems for light liquids* (eg oil and petrol), Part 1: *Principles of product design, performance and testing, marking and quality control* (BSI, 2002). Guidance is also provided in the Pollution Prevention Guidelines (PPG) published by the Environment Agency/Scottish Environmental Protection Agency /EHS Northern Ireland (PPG 3, Use and design of oil separators in surface water drainage systems (EA/SEPA/EHSNI, 2006). The design criteria and specifications of a proprietary gravity separator unit should always be obtained from the manufacturer.

Compared to other SUDS, these facilities rely heavily on frequent routine maintenance to prevent pollution. They are usually hidden and pollution that is trapped in the system is not obvious and can contribute to the deterioration of downstream water quality if allowed to accumulate. This can be mitigated to some extent by the incorporation of automatic monitors, as required by the British Standard.

There are two classes of systems. A Class 1 device means the resultant effluent should contain 5 mg/l hydrocarbon content or less under standard test conditions. Class 2 devices can contain up to 100 mg/l in their discharge and are appropriate where drainage is to a foul sewer. It should be noted that these are the test requirements; in practice the effluent may not meet these standards.

There are two types of systems: full retention or bypass separators. A full retention unit is designed to treat all the incoming flows to the designated class. Bypass separators are limited in treating events up to a certain flow rate, after which flows are bypassed to the receiving drainage system. Guidance on the selection of oil separators is provided in Figure 7.7.



(1) Advice on appropriate drainage can be obtained from the environmental regulator.

(2) In certain high risk areas, a Class 2 Full Retention separator may be required.

(3) Specialised high performance equipment, such as plate type separators, may also be appropriate.

Figure 7.7 *Selection chart for light liquid separators (PPG 3, EA/SEP/EHSNI, 2006)*

Oil/water separators used in the drainage industry usually take the form of a chamber or number of chambers situated within a drainage system to collect hydrocarbon pollutants. The majority of *in-situ* separators are formed in concrete. Prefabricated units are generally manufactured in glass-reinforced plastic, steel or concrete. Systems must be watertight and designed to prevent floatation where there is a risk of high groundwater levels.

Oil separators are designed according to a specific flow rate, unlike most other structural controls, which are sized on the basis of capturing and treating a specific volume. The separation chamber should provide for three separate storage volumes:

1. A volume for separated oil storage at the top of the chamber.
2. A volume for settleable solids accumulation at the bottom of the chamber.
3. A volume required to give adequate on-line detention time for separation of oil and sediment from the stormwater.

A basic approach to sizing separators is set out in Box 7.1.

Box 7.1 *Approach to sizing separators*

Retention types are typically designed to contain sufficient volume to retain the inflow for a period of six minutes. The main exception to this is the case of a forecourt separator, which is designed to retain the maximum spillage likely at a filling station (7600 l which is equal to one compartment of a road tanker). The flow rate for a full retention separator is usually based on a rainfall intensity of 50 mm/hr and the nominal size (NS) required for a catchment area A (m^2) is obtained from the following equation:

NS = 0.018A

Bypass types are only designed to treat 10 per cent of the runoff, equivalent to 5 mm/hr. This is to capture the first flush pollutant load. Typically, a skimming device removes the heavily polluted runoff from the upper area of the inlet chamber transferring it to a secondary chamber for full treatment.

The nominal size, NSB, for a bypass separator = 0.0018A.

Both types of separator must have a capacity for silt storage, C (l) either as an integral part of the system or as a separate unit, sized according to:

C = 100 NS or 100 NSB

There is also a minimum acceptable oil storage volume V (l), and a requirement that all full retention separators be fitted with a closure device that will prevent through flow when this value is exceeded. The minimum volume, V (l) is:

V = 10NS or 15NSB

Figure 7.8 shows a schematic of a prefabricated single chamber, full retention, Class 1 separator.

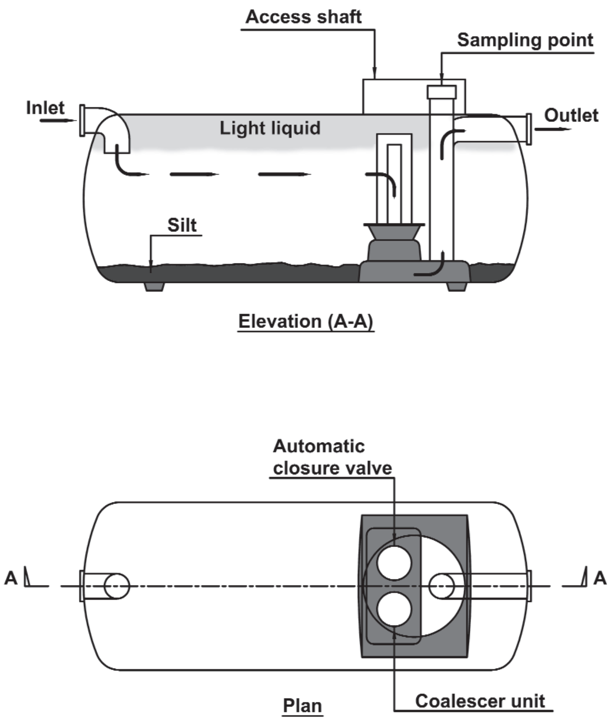


Figure 7.8 *Outline diagram of a prefabricated, single chamber, full retention, Class 1 separator*

Plate separators are alternative designs designed to induce laminar flow conditions through a series of parallel plates. They are generally designed to treat low flow rates only, but can achieve high efficiencies. The typical gravity separator unit may be enhanced with a pre-treatment vortex separation chamber, oil draw-off devices that continuously remove the accumulated light liquids, and flow control valves regulating the flow rate into the unit.

7.7 OPERATION AND MAINTENANCE REQUIREMENTS

Different pre-treatment devices will have different operation and maintenance requirements. However this section gives some generic guidance. Where proprietary systems are installed, maintenance requirements should be obtained from the manufacturer and followed at all times. Some manufacturers will also offer maintenance services. Ease of access for maintenance and inspection is essential. In particular, lids should be kept as lightweight as practicable.

A routine inspection programme should be established for each unit. This should be based on the volume or load of the contaminants of concern, the frequency of releases of contaminants, and the nature of the area being drained. During the first 30 days after installation, sub-surface pre-treatment units should be visually inspected after every rainfall event and the amount of deposition measured to give the operator an idea of the expected rate of sediment deposition. After this initial period, systems should be inspected at least every six months to verify the appropriate level of maintenance. During these inspections, the floating debris and solids should be removed and the sump cleaned out using a conventional sump vacuum cleaner. In most situations, the units should be cleaned out at least annually.

Litter picking at site should be frequent, as rubbish is detrimental to the operation of the facility and the appearance of the site. Frequent street sweeping in the catchment area of a filtration system increases the time interval in which the sedimentation facility has to be cleaned out and reduces the amount of fine suspended solids that can potentially clog the filter media.

Proper disposal of oil, solids and floating debris removed from pre-treatment components must be ensured, and the environmental regulator can offer advice where there are any doubts concerning disposal options. A small portion of water will be removed along with the pollutants during the clean-out process, which should be considered when costing sediment disposal processes. Further guidance on waste management is given in Chapter 23.

Harmful vapours may develop in sub-surface filtration or hydrodynamic separation units, as hydrocarbons may remain there for extended periods of time. Appropriate testing for harmful vapours and venting should be undertaken whenever access for maintenance is required.

Maintenance responsibility for all systems should be placed with an appropriate organisation, and maintenance plans and schedules should be developed during the design phase. Additional detail on the preparation of maintenance specifications and schedules of work is given in Chapter 22. Table 7.2 provides guidance on the type of operation and maintenance schedule that may be appropriate.

Table 7.2 *Pre-treatment systems: operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Removal of litter and debris.	6 monthly.
Occasional maintenance	Change of filter media.	As required.
	Removal of sediment, oil, grease and floatables.	As required.
Remedial actions	Replacement of malfunctioning parts.	As required.
Monitoring	Inspect for evidence of poor operation.	Six monthly.
	Inspect filter media and establish appropriate replacement frequencies.	Six monthly.
	Inspect sediment accumulation rates and establish appropriate removal frequencies.	Monthly during first half year of operation, then every six months.

For oil/water separators, the following items should be undertaken every six months as a minimum:

- check volume of sludge
- check thickness of light liquid
- check function of automatic closure device
- empty the separator if required
- check the coalescing material and clean or change if necessary (Class 1 only)
- check the function of the warning device (if fitted).

General inspection of oil/water separators should occur at a maximum frequency of five years, and should cover the following:

- watertightness of system
- structural condition
- internal coatings
- in-built parts
- electrical devices and installations
- checking of adjustment of automatic closure devices.

It is of key importance that the separator is filled with clean water before it is put into operation and each time after it is emptied for maintenance. Failure to do so will cause the separator to malfunction until stormwater builds up the required permanent water level in the facility. It is possible to fit an alarm to separators that will indicate when the collected oil volume is at a maximum, and this may be a regulatory requirement.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken.

7.8 CONSTRUCTION REQUIREMENTS

Where pre-treatment units are prefabricated, construction concerns generally relate to the following:

1. Compaction of foundations to ensure that uneven settling will not occur.
2. Quality control of foundation levels to ensure inflow and outflow pipes are at the correct elevation.

Particular attention should be paid to manufacturers' information in respect of backfilling and ballasting. Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

7.9 REFERENCES

BSI (British Standards Institution) (2002)
BS EN 858-1: Separator systems for light liquids (eg oil and petrol), Part 1: Principles of product design, performance and testing, marking and quality control.
BSI

EA/SEPA/EHSNI (2006)
Pollution Prevention Guidelines PPG 3. Use and design of oil separators in surface water drainage systems.
Environment Agency/Scottish Environmental Protection Agency/Environment and Heritage Service Northern Ireland
EA, Bristol

Filter strips

8

Contents

Filter strips

8

Description

Filter strips are vegetated strips of land designed to accept runoff as overland sheet flow from upstream development. They lie between a hard-surfaced area and a receiving stream, surface water collection, treatment or disposal system. They treat runoff by vegetative filtering, and promote settlement of particulate pollutants and infiltration.

KEY DESIGN CRITERIA

- recommended minimum width of 6 m
- runoff from an adjacent impervious area must be evenly distributed across the filter strip with a water depth <50 mm for the water quality treatment event
- slopes not exceeding 1in 20, minimum 1in 50.

ADVANTAGES

- well-suited to implementation adjacent to large impervious areas
- encourages evaporation and can promote infiltration
- easy to construct and low construction cost
- effective pre-treatment option
- easily integrated into landscaping and can be designed to provide aesthetic benefits.

DISADVANTAGES

- large land requirement
- not suitable for steep sites
- not suitable for draining hotspot runoff or for locations where risk of groundwater contamination, unless infiltration is prevented
- no significant attenuation or reduction of extreme event flows.

PERFORMANCE

Peak flow reduction:	Poor
Volume reduction:	Poor
Water quality treatment:	Medium
Amenity potential:	Medium
Ecology potential:	Medium

TREATMENT TRAIN SUITABILITY

Source control:	Yes
Conveyance:	No
Site system:	Yes
Regional system:	No

SITE SUITABILITY

Residential:	Yes
Commercial/industrial:	Yes
High density:	Yes
Retrofit:	Yes
Contaminated sites/sites above vulnerable groundwater (unless infiltration prevented)	No

COST IMPLICATIONS

Land-take:	High
Capital cost:	Low
Maintenance burden:	Low

POLLUTANT REMOVAL

Total suspended solids:	Medium
Nutrients:	Low
Heavy metals:	Medium

KEY MAINTENANCE REQUIREMENTS:

- litter/debris removal
- mowing
- repair of eroded or damaged areas.

8.1 GENERAL DESCRIPTION

Filter strips are uniformly graded and gently sloping strips of grass or other dense vegetation designed to treat the water quality event from adjacent impermeable areas through vegetative filtering and infiltration (where appropriate). The runoff is designed to flow as a sheet across the filter strip at a sufficiently low velocity that sediment is filtered out, together with associated pollutants. They are often used as a pre-treatment technique before other SUDS techniques (eg swales, infiltration and filter trenches) to extend the life of downstream components.

Under low to moderate velocities, filter strips effectively reduce particulate pollutant levels by removing sediments, organic materials and trace metals. Settling-out of sediment that contains clay particles removes sorbed nutrients and other pollutants. Some removal of free soluble pollutants in filter strips is accomplished when pollutants infiltrate into the soil, some of which are subsequently taken up by rooted vegetation. The extent of infiltration tends to be limited during intense storms as only a small proportion of the runoff is lost, but it is the dominant mechanism for small rainfall events.

Figure 8.1 provides example plan view and profile schematics for the design of a filter strip.

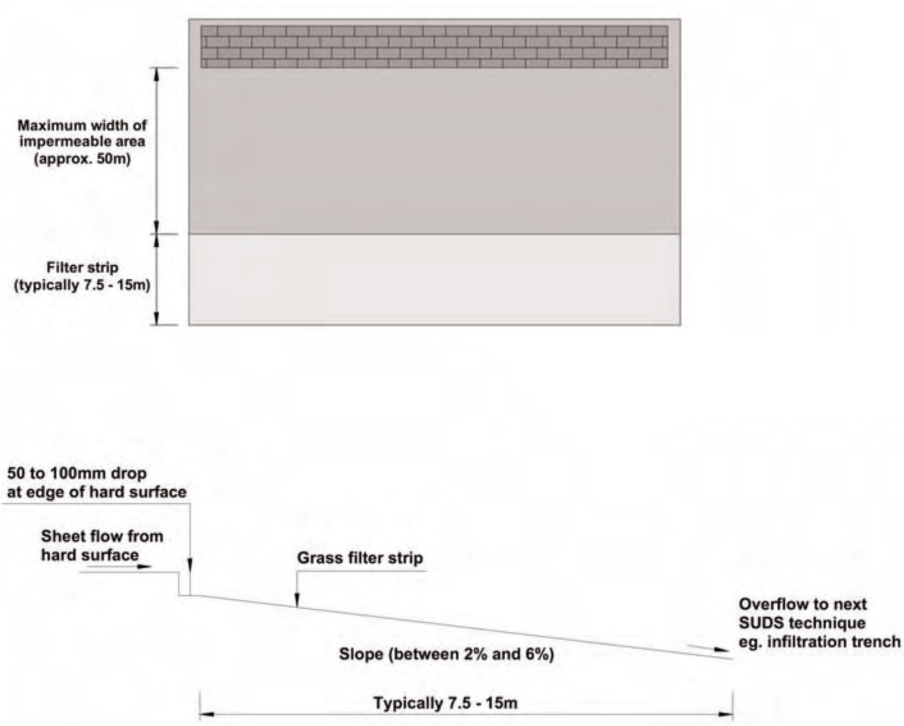


Figure 8.1 *Plan view and elevation of filter strip (adapted from Wilson* et al*, 2004)*

8.2 SELECTION AND SITING OF FILTER STRIPS

Filter strips are best suited to treating runoff from relatively small drainage areas such as roads and highways, roof downspouts, small car parks, and pervious surfaces. Filter strips can serve as a buffer between incompatible land uses, and can provide locations for groundwater recharge in areas with pervious soils.

The criteria presented in Table 8.1 should be evaluated to ensure the suitability of a filter strip for meeting drainage objectives at a particular site.

Table 8.1 *Considerations for using filter strips*

Drainage area	The maximum "length" of impervious area draining to filter strips should be controlled to reduce the risk of sheet flows changing to concentrated flows, although this will also be dependent on the slope of the impermeable area and on the effectiveness of adopted flow spreading techniques. A maximum length of drainage area length of 50 m is suggested.
Space required	It is recommended that there should be at least 1 m width of filter strip for every 6 m "length" of drainage area. Widths of between 6 and 15 m are known to be effective in terms of water quality performance, however the slope of the strip and density of vegetation are also important factors.
Siting	A filter strip should be sited next to and alongside its drainage area. Filter strips should be integrated with the overall site design and landscaping. However they are not suitable where pedestrian traffic is expected.
Site slope and stability	Care must be taken that site gradients do not exceed 1 in 20 to prevent erosion, and channelling flows across the filter strip.
Subsurface soils and groundwater	The topsoil on which the filter strip is built should drain well and must be suitable for supporting the growth of dense vegetation, preferably grass. Filter strips should not be used to drain hotspot runoff if soils are permeable and groundwater may be put at risk.

8.3 HYDRAULIC AND WATER QUALITY DESIGN

To achieve optimum pollutant removal levels, flows for the water quality design storm should be lower than the height of the vegetation and should be limited to approximately 50 mm depth to maintain filtration. It is suggested that the 1 year, 30 minute event is taken as representative of an appropriate water quality treatment event.

Maximum flow velocities of 0.3 m/s are recommended to promote settlement, and 1.5 m/s to prevent erosion during extreme flows. Manning's equation can be used to design the filter strip, as given in Box 8.1.

Box 8.1 *Manning's equation for filter strip design*

$$V = \frac{d^{2/3} S^{1/2}}{n}$$

V = mean cross-sectional flow velocity (m/s)
d = depth of flow (m)
S = longitudinal slope of filter strip (i.e. in the direction of flow) (m/m)
n = Manning's n roughness coefficient ($m^{-1/3}s$)

Appropriate guidance values for Manning's "n" are 0.25 for flows below or at grass level, and 0.1 for above-grass flows.

8.4 PHYSICAL SPECIFICATIONS

Filter strip designs should be specific to the particular location. Their form and aesthetic appearance will depend upon specific site characteristics and development design criteria. However, there are a number of criteria that should be observed for optimum pollutant removal, ease of maintenance and good safety practice.

Geometry

Filter strips should be designed with a minimum longitudinal slope (ie slope along the direction of flow) of 1 in 50 (to prevent ponding) and a maximum slope of 1 in 20 to prevent flow channelling. The top and bottom of the slope should be at the lower end of the allowable slope range to reduce flow velocities and thereby reduce the risk of erosion. The maximum berm height should be 0.3 m.

The filter strip should extend the entire length of the area that is being drained.

Design for maintenance and safety

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

Materials

If a berm is to be constructed at the toe of the filter strip:

(a) The berm material should be of sand, gravel and sandy loam to encourage grass cover.

(b) The crest of the berm should be protected against erosion during overtopping in extreme events.

Geotextile/geomembrane specifications are presented in Appendix C. Material sustainability principles are set out in Section 3.6.

8.5 PRE-TREATMENT/INLETS

A level spreading device should be included upstream of the filter strip to ensure consistent lateral inflow along the length of the device. Level spreading options include porous pavement strips, stabilised turf strips, slotted curbing, rock-filled trenches, and concrete sills. There should be a drop of at least 50 mm from the pavement edge to the filter strip to prevent the formation of a sediment lip. All pre-treatment/level spreading devices should be designed with maintenance considerations in mind.

8.6 OUTLETS

The slope at the outlet should be at the lower end of the allowable slope range to reduce flow velocities and reduce the risk of erosion.

In most situations, the outflow from the filter strip should be routed into a downstream SUDS component for attenuation and additional treatment.

8.7 LANDSCAPING AND VEGETATION

Filter strips can provide green links between developments and the surrounding landscape. They are particularly applicable at the edges of car parks. In such a location, consideration should be given to installing a low-level, inconspicuous barrier to prevent unauthorised vehicular access onto the filter strip. This should not, however, impede sheet flow over the strip. Trees, bollards, crash barriers, slotted kerbs, or intermittently spaced boulders could be considered.

Landscaping and layout of the filter strip and its adjacent area should be such that pedestrians and pets are kept to a minimum. The location of filter strips should be well defined on a site and should be marked with signs to prevent future re-development or alteration and reuse of the treatment areas.

The filter strip surface should be planted with an appropriate grass mixture, or turfed. Filter strips are subject to both wet and dry conditions, as well as sediment and debris accumulation. A mixture of dry-area and wet-area grasses, able to prevent erosion and capable of growing through silt deposits, is required. Wildflower seeds may be added to grass mixtures to increase amenity value.

Trees and dense scrub should generally be avoided on the filter strip. Although they may improve aesthetics, it is difficult to preserve the healthy dense vegetated ground cover, slope uniformity and stability that is required for a well-functioning filter strip. If a berm is constructed at the toe of the filter strip, the vegetation must be resistant to frequent inundation within the shallow ponding limit.

8.8 OPERATION AND MAINTENANCE REQUIREMENTS

Regular inspection and maintenance is important for the effective operation of filter strips as designed. Maintenance responsibility for a filter strip should always be placed with an appropriate organisation.

Access for maintenance vehicles must be available, but this is not usually a constraint due to the likely location of the filter strip adjacent to impermeable areas.

Operation and maintenance requirements for filter strips are described in Table 8.2.

Table 8.2 *Filter strips operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Litter and debris removal.	Monthly (or as required).
	Grass cutting – to retain grass height within specified design range.	Monthly (during growing season), or as required.
	Manage other vegetation and remove nuisance plants.	Monthly (at start, then as required).
Occasional maintenance	Check for poor vegetation growth due to lack of sunlight or dropping of leaf litter, and cut back adjacent vegetation where possible.	Annually.
	Re-seed areas of poor vegetation growth. Alter plant types to better suit conditions, if required.	Annually, or if bare soil is exposed over 10% or more of the filter strip area.
Remedial actions	Repair erosion or other damage by re-turfing or reseeding.	As required.
	Re-level uneven surfaces and reinstate design levels.	As required.
	Scarify and spike topsoil layer to improve infiltration performance, break up silt deposits and prevent compaction of the soil surface.	As required.
	Remove build up of sediment on upstream gravel trench, flow spreader or at top of filter strip.	As required.
	Remove and dispose of oils or petrol residues using safe standard practices.	As required.
Monitoring	Inspect filter strip surface to identify evidence of erosion, compaction, ponding, sedimentation and contamination (eg oils).	Half yearly.
	Check flow spreader and filter strip surface for even gradients.	Half yearly.
	Inspect gravel diaphragm trench upstream of filter strip for clogging.	Half yearly.
	Inspect silt accumulation rates and establish appropriate removal frequencies.	Half yearly.

Sediments excavated from a filter strip or upstream flow spreader that receive runoff from residential or standard road and roof areas are generally not toxic or hazardous material and can be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation to determine its classification and appropriate disposal methods. For industrial site runoff, sediment testing will be essential. In the majority of cases, it will be acceptable to distribute the sediment on site if there is an appropriate safe and acceptable location to do so.

Additional detail on waste management is provided in Chapter 23.

Maintenance plans and schedules should be developed during the design phase. Specific maintenance needs of the filter strip should be monitored and maintenance schedules adjusted to suit requirements. Additional detail on the preparation of maintenance specifications and schedules of work is given in Chapter 22.

Many of the specific maintenance activities for filter strips can be undertaken as part of a general landscaping contract and therefore, if landscape management is already required at site, should have marginal cost implications.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken.

8.9 CONSTRUCTION REQUIREMENTS

The filter strip must be constructed to provide an even and consistent longitudinal slope, with no severe undulations that will cause localised ponding or promote flow in channels. Care should be taken not to compact the soil below a filter strip as this will reduce its capacity for infiltration.

A newly constructed filter strip has to be protected from stormwater flows until vegetation has been established. This may be achieved by:

- diverting runoff around the filter strip until vegetation is established
- using pre-established turf or seeded mattresses
- covering the filter strip with clear plastic until the vegetation is well rooted
- placing an erosion control blanket over the freshly applied seed mix.

If more than 30 per cent of the treatment area is bare after four weeks, reseeding or replanting is required to achieve 90 per cent coverage.

If sediment from construction work accumulates on a filter strip, it should be cleared and the strip fully rehabilitated before the drainage system is adopted by the organisation carrying out the maintenance.

Additional detail on construction activities and the programming of construction activities is provided in Chapter 21. Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

8.10 REFERENCES

DETR (1994)
Construction (Design and Management) Regulations
Department of Environment, Transport and the Regions, HMSO, London

WILSON, S; BRAY, R and COOPER, P (2004)
Sustainable Drainage Systems: Hydraulic, Structural and Water Quality Advice (Report C609)
CIRIA, London

Trenches

9

Contents

9 Trenches

Description

Trenches are shallow excavations filled with rubble or stone that create temporary subsurface storage for either infiltration or filtration of stormwater runoff. Ideally they should receive lateral inflow from an adjacent impermeable surface, but point source inflows may be acceptable. Infiltration trenches allow water to exfiltrate into the surrounding soils from the bottom and sides of the trench. Filtration or filter trenches can be used to filter and convey stormwater to downstream SUDS components.

KEY DESIGN CRITERIA

- excavated trench 1–2 m depth filled with stone aggregate
- effective upstream pre-treatment to remove sediment and fine silts
- Infiltration should not be used where groundwater is vulnerable or to drain pollution hotspots
- observation wells and/or access points for maintenance of perforated pipe components.

ADVANTAGES

- infiltration can significantly reduce both runoff rates and volumes. It has been shown that important hydraulic benefits are also achieved with filter trenches
- infiltration provides a significant reduction in the pollutant load discharged to receiving body
- trenches can be incorporated easily into site landscaping and fit well beside roads.

DISADVANTAGES

- high clogging potential without effective pre-treatment – not for sites with fine particled soils (clays/silts) in upstream catchment
- build-up of pollution/blockages difficult to see
- high historic failure rate due to poor maintenance, wrong siting or high debris input
- limited to relatively small catchments
- high cost of replacing filter material should blockage occur.

PERFORMANCE:

Infiltration Trench (IT); Filter Trench (FT)

Peak flow reduction:	Medium
Volume reduction:	Low (FT) High (IT)
Water quality treatment:	High
Amenity potential:	Low
Ecology potential:	Low

TREATMENT TRAIN SUITABILITY:

Source control:	Yes (IT)
Conveyance:	Yes
Site system:	No
Regional system:	No

SITE SUITABILITY:

Residential:	Yes
Commercial/Industrial:	Yes
High density:	Yes
Retrofit:	Yes
Contaminated sites/sites above vulnerable groundwater	No (IT) Yes (FT)

COST IMPLICATIONS:

Land-take:	Low
Capital cost:	Low (IT) Medium (if liner required)
Maintenance burden:	Medium

POLLUTANT REMOVAL

Total suspended solids:	High
Nutrients:	Low/Medium
Heavy metals:	High

KEY MAINTENANCE REQUIREMENTS

- Regular inspection for signs of clogging
- Removal of sediment from pre-treatment system
- Removal and cleaning or replacement of stone.

9.1 GENERAL DESCRIPTION

Infiltration trenches, and filtration trenches/filter drains, are shallow excavations filled with rubble, stone or other void-forming media that creates temporary subsurface storage for stormwater runoff which is then either filtered through the stone media and conveyed downstream, or else infiltrated into the soil. Infiltration trenches are a form of soakaway and the principles set out in Section 6.3 are appropriate.

Trenches can be used to capture sheet or point flow from a drainage area or can function as an off-line device. Infiltration treats runoff by filtration through the soil, reduces runoff rates and volumes and can help preserve the natural water balance, replenish groundwater and preserve baseflow. Filter trenches are used where underlying soils are impermeable, to drain hotspot runoff, or where groundwater is vulnerable to pollution. Filter trenches provide a quiescent zone for removal of fine silts and also encourage filtration, adsorption and biodegradation processes. Geocellular products can be used as an alternative to stone for infiltration or conveyance systems. They have a higher void ratio but limited treatment capacity, and are often used to provide additional storage zones for higher order events in conjunction with other treatment components.

Trenches are not intended to function as sediment traps and must always be designed with an effective pre-treatment system – eg grass filter strip for lateral inflow, grass channel, swale, detention basin, sediment trap or forebay for point inflows – in order to prevent clogging and failure (see Chapter 6). Trench designs may be modified to include vegetative cover (establishing a type of biofiltration area – see Chapter 11), and a geotextile filter layer can be included within the upper layers. However, it must be ensured that maintenance of such systems is not then ignored. Where there is no effective upstream removal of sediments and/or fine silts, then the geotextile layer is likely to require regular removal and replacement.

For point source inflows, filter trenches can include a short length of perforated pipe close to the top of the trench to distribute the inflow runoff and ensure adequate conveyance. To maximise the treatment and attenuation benefits, the perforated pipe in the base should only be provided over the last few metres before the outlet. A high level perforated pipe can be installed to provide an overflow for flows in excess of the design event, although it is recommended that such events are routed around treatment components. Where a network of filter drains is established, high-level pipes can be used to transfer excess waters around the system in the event of local overloading. For infiltration trenches, an overflow pipe should be included in case of reduced infiltration capacity.

Trench schematics are given in Figures 9.1 and 9.2.

Trenches can replace conventional pipework as conveyance systems, and the use of adjacent filter strips or flow spreaders can remove the need for kerbs and gullies when systems are located adjacent to roads or highways. They should generally not be used as end-of-pipe systems due to the high flows that can occur. Trenches work best when incorporated into a treatment train with other techniques and should be used in conjunction with other SUDS components to safely pass and store extreme storm flows.

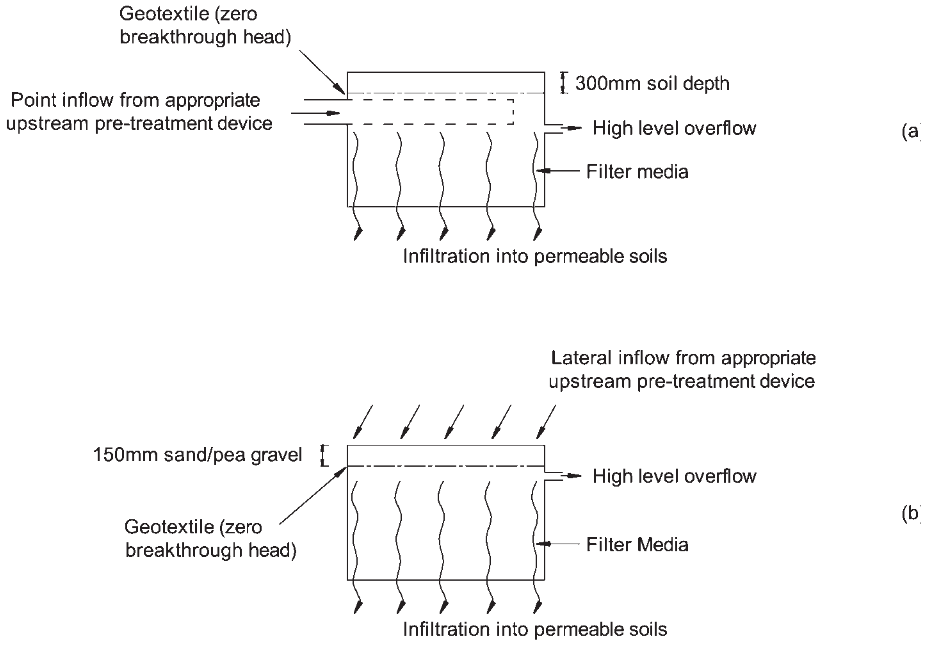


Figure 9.1 *Infiltration trench schematics*

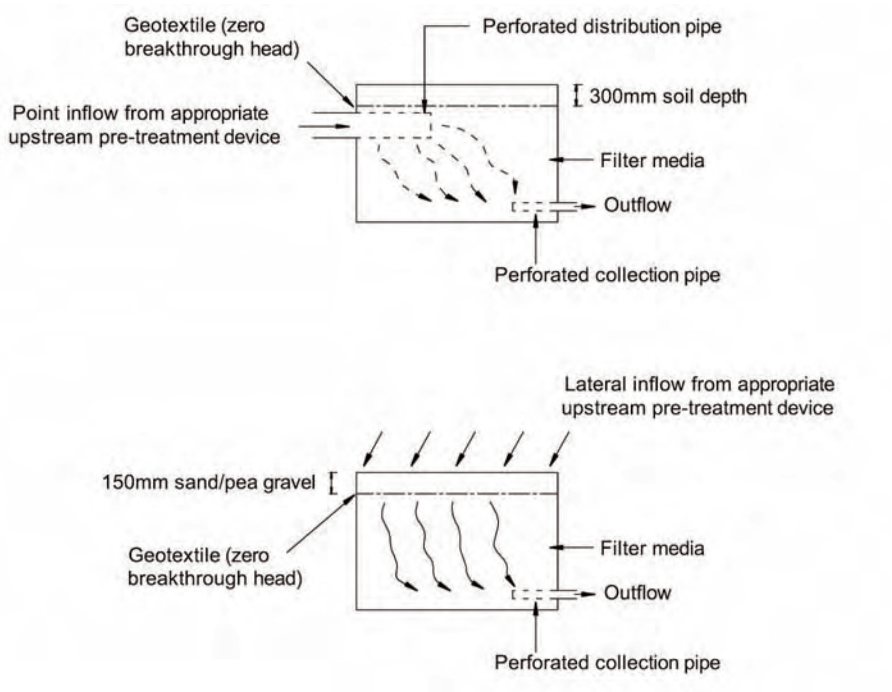


Figure 9.2 *Filter trench schematics*

9.2 SELECTION AND SITING OF TRENCHES

Trenches are best located adjacent to impermeable surfaces such as car parks or roads/highways. In some situations and with careful design they can be used to convey point source inflow downstream, but effective maintenance must be rigorously facilitated and implemented. They can be used for draining residential and non-residential runoff and, when lined, can be used to manage stormwater from hotspot/industrial areas. Unless very effective pre-treatment of sediments is included within the design, they are applicable primarily to impervious areas where there are no high levels of particulates in the runoff and should be considered for sites only where the sediment load is low.

The criteria presented in Table 9.1 should be evaluated to ensure the suitability of trenches for meeting drainage objectives at a particular site.

Table 9.1 *Considerations for using trenches*

Drainage area	Trenches are generally appropriate for catchments with small impermeable areas.
Space required	Trenches can be effectively incorporated into landscaping and public open spaces and, with careful design, can have minimal landtake requirements. With a vegetated surface they can form part of a grassed area, thereby enabling dual use. However, maintenance of such systems must be given full consideration.
Siting	Trenches should be integrated into the site planning and should take account of the location and use of other site features. Maintenance access should be given full consideration. One of the main attractions of filter and infiltration trenches is that they can be located beneath open spaces, thereby enabling dual use of land. Due to their relatively narrow shape, trenches can be adapted to many types of sites, can be easily used in retrofit situations and can often fit into the margin, perimeter or other unused areas of developed sites.
Site slope & stability	Trenches are typically restricted to sites without significant slopes, unless they can be placed parallel to contours. The longitudinal slope should not exceed 2% as low velocities are required for pollutant removal and to promote infiltration. Trenches should not be sited on unstable ground and ground stability should be verified by assessing site soil and groundwater conditions.
Subsurface soils and groundwater	Where trenches are designed for infiltration, the seasonally high groundwater table must be more than 1 m below the base of the facility and the design must comply with the environmental regulator's policy on infiltration and groundwater protection. Infiltration tests should be undertaken as described in Section 4.8 and Appendix 1. Where infiltration is not required, the seasonally high groundwater level should be below the base of the trench. Trenches are designed for intermittent flow and should be allowed to drain and re-aerate between rainfall events. They must not, therefore, be used on sites with a continuous flow from groundwater or other sources. Unlined trenches should not be used on brownfield sites unless it has been clearly demonstrated that the risk of leaching of contaminants is very low. Unlined trenches should not be used to treat runoff from hotspots if the risk of groundwater pollution due to infiltration is unacceptably high.

9.3 HYDRAULIC AND WATER QUALITY DESIGN

9.3.1 Infiltration trenches

A comprehensive hydrogeological/ geotechnical evaluation should be undertaken to determine the suitability of the site for infiltration drainage. This is particularly important on sites where there is filled ground, as the frequent discharge of additional waters could change the soil characteristics, either chemically or structurally. The soil infiltration rate should be determined at the location and depth of the proposed device. Design practices for infiltration systems are described in Section 4.7. and CIRIA R156 (Bettess, 1996). The slowest observed infiltration rate should be used in the design calculations.

As for soakaways, infiltration trenches should be designed to manage storms up to the standard of service required. This is generally the 1 in 10 or 1 in 30 year storm for the contributing area. As discharge criteria from a development is usually based on a 100 year event, the performance of the infiltration system under such conditions needs to be known. For ease of design, this may result in the trench being designed to the 100 year event. The impact of flooding in excess of the design event will need to be assessed and floodwater may need to be conveyed safely to downstream drainage components. Infiltration trenches are normally constructed with high level overflows and their plan area should be sized to provide storage beneath the pipe invert level.

The trench should discharge from full to half-volume within 24 hours in order that sufficient capacity is available to receive runoff from subsequent storms.

9.3.2 Filtration/filter trenches

There are three elements to the design of filter drains:

1. **Design of filter material to percolate water.** The rate of percolation is a compromise between pollutant removal and the need to restrict the risk of flooding in the catchment to the design storm event. To act as an appropriate trickling filter for small events, contact time with the aggregate should be maximised (via geometric design characteristics).
2. **Design of filter material to store water.** The greater the void ratio the more storage is available in the trench. The level of storage available will depend on the throttle at the outlet.
3. **Design of the pipe system to convey water.**

The rate of percolation of water through the drain filter material can be estimated using Darcy's law. The rate of percolation should be sufficient to meet the design criteria. The storage of water within the trench and aggregate is dependent on the void ratio of the aggregate and the downstream throttle rate. Calculation methods are as for permeable pavements and are set out in Section 12.3.1.

The slotted pipe in the base of the filter drain should be designed using conventional pipe design methods to achieve the flows required to meet the site specific design criteria (see Box 12.4).

9.4 PHYSICAL SPECIFICATIONS

Trench designs should be specific to the particular location. Their form will depend on specific site characteristics and development design criteria. However, there are a number of criteria that should be observed for optimum pollutant removal, ease of maintenance and good safety practice.

Geometry

Trench depths should generally be between 1 and 2 m.

Materials

Granular fill is normally specified as graded stone/rock – locally available where possible, eg trench rock that is 40 to 60 mm in diameter, providing the trench is not required to withstand surface loadings such as vehicular traffic. The voids ratio should be sufficiently high to allow adequate percolation and to reduce the risk of blockage. Geocellular systems specified for storage or conveyance systems are described in detail in Chapter 13.

A geotextile should prevent soil piping but should have zero breakthrough head and greater permeability than the surrounding soil (for infiltration trenches). Where used, the top layer of geotextile will provide some degree of pre-treatment and must be readily separable from the side sections in case it needs more regular replacement. Appropriate geotextile and geomembrane specifications are described in Appendix C. Material sustainability principles are presented in Section 3.6.

Where perforated pipes are used as distribution or collection systems, they should be set within appropriate depths of pipe bedding material.

Design for safety and maintenance

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

The main cause of erosion of filter drains is due to vehicles running off the carriageway and scattering the filter material. This can cause a hazard to vehicles on the carriageway as well. Bollards, large rocks or low railing can be used to prevent traffic from running or parking on the filter drain.

For all trenches, lengths of perforated pipes should be spaced between access sumps (also known as catchpits) so that the pipes can be cleaned by jetting out or rodding. These sumps should be accessible and clearly identifiable.

In general, trenches are not likely to pose a safety risk to the public and should not need to be fenced.

9.5 PRE-TREATMENT/INLETS

The design, operation and maintenance of trench inlet structures and pre-treatment systems is a key factor in their continued satisfactory operation. Roof waters should be connected directly through sediment/debris traps. Sheet flow from an adjacent impermeable area should pass over a vegetated filter strip (see Chapter 8 for design of filter strips). For point inflows or in an off-line configuration, pre-treatment should consist of a sediment forebay or sedimentation chamber or other SUDS component that is easily maintained. Exit velocities from the pre-treatment system to the trench should be non-erosive. Pre-treatment systems are discussed in Chapter 7 and the design of inlet structures is set out in Chapter 19.

9.6 OUTLETS

Filter drains are designed with low level outfalls with appropriate flow control devices. Infiltration trenches are normally constructed with high level outlets. Outlet erosion protection is unlikely to be required as flows are likely to be very low. Unless the trench is an off-line device, the system should be designed with appropriate overflow facilities so that design flows can be conveyed safely downstream.

9.7 LANDSCAPING AND VEGETATION

Trenches may be protected with geotextile and covered with topsoil and planted with grass, in a landscaped area. However, this increases the risk that maintenance responsibilities will be overlooked which could cause performance failure of the system and should therefore be implemented with caution.

9.8 OPERATION AND MAINTENANCE REQUIREMENTS

Regular inspection and maintenance is important for the effective operation of trenches as designed. Maintenance responsibility for a trench should always be placed with an appropriate organisation.

Adequate access should be provided to the trench surface and maintenance points for inspection and maintenance, including for appropriate equipment and vehicles. Operation and maintenance requirements for trenches are described in Table 9.2.

Table 9.2 *Trenches operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Litter and debris removal from trench surface, access chambers and pre-treatment devices.	Monthly (or as required).
	Removal and washing of exposed stones on the trench surface.	Annual (bi-annual the first year) or when silt is evident on the surface.
	Trimming of any roots that may be causing blockages.	Annual(semi-annual the first year).
	Remove weeds on the trench surface.	Monthly (at start, then as required)
Occasional maintenance	Removal of sediment from pre-treatment devices.	Six monthly.
	Remove tree roots or trees that grow close to the trench.	As required.
	At locations with high pollution loads, remove surface geotextile and replace, and wash or replace filter media.	Five yearly.
Remedial actions	Clear perforated pipework of blockages.	As required.
	Rehabilitate infiltration or filtration surfaces.	As required.
	Replace geotextiles and clean and replace filter media, if clogging occurs.	As required.
	Excavate trench walls to expose clean soils if infiltration performance reduces to unacceptable levels.	As required.
	Inspect inlets, outlets and inspection points for blockages, clogging, standing water and structural damage.	Monthly.
Monitoring	Inspect pre-treatment systems, inlets, trench surfaces and perforated pipework for silt accumulation. Establish appropriate silt removal frequencies.	Half yearly.

Sediments excavated from upstream pre-treatment devices that receive runoff from residential or standard road and roof areas are generally not toxic or hazardous material and can be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation to determine its classification and appropriate disposal methods. For industrial site runoff, sediment testing will be essential. In the majority of cases, it will be acceptable to distribute the sediment on-site if there is an appropriate safe and acceptable location to do so. Additional detail on waste management is provided in Chapter 23.

Maintenance plans and schedules should be developed during the design phase. Specific maintenance needs of the trench should be monitored and maintenance schedules adjusted to suit requirements. Additional detail on the preparation of maintenance specifications and schedules of work is given in Chapter 22.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken.

9.9 CONSTRUCTION REQUIREMENTS

Trenches should be protected before completion and stabilisation of the upstream development areas. They should not be used for untreated drainage of construction sites, where runoff is likely to contain large amounts of silt, debris and other pollutants as this will cause rapid clogging of the systems.

The ground surrounding infiltration trenches should be left undisturbed during construction, as any trafficking of the ground or ground re-working will affect the infiltration characteristics of the soil. Geotextile and stone fill should be clean before construction.

Filter trench formations should be flat or to a level, shallow grade to reduce the risk of ponding and negative filter gradients.

The drain down time after a storm should be observed after completion or modification of the facility to confirm that the desired drain time has been obtained (BRE, 1991).

All trench excavations should follow construction best practice and be supported, if required. No personnel should be allowed to enter an unsupported trench deeper than 1.2 m. Trench supports must be designed to guarantee the safety of those working in the trench. Support may also be needed for shallower trenches in weak ground.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Additional detail on construction and programming of construction is provided in Chapter 21.

9.10 REFERENCES

BETTESS, R (1996)
Infiltration drainage - manual of good practice (Report R156)
CIRIA, London

BRE (Buildings Research Establishment) (1991)
Digest 365: *Soakaway Design*.
BRE

DETR (1994)
Construction (Design and Management) Regulations.

Swales

10

Contents

Swales

10

Description

Swales are linear vegetated drainage features in which surface water can be stored or conveyed. They can be designed to allow infiltration, where appropriate. They should promote low flow velocities to allow much of the suspended particulate load in the stormwater runoff to settle out, thus providing effective pollutant removal. Roadside swales can replace conventional gullies and drainage pipes.

KEY DESIGN CRITERIA

- limit velocities during extreme events to 1 – 2 m/s, depending on soil type, to prevent erosion
- maintain flow height of water during frequent events below the top of the vegetation (typically 100 mm)
- maximum side slopes of 1 in 3 (where soil conditions allow)
- minimum base width normally 0.5 m.

ADVANTAGES

- easy to incorporate into landscaping
- good removal of urban pollutants
- reduces runoff rates and volumes
- low capital cost
- maintenance can be incorporated into general landscape management
- pollution and blockages are visible and easily dealt with.

DISADVANTAGES

- not suitable for steep areas
- significant
- not suitable in areas with roadside parking
- limits opportunities to use trees for landscaping
- risks of blockages in connecting pipework.

PERFORMANCE:

Peak flow reduction:	Medium
Volume reduction:	Medium
Water quality treatment:	Good
Amenity potential:	Medium
Ecology potential	Medium

TREATMENT TRAIN SUITABILITY:

Source control:	Yes
Conveyance:	Yes
Site system:	Yes
Regional system:	No

SITE SUITABILITY:

Residential:	Yes
Commercial/industrial:	Yes
High density:	Limited
Retrofit:	Limited
Contaminated sites(s) above vulnerable groundwater (with liner)	Yes

COST IMPLICATIONS:

Land-take:	High
Capital cost:	Low
Maintenance cost:	Medium

POLLUTANT REMOVAL:

Total suspended solids:	High
Nutrients:	Low
Heavy metals:	Medium

KEY MAINTENANCE REQUIREMENTS

- litter/debris removal
- grass cutting and removal of cuttings
- clearing of inlets, culverts and outlets from debris and sediment
- repair of eroded or damaged areas.

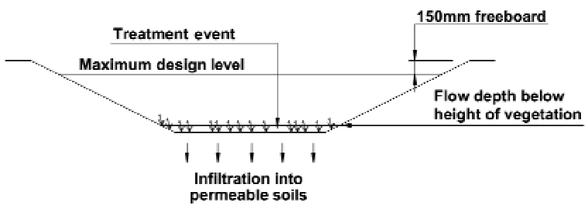
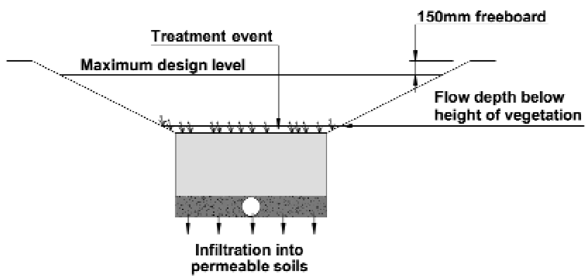
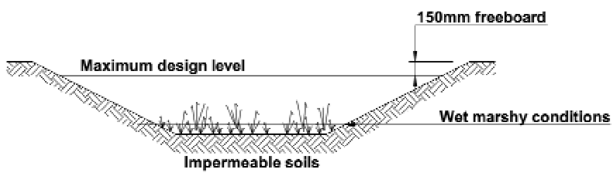
10.1 GENERAL DESCRIPTION

Swales are shallow channels designed to store and/or convey runoff and remove pollutants. They may be used as conveyance structures to pass the runoff to the next stage of the treatment train and can be designed to promote infiltration where soil and groundwater conditions allow.

The swale channel is broad and shallow and covered by dense vegetation, usually grass, to slow down flows and trap particulate pollutants. A swale can have check dams or berms installed across the flow path, to promote settling and infiltration.

There are three kinds of swale, each with different surface water management capability. They are described in Table 10.1.

Table 10.1 *Swale types*

Swale type	Description	Elevation
1. Standard conveyance swale	Conveyance swales are broad, shallow vegetated channels. These are particularly effective ways of directing and conveying runoff from the drained area to another stage of the surface water management train. They can be designed for vegetative filtration or detention, depending on the level of flow constraint and ponding depths appropriate at the site. Very small swales (mini-swales) can be used to manage small events with effective overflow facilities to alternative SUDS/piped systems. In some locations, such as pollution hotspots, conveyance swales may require lining to prevent infiltration.	
2. Dry swale	The dry swale is a vegetated conveyance channel, designed to include a filter bed of prepared soil that overlays an under-drain system. This provides additional treatment and conveyance capacity beneath the base of the swale. As they remain dry most of the time, they do not become boggy during wet weather. In some locations, such as pollution hotspots, dry swales may require lining to prevent infiltration.	
3. Wet swale	This system is equivalent to the conveyance swale (1), but designed to encourage wet and marshy conditions in the base to enhance treatment processes. This can be achieved using liners or, where underlying soils are poorly drained (or water tables are high), in combination with shallow gradients.	

A typical swale schematic is given in Figure 10.1.

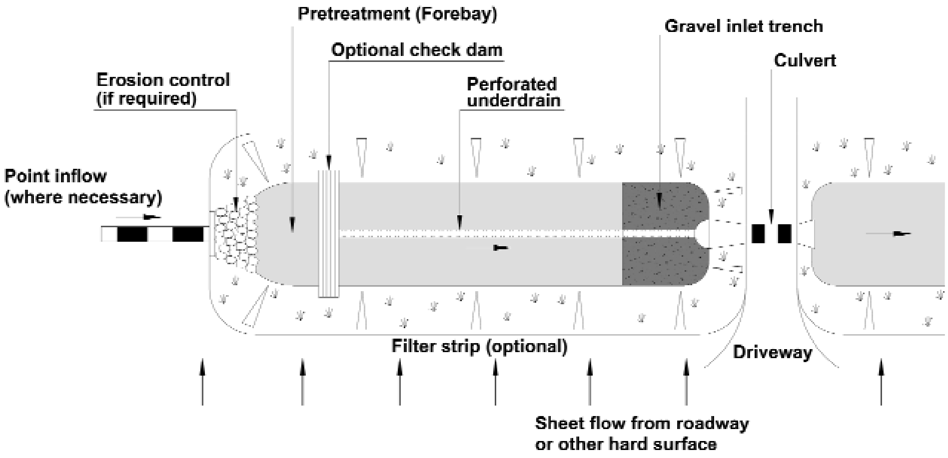


Figure 10.1 *Schematic of an enhanced dry swale*

Swales can replace conventional pipework, and the use of adjacent filter strips or flow spreaders should remove the need for kerbs and gullies. They should generally not be used as end-of-pipe systems due to the high flows that can occur there and the consequent risk of erosion. Swales work best when incorporated into a treatment train with other techniques and should be used in conjunction with other SUDS components to pass safely and store extreme storm flows.

10.2 SELECTION AND SITING OF SWALES

Swales can be used in a wide variety of situations. Swales are typically located next to roads but can also be located in landscaped areas, adjacent to car parks and in other open spaces. They are ideal for use as drainage systems on industrial sites because any pollution that occurs is visible and can therefore be dealt with before it causes damage to the receiving watercourse. They are less appropriate in private gardens where excess fertiliser and weed killer application can cause pollution of runoff.

The criteria presented in Table 10.2 should be evaluated to ensure the suitability of swales for meeting drainage objectives at a particular site.

Table 10.2 *Considerations for using swales*

Drainage area	Swales are generally appropriate for catchments with small impermeable areas.
Space required	Swales must be effectively incorporated into landscaping and public open spaces as they demand significant land-take due to their shallow side-slopes. Swales are generally difficult to incorporate into dense urban developments where limited space may be available.
Siting	Swales should be integrated into the site planning and should take account of the location and use of other site features. The siting of a swale should be such that the longitudinal slope can be maintained at the desired gradient and water can flow into them laterally from impermeable areas. Maintenance access should be easy and good growth of vegetation should be ensured by siting swales in areas that receive sufficient sunlight.

Table 10.2 *Considerations for using swales (continued)*

Site slope & stability	Swales are usually restricted to sites without significant slopes, though careful planning should enable their use in steeper areas by considering the contours of the site. The longitudinal slope should not exceed 4% (10% with check dams) as low runoff velocities are required for pollutant removal and to prevent erosion. Swales should not be sited on unstable ground and ground stability should be verified by assessing site soil and groundwater conditions.
Subsurface soils and groundwater	Where swales are designed for infiltration, the seasonally high groundwater table must be more than 1 m below the base of the facility and the design must comply with the environmental regulator's policy on infiltration and groundwater protection. Infiltration tests should be undertaken in accordance with Appendix B (see Section 4.8). Where infiltration is not required, the seasonally high groundwater level should be below the underdrain of the swale for dry swales. Lining of swales adjacent to residential roads is not generally considered necessary, unless the site lies above a sensitive groundwater zone. However, this should be checked with the environmental regulator on a site-by-site basis. Unlined swales should not be used on brownfield sites unless it has been demonstrated clearly that the risk posed by leaching of contaminants is acceptable. Unlined swales should not be used to treat runoff from hotspots if the risk of groundwater pollution due to infiltration is unacceptably high.

10.3 HYDRAULIC AND WATER QUALITY DESIGN

The hydraulic design of swales should ensure that the following criteria are met for water quality performance:

1. Where swales are designed for filtration and infiltration

The flow height for an appropriate "water quality treatment event" should be maintained below the height of vegetation. It is suggested that a 1 in 1 year, 30 minute event is appropriate. Vegetation in the flow channel should typically be maintained at a height of 100–150 mm. The maximum flow velocity in the swale for the water quality treatment event should be 0.3 m/s. Wet swales should be designed using the same approach, however velocities will tend to be lower.

To calculate the average velocity of water in a swale, Manning's equation should be used (see Chapter 4 for hydraulic calculation methods). The Manning's "n" value, or the "roughness coefficient" indicates to what extent the surface of the swale will resist flow and is critical in its sizing. For depths of water that are below or equal to the height of the grass, Manning's "n" can be assumed to be 0.25 for most situations.

A Manning's "n" value of 0.1 for above-grass flow is generally appropriate for use in the analysis of extreme events. Check dams and appropriate pre-treatment systems can be used to improve both hydraulic and water quality performance of a swale system by reducing velocities, increasing residence time, increasing infiltration and/or storage. The impact of check dams on maintenance activities should, however, be evaluated.

Enhanced drainage beneath the swale will provide increased capacity, will reduce the risk of localised ponding and marshy areas developing where gradients are flat, and will facilitate infiltration where ground conditions allow. Where swales are being designed for conveyance capacity in extreme events, it is suggested that design criteria for these systems should not assume additional allowances for loss of volume. Where swales are to be designed to discharge all flows by infiltration, the systems should be designed as a form of soakaway (see Chapter 6) or infiltration basin (see Chapter 15).

2. Enhanced dry swales

Dry swales which are served by an underdrain need not have an above-ground outlet and therefore act as a connected length of dry basins. Their performance is complex as the relative head in each swale serving the underdrain will define its drainage characteristic. An added uncertainty is that where the bedding around the underdrain has a relatively low permeability, the underdrain itself may not be the limiting condition. Careful design with detailed modelling is needed to assess a system's performance to ensure that design events can be dealt with without flooding of downstream basins. As velocity is not an issue in this situation (as these systems are most suited to relatively flat areas or short lengths), the design condition is for hydraulic performance. Normal criteria of 30 or 100 years should be used. The underdrain should have a performance of around 2 l/s/ha to ensure that systems can deal with multi-event scenarios.

The following should also be accounted for when considering the hydraulic design of the swale:

1. The swale should have adequate capacity to convey and/or store the 10 to 30 year (site level of service) return period event for the site.
2. The swale should have the ability to convey safely extreme event flows, or else excess flows should be safely passed to appropriate temporary storage areas.
3. The design event runoff volumes should half empty within 24 hours. This will help to ensure that storage and treatment volumes are available for subsequent events and, for dry swales, should also protect vegetation from damage by saturated conditions.
4. Flow velocities for extreme events must be kept below 1.0 m/s (or 2.0 m/s if slope stability, soil erosion and safety conditions allow) to prevent erosion.

10.4 PHYSICAL SPECIFICATIONS

Swale designs should be specific to the particular location. Their form and aesthetic appearance will depend on specific site characteristics and development design criteria. However, there are a number of criteria that should be observed for optimum pollutant removal, ease of maintenance and good safety practice.

Geometry

The shape of a swale should be trapezoidal or parabolic in cross section as these are easiest to construct and maintain, and offer good hydraulic performance. Swale side slopes should be no greater than 1 in 4 to promote sheet flow and low velocities, and to maximise the wetted perimeter, promote filtration and minimise erosion. Gentle side slopes also promote pre-treatment, enhance safety and allow easy access for mowing. Side slopes may be increased to a maximum of 1 in 3 providing all technical and safety implications have been fully considered.

The normal maximum dry swale depth is between 400 and 600 mm (providing all technical and safety issues have been considered). A freeboard of 150 mm should be provided over the design flow depth to allow for blockages.

Conveyance swales should have a minimum longitudinal slope of 1 in 300, although those with slopes of less than 1 in 100 are at risk of becoming waterlogged and underdrains may be appropriate. There is no minimum slope requirement for underdrained swales or wet swales. Longitudinal channel slopes should not exceed 1 in 40 (1 in 25 where technical and safety implications have been fully considered), although check dams can be used to increase slopes. Check dams should cover the full horizontal width of the swale to a maximum depth overspill of 300 mm onto a reinforced pad.

It is recommended that swales should have a minimum length of 30 m to maximise water quality benefits. However, the actual length will be a function of the site constraints and hydraulic properties of the swale in any particular location.

The base of a swale should be flat, preferably with a width of between 0.5 and 2 m. Swales with a greater base width should have a flow divider along the entire channel length, to prevent channelling and erosion.

Design for safety and maintenance

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

Swales are shallow surface features that do not present significant risk or danger to the health and safety of the general public. Risks are reduced by inherent design considerations including shallow side slopes, infrequency of inundation, and shallow flow depths. Wet swale designs should follow safety guidance given in the chapters on ponds and wetlands (Chapters 17 and 18).

In certain locations, some form of physical barrier other than kerbs may be appropriate to prevent vehicles parking on the swale edges (eg large rocks, bollards or low railing). Alternatively the edge of the swale may be reinforced to prevent damage from vehicles.

Materials

Flow dividers (if required) should be constructed of a firm material that will resist weathering and erosion, such as concrete, recycled plastic or a compacted soil berm seeded with the swale vegetation. Materials used for this purpose must not leach chemicals into the swale. If erosion is likely to be a problem, then erosion control fabrics, coir blankets or geotextiles can be used. Geotextile/geomembrane specifications are presented in Appendix C. Material sustainability principles are set out in Section 3.6.

Figure 10.2 shows example details for a dry swale and Figure 10.3 shows details of a wet swale.

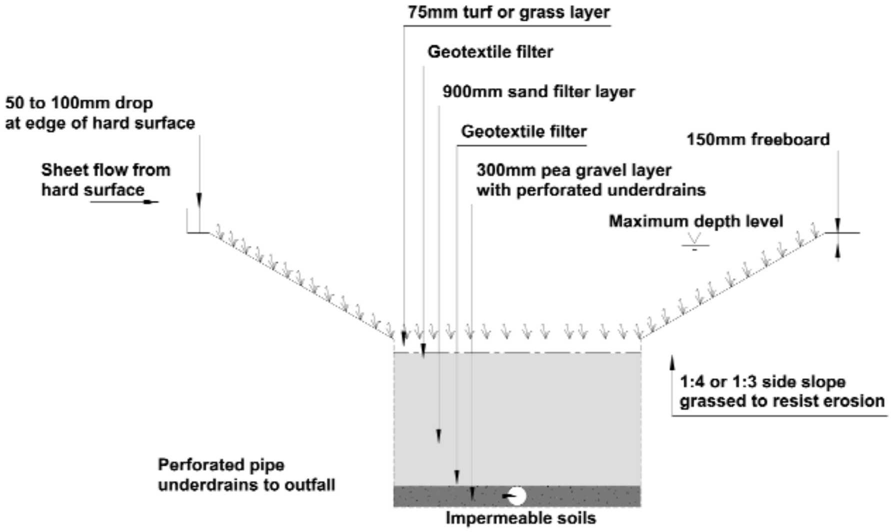


Figure 10.2 *Example detail of a dry swale*

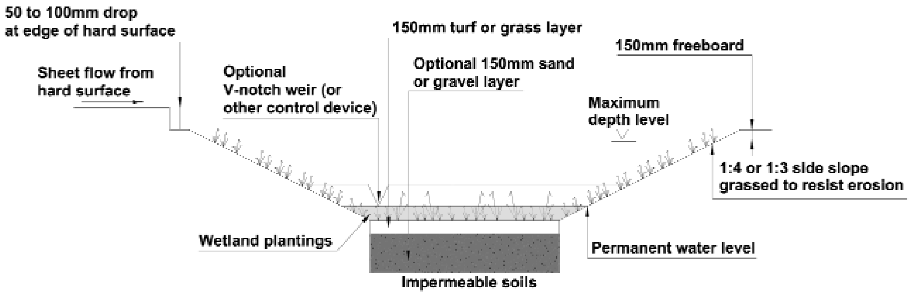


Figure 10.3 *Example detail of a wet swale*

10.5 CHECK DAMS

Where required, check dams are typically provided at 10 – 20 m intervals and the water level at the toe of the upstream dam should be the same level as the crest of the downstream dam. Check dams may be constructed from coarse aggregate (100 mm to 600 mm, eg Class 6B material as specified in the Specification for Highway Works (Highways Agency *et al*, 1998a), wooden boards, gabions, or earth (if adequately protected against erosion). Energy dissipation/erosion protection material should also extend 1 – 2 m downstream of the dam across both the base and sides of the swale. Check dams should be constructed into the sides of the swale to ensure that water does not bypass the structure and a small orifice or pipe at the base of the dam will allow low flows to be conveyed downstream. Risks of orifice blockage should always be considered. Interconnections should be designed so that flow does not re-suspend settled material or cause local erosion, and so that floating solids and surface films are retained. Figure 10.4 shows typical check dam details and Figure 10.5 is a photograph of a granular check dam.

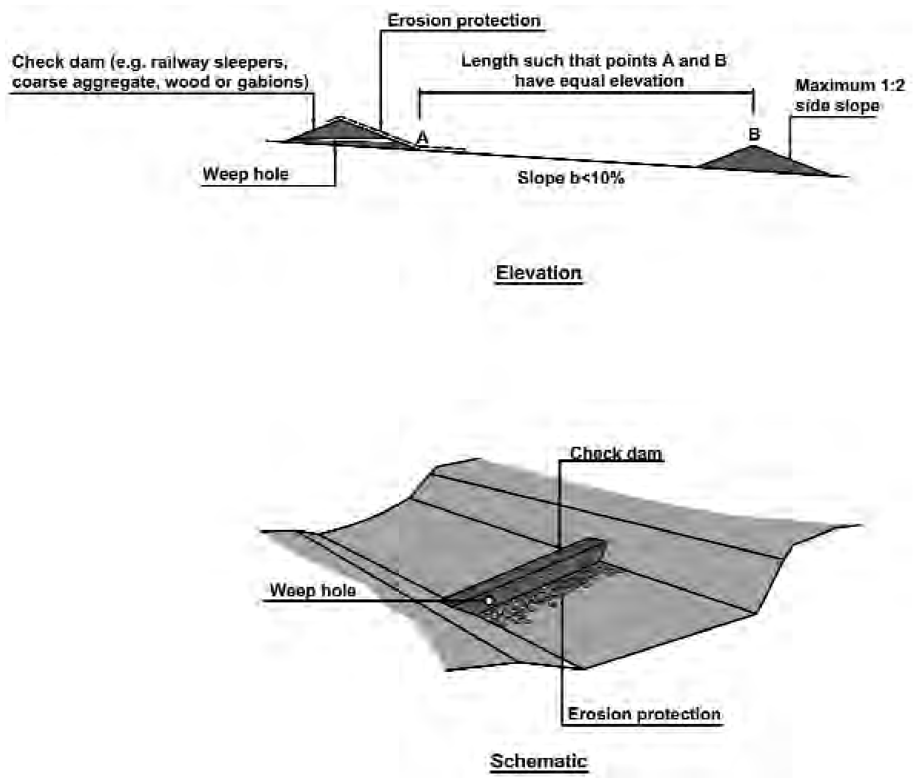


Figure 10.4 *Typical check dam details*

Figure 10.5 *A check dam*

10.6 PRE-TREATMENT/INLETS

Water should preferably be directed laterally into a swale rather than as a single point inflow by draining runoff as sheet flow from the edge of a contributing impermeable area and excluding kerbing. This minimises erosion and disperses pollution widely in the surface vegetation. As an alternative, a series of drop kerbs at frequent intervals can be used. However, the transition from the kerb to the swale should ensure that the vegetation behind the kerb does not obstruct the flow of water to the swale. Where runoff is directed into swales by flow-concentrating devices such as gullies or pipes, the risk of erosion and silting is increased. This should be mitigated by constructing inlets with flow spreaders and erosion control, together with appropriate pre-treatment.

Where swales are located next to highways, a lateral gravel-filled drain may be provided at the edge of the pavement construction to prevent water seeping into the pavement layers and subgrade and affecting the structural strength of the road.

Shallow side slopes or vegetated filter strips at the edge of the impervious surface are useful as a pre-treatment system for runoff entering swales and will improve water quality performance of the system. Other forms of pre-treatment may also be used (see Chapter 6). There should be a drop of at least 50 mm from the pavement (or hard surface) edge to any vegetated surface to prevent the formation of a sediment lip.

10.7 OUTLETS

An outlet pipe has to be provided from the swale channel (for conveyance swales) or underdrain systems (for enhanced swales) to the point of discharge. Outlet erosion protection may be required. An overflow structure and non-erosive overflow channel should be provided to pass safely flows in excess of the swale storage capacity to the downstream drainage system.

10.8 LANDSCAPING AND VEGETATION

Vegetation in swales must be sufficiently robust to withstand the pollution from runoff. It must also be suitable to:

1. Provide dense cover and dense root structure to resist erosion.
2. Slow flows and increase residence time to filter out pollutants.

A variety of species should be used to suit the aesthetics of a site and to enhance the visual landscape. Wild grass and flower species can be introduced for visual interest and to provide wildlife habitat.

Native species should always be used. These will help ensure a dense and durable cover of vegetation is developed and will provide appropriate habitat for indigenous species. Fine growing grasses maximise filtration, and mixtures of perennial ryegrass and fescues are particularly suitable for use in swales in the UK.

Emergent vegetation can be planted in wet swales or, alternatively, wetland soils may be spread on the swale bottom for seed stock. However, dense planting should be avoided, and systems should be allowed to colonise naturally to a large extent. For dry swales, plants can be placed as turf, seeds or less commonly as potted plants. Turf provides immediate protection, provided the seams are protected by laying the strips perpendicular to the flow of water and hand tamping them after laying. Turf should also be secured with pegs where high flow velocities are expected and on side slopes that are greater than 1 in 4. A swale is best seeded during spring and early summer months to give vegetation the whole length of a growing season to establish.

Landscaping and planting best practice is presented in detail in Chapter 20.

10.9 OPERATION AND MAINTENANCE REQUIREMENTS

Regular inspection and maintenance is important for the effective operation of swales as designed. Maintenance responsibility for a swale should always be placed with an appropriate organisation.

Adequate access must be provided to all swale areas for inspection and maintenance, including for appropriate equipment and vehicles. Operation and maintenance requirements for swales are described in Table 10.3.

Table 10.3 *Swales operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Litter and debris removal.	Monthly (or as required).
	Grass cutting – to retain grass height within specified design range.	Monthly (during growing season), or as required.
	Manage other vegetation and remove nuisance plants.	Monthly (at start, then as required).
Occasional maintenance	Check for poor vegetation growth due to lack of sunlight or dropping of leaf litter, and cut back adjacent vegetation where possible.	Annually.
	Re-seed areas of poor vegetation growth. Alter plant types to better suit conditions, if required.	Annually, or if bare soil is exposed over 10 % or more of the swale treatment area.
Remedial actions	Repair erosion or other damage by re-turfing or reseeding.	As required.
	Re-level uneven surfaces and reinstate design levels.	As required.
	Scarify and spike topsoil layer to improve infiltration performance, break up silt deposits and prevent compaction of the soil surface.	As required.
	Remove build up of sediment on upstream gravel trench, flow spreader or at top of filter strip.	As required.
	Remove and dispose of oils or petrol residues using safe standard practices.	As required.
Monitoring	Inspect inlets, outlets and overflows for blockages, and clear if required.	Monthly.
	Inspect infiltration surfaces for ponding, compaction, silt accumulation. Record areas where water is ponding for > 48 hours.	Monthly, or when required.
	Inspect inlets and facility surface for silt accumulation. Establish appropriate silt removal frequencies.	Half yearly.

Sediments excavated from swales that receive runoff from residential or standard road and roof areas are generally not toxic or hazardous material and can be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation to determine its classification and appropriate disposal methods. For industrial site runoff, sediment testing will be essential. In the majority of cases, it will be acceptable to distribute the sediment on site if there is an appropriate safe and acceptable location to do so. Additional detail on waste management is provided in Chapter 23.

Maintenance plans and schedules should be developed during the design phase. Specific maintenance needs of the swale should be monitored and maintenance schedules adjusted to suit requirements. Additional detail on the preparation of maintenance specifications and schedules of work is given in Chapter 22.

Many of the specific maintenance activities for swales can be undertaken as part of a general landscaping contract and, therefore, if landscape management is already required at site, should have marginal cost implications.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken.

10.10 CONSTRUCTION REQUIREMENTS

Swales should not receive any runoff until vegetation in the system is fully established and construction at the site has reached a state where sediment from the site will not cause siltation of the swale. This can be achieved by:

(a) Diverting flows until the vegetation is well rooted.

(b) Placing an erosion control blanket (eg jute, straw or geosynthetic mats) over the freshly applied seed mix or:

(c) Using bare earth as a temporary cover during the wet season. These areas should be seeded with a suitable grass mix as soon as the weather is conducive to seed germination.

If more than 30 per cent of the planted area is bare after four weeks, reseeding or replanting should be considered to achieve 90 per cent coverage. If sediment from construction work accumulates on a swale, it should be cleared and the swale fully rehabilitated before the drainage system is adopted by the organisation carrying out the maintenance.

Care must be taken that design levels and slopes for inlets and swale base and sides are constructed accurately to avoid runoff bypassing swale inlets, ponding in the swale base and flow channelling. Care should be taken not to compact the soil below a swale as this will reduce its capacity for infiltration.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Additional detail on construction and the programming of construction is provided in Chapter 21.

10.11 REFERENCES

DETR (1994)
Construction (Design and Management) Regulations
Department of Environment, Transport and the Regions, HMSO, London

Highways Agency, Scottish Executive, National Assembly for Wales and Department for Regional Development Northern Ireland (1998)
Manual of contract documents for highway works. Volume 1: Specification for highway works.
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Bioretention

11

Contents

Bioretention

11

Description

Bioretention areas are shallow landscaped depressions which are typically underdrained and rely on engineered soils and enhanced vegetation and filtration to remove pollution and reduce runoff downstream. They are aimed at managing and treating runoff from frequent rainfall events.

KEY DESIGN CRITERIA

- sufficient area to temporarily store the Water Quality Treatment Volume (Vt) at a depth <0.15 m on the surface
- the water quality treatment event should half drain within 24 hrs to provide adequate capacity for multi-event scenarios
- minimum depth to groundwater of 1 m, if unlined
- overflow/bypass facilities for extreme events.

ADVANTAGES

- can be planned as landscaping features
- very effective in removing urban pollutants
- can reduce volume and rate of runoff
- flexible layout to fit into landscape
- well-suited for installation in highly impervious areas, provided the system is well-engineered and adequate space is made available
- good retrofit capability.

DISADVANTAGES

- requires landscaping and management
- susceptible to clogging if surrounding landscape is poorly managed
- not suitable for areas with steep slopes.

PERFORMANCE:

Peak flow reduction:	Medium
Volume reduction:	Medium (High with infiltration)
Water quality treatment:	Good
Amenity potential:	Good
Ecology potential:	Medium

TREATMENT TRAIN SUITABILITY:

Source control:	Yes
Conveyance:	No
Site system:	Yes
Regional system:	No

SITE SUITABILITY;

Residential:	Yes
Commercial/Industrial:	Yes
High density:	No
Retrofit:	Yes
Contaminated sites/sites above vulnerable groundwater (with liner)	Yes

COST IMPLICATIONS:

Land-take:	High
Capital cost:	Low
Maintenance cost:	Medium

POLLUTANT REMOVAL:

Total suspended solids:	High
Nutrients:	Low
Heavy metals:	High

KEY MAINTENANCE REQUIREMENTS

- regular inspection
- litter/debris removal
- replacement of mulch layer
- vegetation management
- soil spiking and scarifiying.

11.1 GENERAL DESCRIPTION

Bioretention areas, also referred to as bioretention filters or rain gardens, are structural stormwater controls that capture and treat stormwater runoff from frequent rainfall events. Excess runoff from extreme events is passed forward to other drainage facilities. The water quality volume is treated using soils and vegetation in shallow basins or landscaped areas to remove pollutants. The filtered runoff is then either collected and returned to the conveyance system or, if site conditions allow, exfiltrated into the surrounding soil. Part of the runoff volume will be removed through evaporation and plant transpiration. Suitable flow routes or overflows are required to convey water in excess of the design volumes to appropriate receiving drainage systems safely.

The "treatment area" should usually consist of the components given in Table 11.1.

Table 11.1 *Bioretention components*

Component	Purpose
Grass filter strip/grass channel	To reduce incoming runoff velocities and to filter particulates.
Ponding area	For temporary storage of surface water prior to evaporation, infiltration, plant uptake. The ponding area also promotes additional settling.
Organic/mulch area	For filtration, and to create an environment conducive to the growth of micro-organisms that degrade hydrocarbons and organic matter.
Planting soil	For filtration, and as a planting medium. The clay component will provide good adsorption sites for hydrocarbons, heavy metals, nutrients etc.
Woody and herbaceous plants	To provide vegetative uptake of pollutants.
Sand bed	To provide good drainage and aerobic conditions of the planting soil. The sand bed also provides final, polishing treatment.

Typical example schematics are shown in Figure 11.1.

Trees and large shrubs can be included as they:

- intercept precipitation and allow water to evaporate
- dissipate rainfall-runoff energy
- facilitate surface water infiltration and groundwater recharge
- provide shade and can reduce potential runoff temperatures.

Bioretention areas are suitable for numerous situations including residential plots, car parks, along highways and roads, within larger landscaped pervious areas, and as landscaped islands draining impervious areas. The concepts of bioretention can also be included in swales and infiltration basins to improve pollutant removal and enhance amenity value.

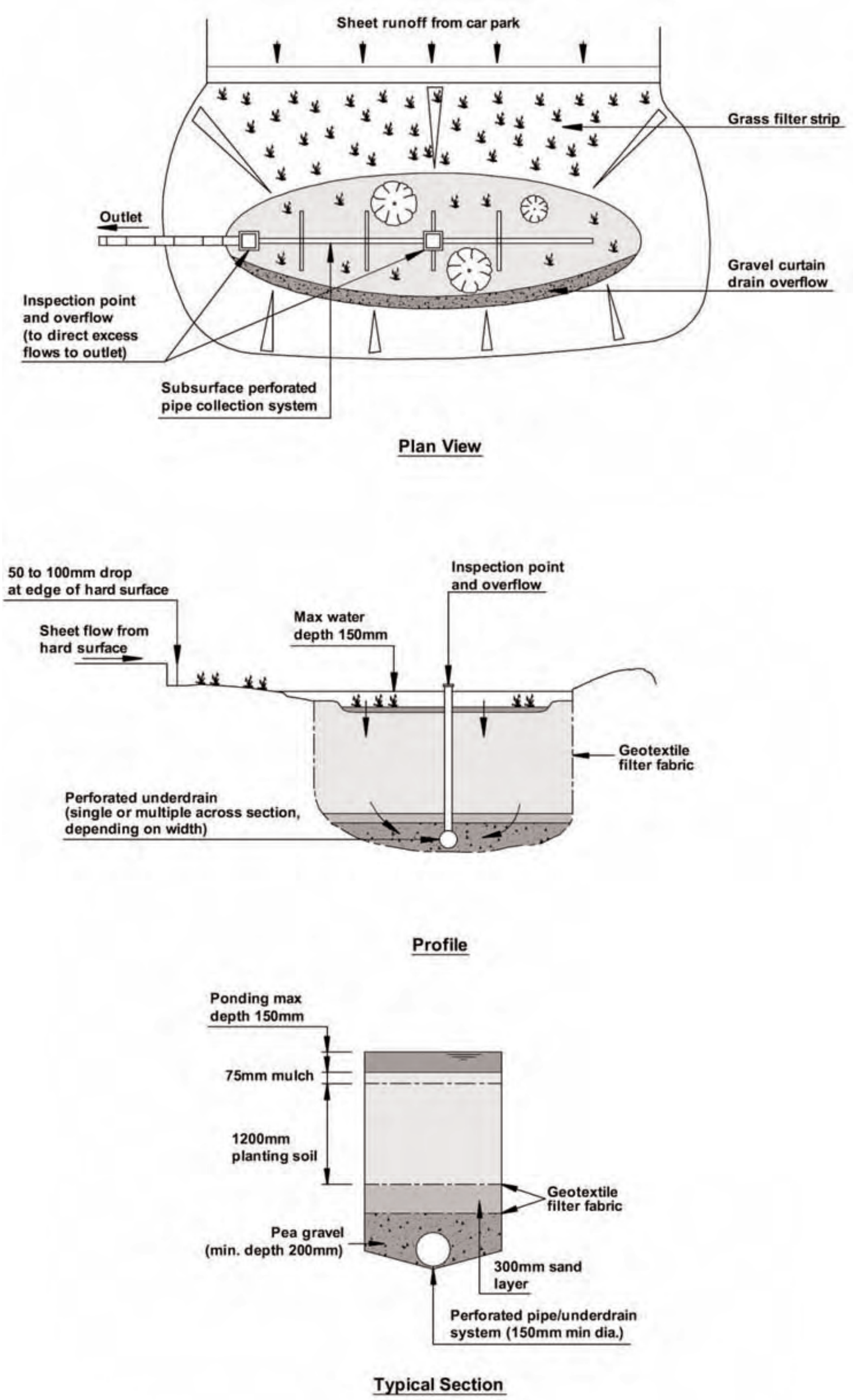

Figure 11.1 *Plan and elevation schematics of a typical on-line bioretention area*

Figure 11.2 provides examples of bioretention area applications.

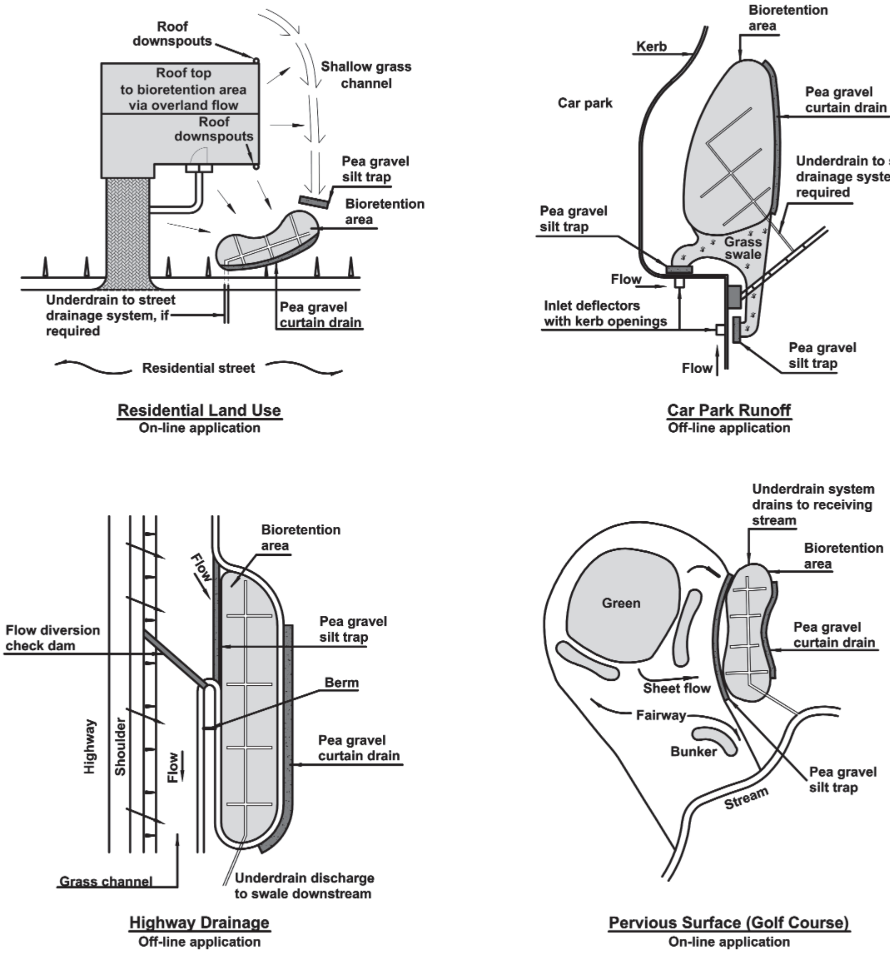

Figure 11.2 *Bioretention area applications (adapted from Claytor and Schueler, 1996)*

11.2 SELECTION AND SITING OF BIORETENTION AREAS

Bioretention areas are applicable to most types of development, and can be used in both residential and non-residential areas. However, the base will require lining where infiltration to the ground is not appropriate, eg some industrial sites.

The criteria presented in Table 11.2 should be considered to ensure the suitability of bioretention areas for meeting drainage objectives at a particular site.

Table 11.2 *Considerations for the use of bioretention areas*

Drainage area	Bioretention areas are generally applied to small catchments, although larger sites can be divided into several smaller parcels with multiple and/or linked bioretention zones.
Space required	Typically bioretention areas require 5 to 10% of the overall site area. However, with imaginative site design, they can be incorporated into the site landscaping.
Siting	Bioretention area locations should be integrated into the site planning, and aesthetic considerations should be taken into account in their siting and design. Bioretention areas are designed for intermittent flow and must be designed to drain and re-aerate between rainfall events. They should not be used on sites with a continuous groundwater flow, sump pumps, or other sources.
Site slope & stability	Bioretention areas can be used in most ground conditions. They tend to be difficult to incorporate effectively within steeper catchments. Unlined bioretention areas should not be used in locations where infiltrating water may cause slope stability or foundation problems eg areas of landslides, at the top of cutting or embankment slopes, or close to building foundations, unless a full assessment of the risks has been carried out by a suitably-qualified geotechnical engineer or engineering geologist. The effects of water storage on the structural capacity of the underlying soils must also be carefully assessed and slopes and collection systems used to manage the risks associated with ponding water.
Subsurface soils and groundwater	Where bioretention areas are designed for infiltration, the seasonally high groundwater table must be more than 1m below the base of the facility and the design must comply with the environmental regulator's policy on infiltration and groundwater protection. Where infiltration is not required, the seasonally high groundwater level should be below the level of the liner. Infiltration devices will normally require a minimum infiltration rate of 1.0 x 10^{-6} m/s to work effectively. Unlined bioretention areas should not be used on brownfield sites unless the contaminants and their effect on the environment have been fully evaluated. Unlined bioretention areas should not be used to treat runoff from hotspots if there is a risk of groundwater pollution.

11.3 HYDRAULIC AND WATER QUALITY DESIGN

The bioretention system should be designed to provide sufficient area to temporarily store the water quality treatment volume as a layer of not more than 150 mm depth on the surface. This will enhance evaporation and should limit the amount of time water is standing on the surface of the facility. Under normal conditions, the length of time that water is lying on the surface should be limited otherwise the choice of plant species will be limited. It is recommended that a bioretention system should dewater within 48 hours of a design storm occurring and should half empty through the soil filter and/or surrounding ground within 24 hours. This provides sufficient contact time to remove pollutants but ensures that system is ready to receive subsequent events.

The surface area required to achieve this can be calculated by using the equation given in Box 11.1:

Box 11.1 *Calculating required bioretention surface area*

$$A_f = \frac{V_t \times L}{k(h + L)\,t}$$

Where:

Af = Surface area of filter bed (m^2)
Vt = Water quality treatment volume (m^3)
L = filter bed depth (m)
k = coefficient of permeability of filter medium for water (m/s) For planting soil beds,
k = 0.000002 m/s – an average value for a silty loam
h = average height of water above filter bed (half maximum height) (m)
t = Time required for water quality treatment volume to percolate through filter bed(s).

A simpler relationship is available, which is 5–7 per cent of the drainage area multiplied by the runoff coefficient, and this can be used as a design check. Five per cent applies to bioretention areas that include a sand bed, and 7 per cent applies to those without.

For sizing of the underdrain, conventional hydraulic design methods (see Box 12.4) should be used to design a system to carry away the infiltrating water and to ensure that the overlying soils do not become saturated. The underdrains should have a hydraulic capacity exceeding that of the surrounding soils. The underdrains should be connected to a positive outflow and be constructed using slotted pipes or geocellular units. They should be wrapped in a geotextile to minimise the risk of fine soil particles and sediment being carried into it and causing blockage.

11.4 PHYSICAL SPECIFICATIONS

Bioretention area designs should be specific to the particular location. Their form and aesthetic appearance will depend on specific site characteristics and development design criteria. However, there are a number of criteria that should be observed for optimum pollutant removal, ease of maintenance and good safety practice.

Geometry

The geometric design of bioretention areas can be very flexible allowing their use for all parts of a site.

Shape is not critical for bioretention areas, but minimum widths of 3 m and length to width ratios of 2:1 will allow random planting of small trees and/or woody shrubs (providing a more robust planting that can withstand pollutants) and will also facilitate operation and maintenance of the system.

The soil bed should have a minimum depth of 1 m. Where trees are planted, the depth should be 1.2 – 1.5 m.

Designing for maintenance and safety

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

An observation cleanout pipe should be provided to the underdrain. The pipe must be securely capped to prevent vandalism.

Materials

The mulch layer (with a maximum depth of 75 mm) is spread over the bioretention area. Standard landscape mulch should be used. Grass cuttings should not be used as surface mulch as they will increase the level of nutrients in the outflow waters. Alternatively, a layer of pea gravel may be provided.

The soil bed should be sufficiently permeable to allow water to pass through it to prevent the surface of the retention area becoming waterlogged. The soil layer should be a sandy loam or a loamy sand mixture with the proportions provided in Table 11.3. Further guidance on the definition of sandy loam and loamy sand is given in British Standard BS 3882 Specification for topsoil (BSI, 1994). The permeability of the soil should be at least 3.5×10^{-6} m/s (12.6 mm/h).

Table 11.3 *Soil specification for bioretention areas (Claytor and Schueler, 1996)*

Component	Proportion in soil mixture (Claytor and Schueler, 1996)
Sand	35 – 60%
Silt	30 – 50%
Clay	10 – 25%
Organic matter	0 – 4%
Topsoil	–

Soil pH in the soil bed should be in the range 5.2 to 7. The soil should be uniform and free from stones, stumps, roots or any other coarse objects that are greater than 50 mm diameter. It should also be free of all undesirable weeds.

The sand filter should have a minimum thickness of 0.3 m and consist of sand with a grain size of 0.5 to 1 mm. The gravel around the underdrain should comprise 20 mm to 5 mm aggregate in accordance with British Standard BS 882 (BSI, 1992) or similar.

Geotextile/geomembrane specifications are set out in Appendix C. Material sustainability principles are presented in Section 3.6.

11.5 PRE-TREATMENT/INLETS

The requirements for pre-treatment/inlets are as for swales. For point source inflows, a diversion inlet can be included that allows the water quality volume into the bioretention area and passes larger volumes of runoff to an overflow system. Inlets and flow diversion structures are discussed in detail in Chapter 19. Pre-treatment options are discussed in Chapter 6.

11.6 OUTLETS

An outlet pipe has to be provided from the underdrain system of the facility to the point of discharge. Due to the slow rate of filtration, outlet protection is generally not necessary.

An overflow structure and non-erosive overflow channel must be provided to pass flows in excess of the bioretention storage capacity to the downstream drainage system safely.

Outlet structures are discussed in detail in Chapter 19.

11.7 LANDSCAPING AND VEGETATION

Plants in bioretention areas must be sufficiently robust to withstand the pollution from runoff.

In general, the same considerations apply for bioretention areas as for swales and the choice of planting should recognise that different areas in the facility are subject to different saturation levels. The bioretention area can therefore be divided into three zones as shown in the following table.

Table 11.4 *Planting for different bioretention zones*

Bioretention zone	Description (in terms of planting)
Upland area	Planted with species that can withstand extended dry periods as well as periods of intense wetting, due to their position in well-drained soils.
Lower layer	Planted with species adapted to standing in fluctuating water levels for extended periods.
Middle layer	Planted with species that can tolerate fluctuating water levels for brief periods

A minimum of three types of shrubs should be used to give diversity which protects against insect attack and disease. This approach will also give a more consistent rate of evapotranspiration and pollutant and nutrient uptake. Herbaceous ground cover should be provided to protect the mulch from erosion (at least three to four species).

There are several variations from the most commonly planting applied planting scheme described above and two of them are briefly outlined below:

(a) **Ornamental planting areas.** These can also act as a bioretention areas where aesthetics are of key importance. If ornamental planting is applied, the retention area should be considered as a mass bed planting so that foliage will cover the entire area at the end of second growing season. A variety of species should be used to give interest all year round, with perennials giving colour from spring to autumn and ornamental grasses and evergreen or berry producing shrubs ensuring that the area remains visually acceptable during the winter. Low maintenance ornamental species are most appropriate.

(b) **Open space meadows.** These areas can be used for bioretention, and tend to have significantly reduced maintenance requirements. The planting used in this case tends to be a variety of ornamental grasses interlaced with variety of wildflowers.

Fencing of bioretention areas is generally not desirable as it may reduce the amenity benefits provided by the facility and provide a barrier to easy maintenance.

Additional information on landscaping and planting best practice is presented in Chapter 20.

11.8 OPERATION AND MAINTENANCE REQUIREMENTS

Regular inspection and maintenance is important for the effective operation of bioretention areas as designed. Maintenance responsibility for a bioretention area should always be placed with an appropriate organisation.

Operation and maintenance requirements for bioretention areas are described in Table 11.5.

Table 11.5 *Bioretention areas operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Litter and debris removal.	Monthly (or more frequently for aesthetic reasons).
	Mulching – remove and replace.	Annually.
	Pruning and trimming of trees – recycle back into mulch.	2 years.
	Spiking, scarifying and thatch removal.	3 years (when mulching).
Occasional maintenance	Watering of plants.	As required.
	Weeding.	As required (probably annually).
Remedial actions	Removal of damaged or silt covered vegetation to a depth 50 mm below original design level.	As required.
	Treatment of diseased trees.	As required.
	Treatment and restoration of eroded areas.	As required.
	Re-turfing.	As required.
	Reinstatement of design levels, restoration or improvement of infiltration and silt removal.	As required.
Monitoring	Inspect inlets, outlets and overflows for blockages, and clear if required.	Monthly/after large storms.
	Inspect infiltration surfaces for ponding. Record dewatering time of the facility to determine if maintenance is necessary.	Monthly, or when required.
	Inspect inlets and facility surface for silt accumulation. Establish appropriate silt removal frequencies.	Half yearly.
	Test planting soil for pH – if adjustment is necessary, amalgamate with appropriate substances.	Annually.

Adequate access must be provided for all bioretention areas for inspection and maintenance, including the appropriate equipment and vehicles.

When found necessary, infiltration in the facility should be restored or improved by removing silt or damaged vegetation and reinstating design levels. Damaged or silt-covered vegetation should be removed to a depth 50 mm below original design level and cultivated to a fine tilth. Infiltration rates can also be affected by the build-up of "thatch". Details on techniques for infiltration surface rehabilitation and thatch management are given in Chapter 22 (Operation and Maintenance). Any re-turfing that is required should be done using turf of a quality and appearance to match the existing sward. Detail on appropriate re-turfing methods is given in Chapter 20 (Landscaping).

Sediments excavated from pre-treatment devices that receive runoff from residential or standard road and roof areas are generally not toxic or hazardous material and can therefore be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation to determine its classification and appropriate disposal methods. For industrial site runoff, sediment testing will be essential. In the majority of cases, it will be acceptable to distribute the sediment on-site if there is an appropriate safe and acceptable location to do so. Additional detail on waste management is provided in Chapter 23.

Specific maintenance needs of the bioretention area should be monitored and maintenance schedules adjusted to suit requirements. Additional detail on the preparation of maintenance specifications and schedules of work is given in Chapter 22.

In general, the maintenance for bioretention areas often can be undertaken as part of landscape maintenance and, if landscape management is already required at the site, it should have marginal cost implications.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken.

11.9 CONSTRUCTION REQUIREMENTS

Bioretention areas should ideally be constructed at the end of development, to minimise erosion and sediment generation, and a dense and vigorous vegetative cover should be established over the contributing pervious catchment area before runoff is accepted into the facility. If this is impractical, bioretention areas should be protected from runoff by using silt fences or straw bales as recommended in the CIRIA publication C532 *Control of water pollution from construction sites*, (Masters-Williams *et al*, 2001).

To minimise the risk of premature system failure the following points should be closely monitored during the construction of bioretention areas:

- care should be taken not to compact the soils below the bioretention area, and particularly the filter and soil planting bed, as this will reduce infiltration capacities
- to excavate a bioretention area, a backhoe excavator should be used and construction plant should avoid running over the bioretention area
- mulch should not be piled up around plants as this will cause disease and encourage pests
- care should be taken to ensure that geotextiles are not clogged or torn during construction
- if soil for the filter layer is imported, soil testing should be carried out: the test should include a particle size distribution, pH and organic matter test for each retention area.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Additional detail on construction and the programming of construction is provided in Chapter 21.

11.10 REFERENCES

BSI (British Standards Institution) (1994)
BS 3882: *Specification for topsoil*
BSI

BSI (British Standards Institution) (1992)
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Pervious pavements

12

Contents

Pervious pavements 12

Description

Pervious pavements provide a pavement suitable for pedestrian and/or vehicular traffic, while allowing rainwater to infiltrate through the surface and into the underlying layers. The water is temporarily stored before infiltration to the ground, reuse, or discharge to a watercourse or other drainage system. Pavements with aggregate sub-bases can provide good water quality treatment.

KEY DESIGN CRITERIA

- pervious surface and sub-base to be structurally designed for site purpose and design vehicular loading
- surface infiltration rate should normally be an order of magnitude greater than the design rainfall intensity
- temporary subsurface storage volume to meet requirements for infiltration and/or controlled discharge
- geotextile may be specified as a filtration treatment component near the top of the structure
- soil and other material must be prevented from contaminating the pavement surface and sub-structure.

ADVANTAGES

- effective in removing urban runoff pollutants
- lined systems can be used where infiltration is not desirable, or where soil integrity would be compromised
- significant reduction in volume and rate of surface runoff
- suitable for installation in high density development
- good retrofit capability
- no additional land take, allows dual use of space
- low maintenance
- removes need for gully pots and manholes
- eliminates surface ponding and surface ice.
- good community acceptability.

DISADVANTAGES

- cannot be used where large sediment loads may be washed/carried onto the surface
- in the UK, current practice is to use on highways with low traffic volumes, low axle loads and speeds of less than 30 mph
- risk of long-term clogging and weed growth if poorly maintained.

PERFORMANCE:

Peak flow reduction:	Good
Volume reduction:	Good
Water quality treatment:	Good
Amenity potential:	Poor
Ecology potential:	Poor

TREATMENT TRAIN SUITABILITY:

Source control:	Yes
Conveyance:	No
Site system:	Yes
Regional system:	No

SITE SUITABILITY:

Residential:	Yes
Commercial/industrial:	Yes
High density:	Yes
Retrofit:	Yes
Contaminated sites/sites above vulnerable groundwater (with liner)	Yes

COST IMPLICATIONS:

Net Land-take:	Low
Capital cost:	Medium
(Net capital cost:	Low)
Maintenance cost:	Low

POLLUTANT REMOVAL:

Total suspended solids:	High
Nutrients:	High
Heavy metals:	High

KEY MAINTENANCE REQUIREMENTS

- sweeping
- regular brushing and vacuuming.

12.1 GENERAL DESCRIPTION

Pervious pavements are SUDS structures that allow rainwater to infiltrate through the surface and into the underlying layers, where water is temporarily stored before infiltration to the ground, reuse or release to a watercourse or other drainage system. The three principal system types are described in Figure 12.1 (a) – (c). Type A reflects a system where all the rainfall passes through the sub-structure (where it may be stored temporarily) into the soils beneath. Normally, there will be no discharge from the system. However an emergency overflow may be required to cater for events in excess of the design event, or to allow for the system becoming less efficient eg as a result of siltation.

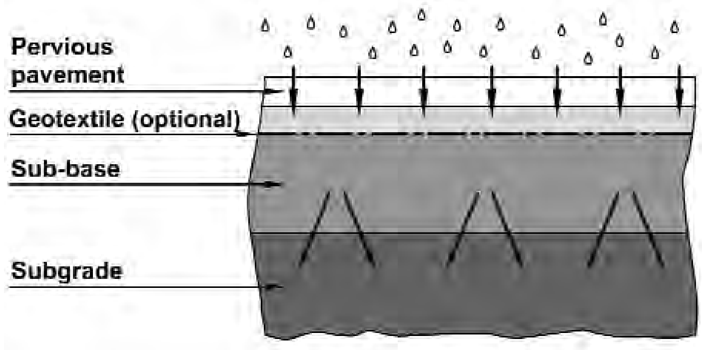

Figure 12.1(a) *Pervious pavement system types: Type A – Total Infiltration*

In a Type B system, a series of perforated pipes at formation level will convey the proportion of the rainfall that exceeds the infiltration capacity of the sub-soils, to the receiving drainage system. By preventing the build-up of water above the sub-grade, the risks to soil stability are reduced.

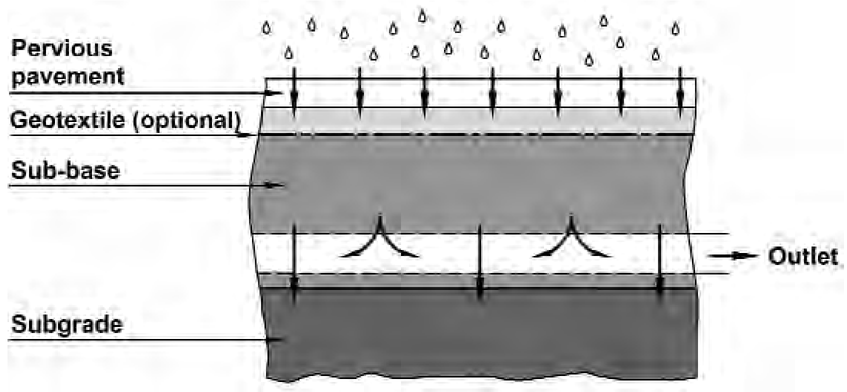

Figure 12.1(b) *Pervious pavement system types: Type B – Partial Infiltration*

There is no infiltration in a Type C system, and the system is generally wrapped in an impermeable, flexible membrane placed above the sub-grade (formation level). Once the water has filtered through the sub-base, it is conveyed to the outfall via perforated pipes or fin drains. This is used for situations where:

- soils have low permeability or low strength (and could therefore be damaged by the introduction of infiltrating water)
- the water is to be harvested and reused
- the underlying groundwater is sensitive and requires protection
- the water table is within 1 m of the sub-base
- the site is contaminated and the risks of mobilising contaminants must be minimised.

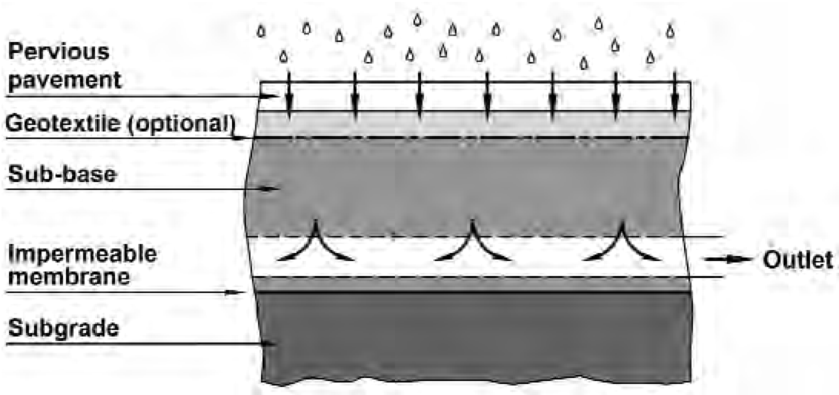

Figure 12.1(c) *Pervious pavement system types: Type C – No Infiltration*

Pervious pavements can be made of porous material or constructed as a permeable surface – the distinction being:

Porous pavements infiltrate water across their entire surface material, eg reinforced grass or gravel surfaces, porous concrete and porous asphalt

Permeable pavements are formed of material that is itself impervious to water. The materials are laid to provide void space through the surface to the sub-base, eg concrete block paving specifically designed to allow surface water falling onto the surface to infiltrate through the joints or voids between the blocks into the underlying pavement structure.

Pervious surfaces, together with their associated substructures, intercept surface water runoff and provide a pollutant treatment medium prior to discharge to receiving waters. Treatment processes that occur within the surface structure, the subsurface matrix (including soil layers where infiltration is allowed) and the geotextile layers include:

- filtration
- adsorption
- biodegradation
- sedimentation.

Type C system designs may be modified to allow a proportion of runoff to be stored and used for various non-potable applications such as irrigation, toilet flushing etc. For additional information on opportunities for using rainwater, see Section 6.5 of this publication and also CIRIA publication C539 (CIRIA, 2001a) and Project Report 80 (CIRIA, 2001b).

The aggregate sub-base can sometimes be replaced with geocellular block systems (see Chapter 13). These will provide a higher storage capacity (with >90 per cent voids ratio), but the benefits of treatment within the sub-base gravels will be lost and additional treatment options may have to be considered.

Typically pervious pavements are used to manage rainfall landing directly on the surface, but their capacity is such that they may also be used to provide storage and filtration of water that drains from adjacent areas, such as roofs or adjacent impermeable areas of car parks. The use of pervious pavement should be avoided where there is a high risk of silt loads on the surface resulting in the possibility of clogging.

Typical applications of such systems are shown in Figure 12.2. Roof drainage directs large volumes of water into the pavement very quickly and inlet diffusers will be required to regulate the flow velocities.

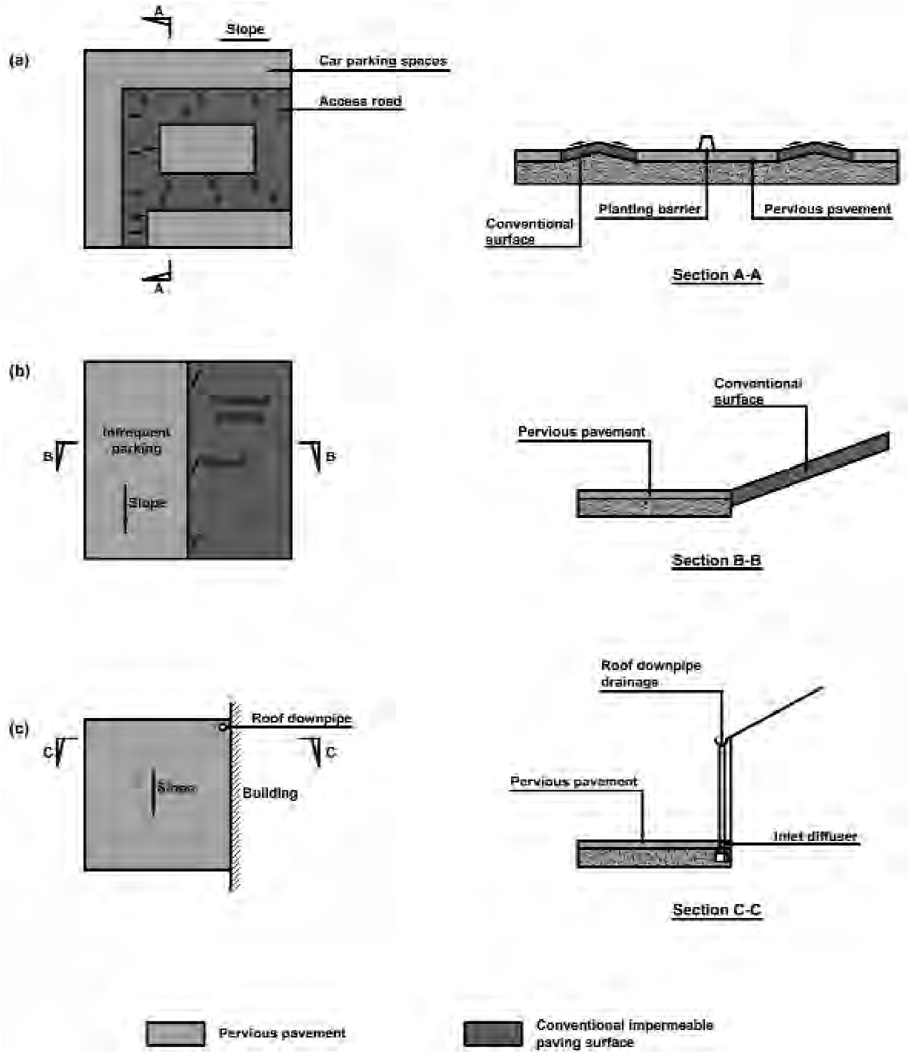

Figure 12.2 *Typical applications of pervious pavement systems*

Pervious surfaces can also be designed as a "green" surface by using grass protection systems. There are many variations of products commercially available with a wide range of finishes, making them suitable for the majority of landscape applications. Technical details of many of these systems are discussed in CIRIA publication C582 (Pratt *et al*, 2001). A green system is shown in Figure 12.3.

Figure 12.3 *Green pervious pavement systems*

Figures 12.4 – 12.6 provide example schematics for typical pervious pavement layouts. Figure 12.4 shows a modular interlocking plastic paving system infilled with gravel/grass/aggregate which is typically used for light/medium loadings such as car parks.

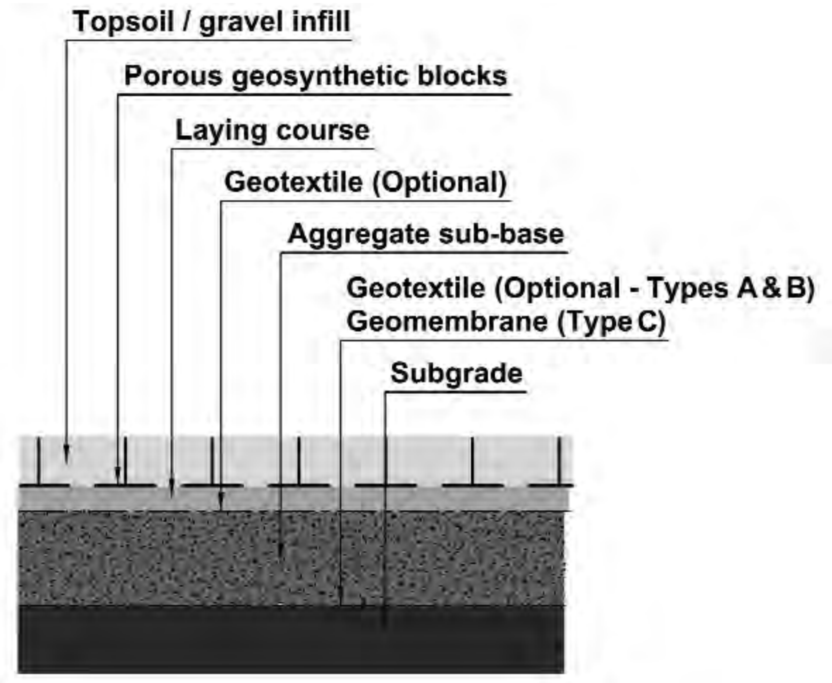

Figure 12.4 *Geosynthetic gravel/grass pavement systems (adapted from Pratt* et al*, 2001)*

Figure 12.5 shows a porous asphalt, porous concrete or resin-bound aggregate surface.

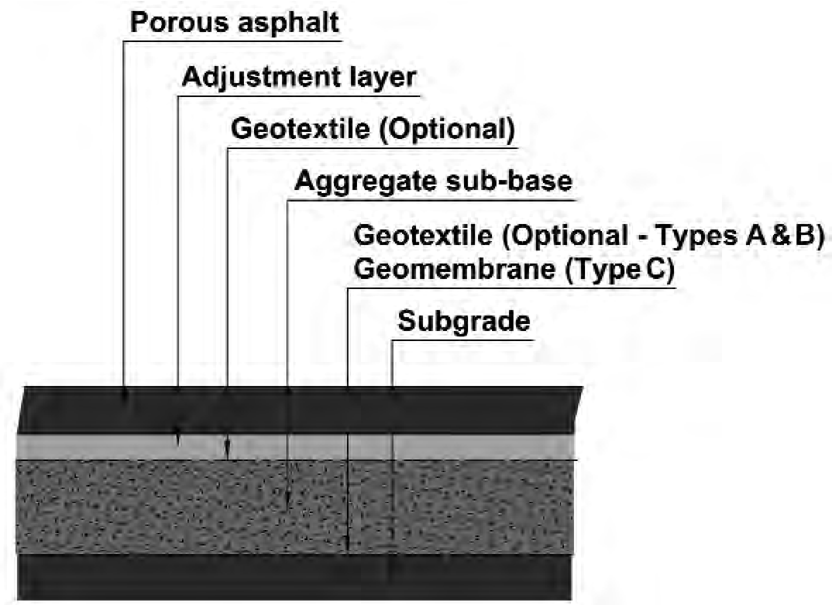

Figure 12.5 *Continuous laid porous material (adapted from Pratt* et al*, 2001)*

This porous asphalt is not the same as the material that has been used on some motorways and trunk roads to reduce spray and noise which is only a thin porous layer placed over conventional impermeable materials.

Figure 12.6 shows a pre-cast block surface with voids between the blocks that allow infiltration.

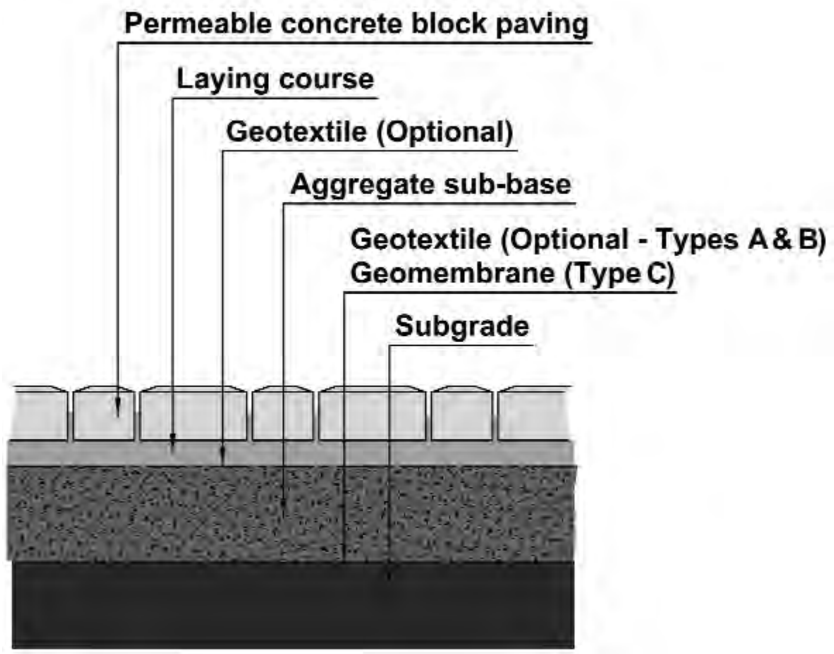

Figure 12.6 *Permeable concrete block pavement (adapted from Pratt* et al*, 2001)*

Other surface system types include reinforced open-textured soil or granular material, porous elemental surfacing blocks, large elemental surfacing blocks with a pattern of voids, and *in-situ* cast concrete systems with large voids.

12.2 SELECTION AND SITING OF PERVIOUS PAVEMENTS

Pervious pavements can be used on a wide variety of sites for both infiltration and attenuation of surface water collected from paved areas and roof catchments. The issues listed in Table 12.1 should be considered to ensure the suitability of a pervious pavement for meeting drainage objectives on a site or development.

Table 12.1 *Considerations for using pervious pavements*

Drainage area	A pervious pavement generally accepts rain that is directly falling on its surface. Where runoff from other impervious areas is accepted into the facility, the maximum additional drainage area is limited by constraints on the available sub-base volume of the facility and its outflow characteristics.
Space required	Pervious pavements are typically built as an alternative to impermeable surfaces and therefore require no additional development space for their construction. With the high proportion of road surface required in any urban environment, there is plenty of opportunity to apply this drainage technique.
Siting	Pervious pavements can be fitted into almost any development site. They require only a small head difference from the runoff surface to their outflow and can therefore be employed on very flat terrain. In the UK, the use of constructed pervious surfaces as a source control technique is currently implemented for highways with low traffic volumes, axle loads and speeds (less than 30 mph), car parking areas and other lightly trafficked or non-trafficked surfaces. Outside the UK, pervious surfaces have been used in locations with heavy axle loads. Such pavements should be designed on an individual basis and in conjunction with manufacturers and experienced geotechnical and pavement engineers.

Table 12.1 *Considerations for using pervious pavements (continued)*

Site slope & stability	Pervious pavements can be used in most ground conditions and can be sited on waste, uncontrolled or non-engineered fill providing a liner is employed and the degree of compaction of the foundation material is high enough to prevent significant differential settlement. Unlined pavements should not be used in locations where infiltrating water may cause slope stability or foundation problems, eg areas of landslides, at the top of cutting or embankment slopes, or close to building foundations, unless a full assessment of the risks has been carried out by a suitably-qualified geotechnical engineer or engineering geologist. The effects of water storage on the structural capacity of the underlying soils must also be assessed carefully and slopes and collection systems used to manage the risks associated with ponding water. There should be a nominal fall on the pavement formation level. On steeper sites, internal dams may be installed to maximise storage.
Subsurface soils and groundwater	Where pervious pavement systems are designed for infiltration, the seasonally high groundwater table must be more than 1 m below the base of the facility and the design must comply with the environmental regulator's policy on infiltration and groundwater protection. Where infiltration is not required, the seasonally high groundwater level should be below the level of the liner. Unlined pavements should not be used on brownfield sites unless the contaminants and their effect on the environment have been fully evaluated. Unlined pavements should not be used to treat runoff from hotspots if there is a risk of groundwater pollution.

12.3 PAVEMENT DESIGN

Any pervious pavement will need to be able to capture the required design storm event and discharge it in a controlled manner to the subgrade or drainage system, while providing sufficient structural resistance to withstand loadings imposed by vehicles above.

Table 12.2 recommends appropriate pavement systems for a range of sub-grade conditions, while Table 12.3 gives guidance on soil classification. Both tables are taken from Interpave's *Guide to the Design, Construction and Maintenance of Concrete Block Permeable Pavements*, Edition 3, (Interpave, 2005).

Table 12.2 *Guidance on selection of a pavement system type (adapted from Interpave, 2005)*

Ground characteristics		System 1: Total infiltration	System 2: Partial infiltration	System 3: No infiltration
Permeability of subgrade defined by coefficient of permeability k(m/s)	10^{-6} to 10^{-3}	✓	✓	✓
	10^{-8} to 10^{-6}	×	✓	✓
	10^{-10} to 10^{-8}	×	×	✓
Highest expected water level within 1000 mm of formation level		×	×	✓
Pollutants present in subgrade		×	×	✓

Table 12.3 *Soil classification guide (Interpave, 2005)*

Soil classification	Typical range for coefficient of permeability, k (m/s)	Typical range of CBR values
Heavy clay	10^{-10} to 10^{-8}	2 to 5
Silty clay	10^{-9} to 10^{-8}	3 to 6
Sandy clay	10^{-9} to 10^{-6}	5 to 20
Poorly graded sand	5×10^{-7} to 5×10^{-6}	10 to 40
Well graded sand	5×10^{-6} to 10^{-4}	10 to 40
Well graded sandy gravel	10^{-5} to 10^{-3}	30 to 80

A recommended design flow chart, adapted from CIRIA publication C582 (Pratt *et al*, 2001) is provided as Figure 12.7.

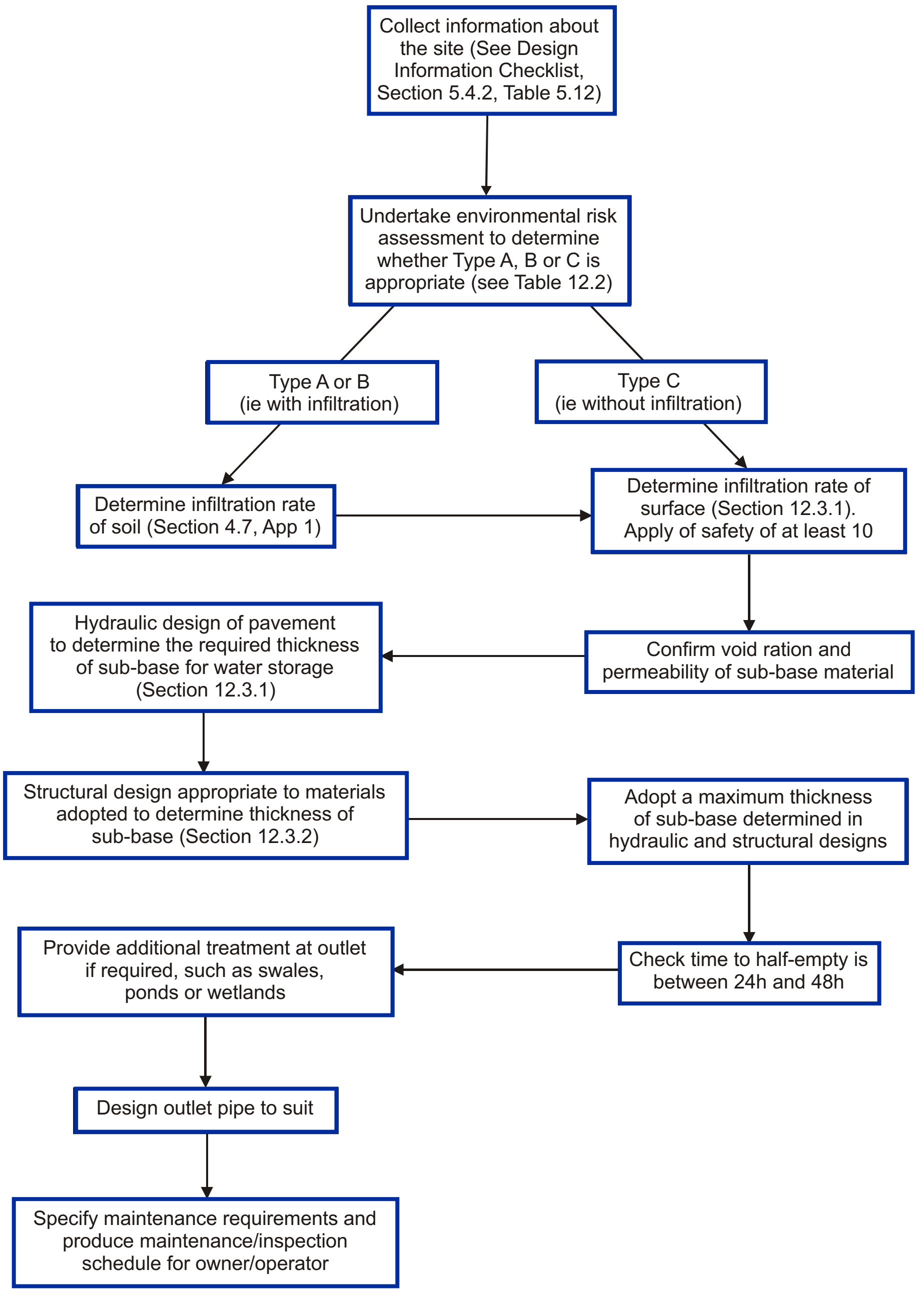

Figure 12.7 *Pervious surface design flow chart (adapted from Pratt* et al*, 2001)*

12.3.1 Hydraulic design

There are four aspects to the hydraulic design of pervious pavements:

1) Confirmation of adequate rate of infiltration of rainwater through the pavement surface.
2) Storage volume required for design storm rainfall event management.
3) Adequacy of outfall capacity to convey water from the pavement structure.
4) Management of extreme events (ie in excess of the design storms).

1) Infiltration of rainwater through the surface

The design surface infiltration rate should be significantly greater than the design rainfall intensity to avoid surface water ponding and the calculation of the inflow rate should include all anticipated runoff from adjacent areas. Typically, infiltration rates of pervious surfaces are significantly greater than design rainfall intensities and are not generally limiting factors for the use of a pervious pavement. Geotextiles in the upper layers can adversely affect the infiltration rate if they become blinded with fine silt. Surface ponding is not necessarily a problem, provided it is planned for in the surface design and the maximum water depth on the surface and the time for which it remains is acceptable.

The typical percolation rate through concrete block paving joints is of the order of 4000 mm/hr. This rate will decrease but stabilise with age, due to the build-up of silt and other debris in the joints. It is recommended that a factor of safety of 10 is applied to allow for clogging to affect a proportion of the surface area over the design life.

2) Pavement sub-surface storage capacity

The required capacity of the sub-base depends on rainfall characteristics, design return period, infiltration potential into the subgrade, discharge constraints, and the impermeable area draining to the pervious pavement. The actual capacity available is a function of the depth and area of storage material and the voids volume.

The thickness of the sub-base required to provide sufficient water storage capacity can be obtained by calculation (as described in Interpave's guidance on the design of permeable pavements eg Interpave, 2005) or by detailed hydrological and hydraulic modelling. Note the Interpave procedure involves a simple calculation which assumes no outflow of water during the period of the storm (worst case scenario). Proprietary drainage software now exists that can predict hydraulic profiles across a pavement and computes capacities for design events in more detail.

Figure 12.8 is based on a spreadsheet that assumes a constant rate of discharge during the design storm event. The calculations are based on a fairly standard storage depth of 360 mm with a voids ratio of 0.3, together with the simple assumption of 100 per cent runoff. The rainfall criteria used was the 100 year event, and FSR/FEH rainfall characteristics for M560 and "r" of 20 mm and 0.4 for the south and east of Britain and 20 mm and 0.3 for the north and west were assumed. The throttle limits used in the analysis are from 1 to 5 l/s/ha which ranges from extremely conservative to typical discharge limits.

This analysis shows that at least twice the area of the pervious pavement can be served by the structure when very tight throttle controls are applied, and nearly three times the area when the throttle rate is greater than 5 l/s/ha.

Where partial or total infiltration systems are used, the infiltration rate can be calculated as a discharge rate. For most soils the exfiltration rate will be significantly greater than throttle rates of 1 to 5 l/s/ha and the system can therefore serve even greater areas. However soil stability due to saturation and reduced infiltration rate due to the construction process or fines blockage means that care must be taken against hydraulically over-loading the pervious pavement.

Calculations for a range of rainfall durations should be carried out to verify the performance of the available storage volume.

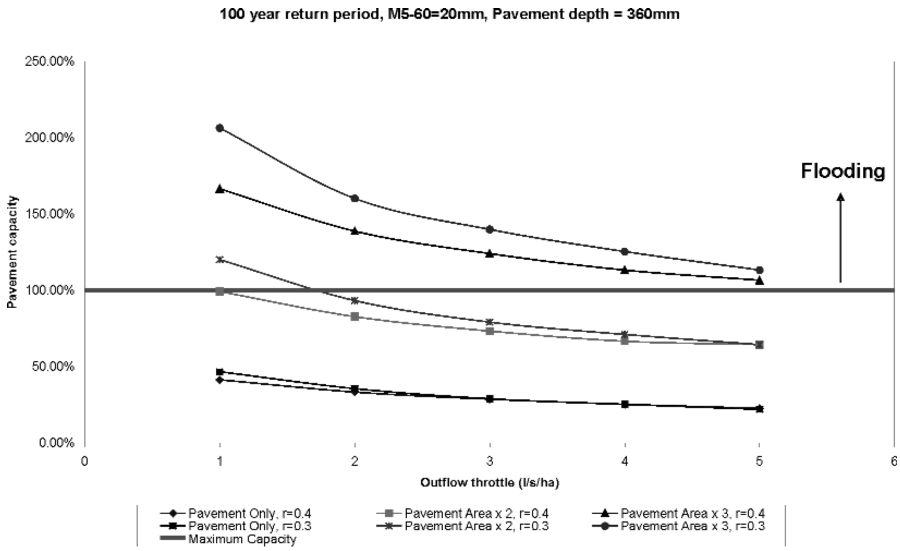

Figure 12.8 *Example of permeable pavement capacity*

3) Outflow from the pavement structure

The drainage capacity of the permeable sub-base material and the spacing of the outlet pipes or collector pipes for sealed systems can be assessed using guidance provided by Cedergren (1974). The maximum surface runoff rate that can be removed by a flat permeable sub-base is estimated using the equation given in Box 12.1.

Box 12.1 *Equation to estimate outfall pipe capacity*

$q = k\,(h/b)^2$

q = runoff rate into the pavement (m/s)
k = coefficient of permeability of sub-base (m/s)
h = thickness of sub-base above impermeable base (m)
b = half the distance between drains (m)

For sloping subgrades and non-symmetrical pipe layouts, the flow in the sub-base can be estimated using Darcy's law as given in Box 12.2.

Box 12.2 *Darcy's Law to calculate sub-base flow*

$Q = A.k.i$

Where:
Q = flow capacity of sub-base (m^3/s)
A = cross-sectional flow area (m^2)
k = coefficient of permeability of sub-base (m/s)
i = hydraulic gradient (assumed to be the slope of the subgrade – generally a conservative assumption).

Pipe perforations should be 10 mm in diameter and should terminate 300 mm from any connection point. The upper ends of the pipes should be capped.

4) Management of events in excess of the design storm

Pervious pavement systems must consider and design for extreme storm events which exceed the design criteria. One option is to use storm drain inlets set slightly above the elevation of the pavement. This would allow for some ponding above the surface, but would accept bypass flows that exceed the surface infiltration capacity. Alternatively, excess volumes of floodwater can be routed safely from the site to a suitably-sized temporary detention area or stream.

Systems should always include emergency overflow provisions in case the design event is exceeded. Temporary storage of runoff from extreme events above the pavement surface should not be permitted where there is a risk of surface clogging from deposited sediments and other debris. Designs using total infiltration should include emergency overflow provisions such as pipes or outlets onto adjacent grassed areas. Partial or no infiltration systems should include pipework to accommodate overflow conditions.

12.3.2 Structural design methods

Although no approved structural design methods for pervious pavements exist in the UK, there are a number of general principles that should be followed when pervious pavements are designed. The document *Permeable pavements: guide to the design, construction and maintenance of concrete block permeable pavements* (Interpave, 2005) or latest version should be referenced for the design of concrete block permeable pavements. The publication *Source control using constructed pervious surfaces*, CIRIA C582 (Pratt *et al*, 2001), should be referenced for supporting detail on pervious pavement design methods and materials. Manufacturers should be contacted for design details of pervious asphalt and other proprietary products.

Key structural criteria are that:

1. The subgrade must be able to sustain traffic loading without excessive deformation.
2. The laying course and sub-base layer must give sufficient load spreading to provide an adequate construction platform and base for the overlying pavement layers.
3. The bituminous, concrete, blocks or other pavement materials must not crack or suffer excessive rutting under the influence of traffic.

A structural design process is set out in Figure 12.9 (taken from Interpave, 2005), but appropriate methods should always be checked with the manufacturer of the pavement system used in the design.

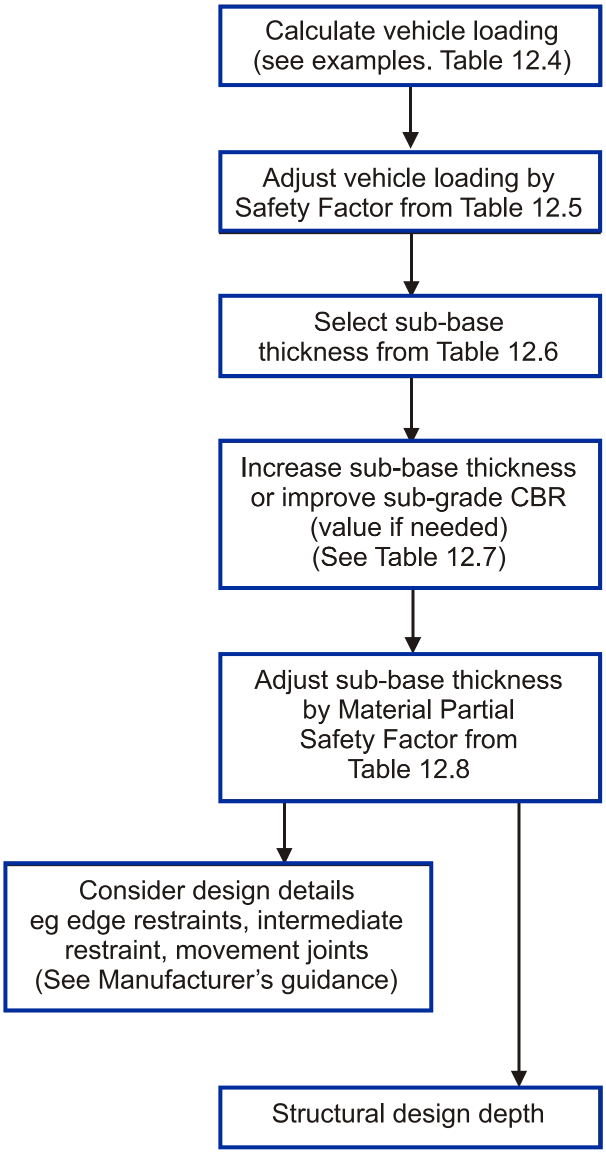

Figure 12.9 *Flow chart for structural design of concrete block pavements (Interpave, 2005)*

Table 12.4 *Axle loads (Interpave, 2005)*

Load category	Maximum axle load (kg)
Category 1 – domestic	1,000
Category 2 – light	2,000
Category 3 – commercial	5,000

Table 12.5 *Load partial safety factors*

Certainty of load	Load partial safety factor
Certain	1.4
Well-informed	1.6
Anecdotal	2.0

The sub-base thickness of open-graded crushed rock required to meet the loading criteria can then be read from Table 12.6.

Table 12.6 *Sub-base thickness of open-graded crushed rock for loading (for CBR of 5%) (Interpave, 2005)*

Factored load (kg)	Course thickness (mm) (open graded crushed rock)	Total sub-base thickness (mm)
1,400	200	200
1,600	225	225
2,000	250	250
2,800	275	275
3,200	300	300
4,000	350	350
7,000	150	275
8,000	150	300
10,000	150	350
15,400	150	450

The pavement layer thickness of open-graded crushed rock is applicable to a subgrade with a CBR of 5 per cent (when saturated for Type A or B pavements). For sub-grade CBR values lower than 5 per cent, either the thickness can be adjusted using the values given in Table 12.7, or the subgrade can be improved to give a higher CBR value.

Table 12.7 *Sub-base thickness adjustment for low CBR values*

Sub-grade CBR (%)	Adjustment to thickness of open-graded crushed rock (mm)
>5	–100
5	No change
4	150
3	250
2	350
1	Sub-grade improvement required ie capping layer

After adjustment, the minimum thickness of un-stabilised material must be at least 150 mm. Finally, the second partial safety factor, which is the material partial safety factor, should be applied, as shown in Table 12.8.

Table 12.8 *Material partial safety factors*

Nature of base material	Material partial safety factor
As stable as Specification for Highway Works 803 material (type 1) or type 3 Clause 805	1
As stable as graded 20 mm crushed rock to BS EN 13242 (4/20)	1.1
As stable as rounded 20 mm graded gravel to BS EN 13242 (4/20) (*)	1.4 (*)

(*) It should be noted that sand and gravel with rounded particles is not recommended for use in pervious pavement sub-base construction.

12.3.3 Structural design considerations

The following factors are important considerations:

1) Pervious pavements use materials with high permeability and void space. All the current structural pavement design methods commonly used in the UK are based on the use of conventional materials, which are dense and relatively impermeable. Therefore, the stiffness of any alternative materials to be used must be reviewed, possibly using equivalence factors. Recommendations are given in CIRIA publication C582 (Pratt *et al*, 2001).

   Water will be present within the construction, and designs should ensure no loss of strength or stiffness of either sub-base layers or foundation subgrade, especially when these layers become saturated. Materials such as clays, silts and chalks can suffer rapid loss of strength and stiffness with very small increases in moisture content and this must be given full consideration in the design. The Californian Bearing Ratio (CBR) is an empirical index used for pavement design and this should be measured or estimated for the saturated foundation soils, unless an impermeable membrane is used to prevent infiltration in which case the non-saturated state can be assessed. CBR samples should be taken in accordance with BS 1377:Part 4 (BSI, 1990).

2) General pavement design methods assume full friction between layers. In general, for pervious pavements, geotextiles immediately above the sub-base promote additional tensile strength. However geotextile within the upper layers must be carefully specified to minimise loss of friction where horizontal forces are likely to be significant (eg braking forces). Geotextiles should be selected with reference to the British Standard *Geotextiles and geotextile-related products* (BS EN 13252:2001) and specifications are discussed in Appendix C and CIRIA Report C582 (Pratt *et al*, 2001). This issue is illustrated in Figure 12.10.

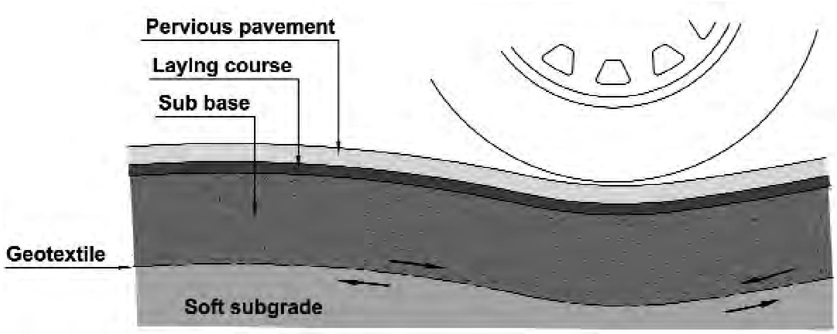

Figure 12.10 *Geotextile requirement to confine lateral movement between layers (adapted from Pratt* et al*, 2001)*

3) The materials used for pervious pavement construction should be either single-sized or carefully graded. Care must be taken to ensure that loss of finer particles between unbound layers does not occur as this can reduce the strength of granular layers. Geotextile can be laid between unbound layers to prevent this from occurring, as shown in Figure 12.11.

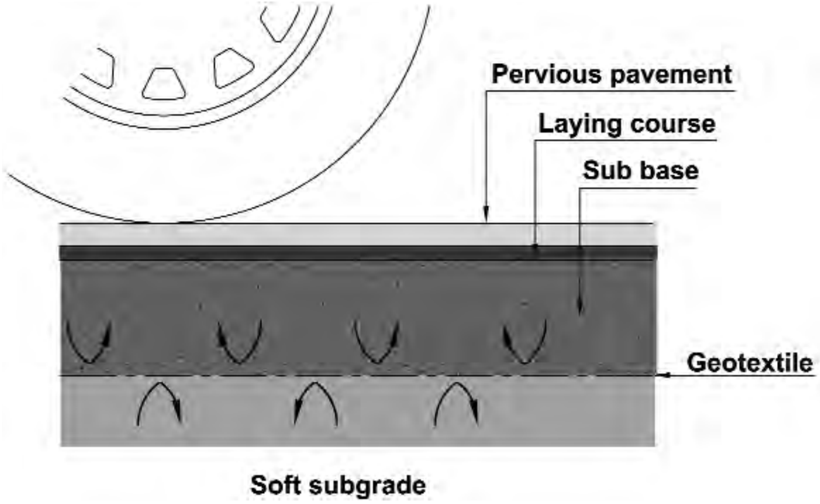

Figure 12.11 *Geotextile requirement to provide sub-grade layer separation (adapted from Pratt* et al*, 2001)*

Where geotextile is not provided between laying course and sub-base, the aggregates should meet the following criteria:

$D_{15 \text{ sub base}} / D_{50 \text{ laying course}} < 5$

and

$D_{50 \text{ sub base}} / D_{50 \text{ laying course}} > 2$

4) For sub-base aggregate, a 450 mm minimum depth should be used to allow for frost susceptibility unless it can be demonstrated that it is not necessary due to the nature of the construction or the sub-grade soils.

Characteristics of each of the sub-base layers are discussed in the following sections.

12.3.4 Sub-base characteristics

(a) Laying course and jointing material

Typical grading specifications are given in Table 12.9, but advice should always be sought from the pervious pavement manufacturer with regard to the exact material type that is suitable for each system.

Table 12.9 *Laying course specification (2/6.3 to BS EN 12620 (BSI, 2002b))*

BS sieve size, mm	Percentage passing
14	100
10	90 – 100
6.3	80 – 99
2	0 – 20
1	0 – 5

(b) Geotextile filter characteristics

Geotextiles which act as filters must allow free flow of water, ie with zero breakthrough head. They should be manufactured from polyethylene, polypropylene or other suitable mono-filament that can withstand the additional loads applied during construction and should have a design life equivalent to the pavement design life.

They must not be adversely affected by pollutants, alkaline or acidic groundwater. Guidance on specifications is given in Appendix C, however it is recommended that specialist advice be sought from the manufacturer or material supplier.

(c) Sub-base aggregate characteristics

The requirement for low fines content means that the load in the sub-base will essentially be carried by point-to-point contact between aggregate particles. To maximise the friction between particles and thus increase strength, the particles should be rough and angular to give good interlock. Crushed rock (granite, basalt, gabbro) or concrete with >90 per cent fracture faces or blast furnace slag is required to achieve this. Sand and gravel with rounded particles should not be used in pervious pavement sub-base construction. Aggregates should comply with *Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction* (BS EN 13242 BSI (2003)) or *Aggregates for concrete* (BS 12620, BSI (2002a)). The choice is a compromise between stiffness, permeability and storage capacity. Typical gradings for sub-base aggregates are provided in Table 12.10. The material type (from the *Specification for highway works* (Highways Agency *et al*, 1998)) is UF5-0C80-GO-0/40 or Clause 805 Type 3 base material.

Table 12.10 *Typical grading requirements for sub-base aggregates (to BS EN 12620)*

Sieve size (mm)	Percent passing	
	Coarse aggregate 4 mm to 40 mm (4/40)	Coarse aggregate 4 mm to 20 mm (4/20)
80	100	–
63	98 – 100	–
40	90 – 99	100
31.5	–	98 – 100
20	25 – 70	90 – 99
10	–	25 – 70
4	0 – 15	0 – 15
2	0 – 5	0 – 5
1	–	–

As the sub-base will be in contact with water for a large part of the time, the strength and durability of aggregate particles when saturated and subject to wetting and drying should be assessed. The materials should also not crush or degrade either during construction or in service. The specification of "Los Angeles" test values, micro deval tests and flakiness tests will address these issues. Sub-base aggregate specification requirements are summarised in Table 12.11.

Recycled material can be used where a source is conveniently available but care should be taken that this is of consistent quality, has an appropriate grading and is free of unacceptable materials such as organic matter or steel scrap.

Table 12.11 *Sub-base aggregate specification requirements*

Properties	Category to BS EN 13242 (BSI, 2003) or BS 12620 (BSI, 2002b)
Grading	Grading 4/40, Gc 85-15, GTc 20/17.5.
Fines content	f_4
Shape	FI_{20}
Resistance to fragmentation	LA_{30}
Durability:Water absorption to BS EN 1097-6:2000, Clause 7 For WA.2%, magnesium sulphate soundness	WA_{242} MS_{18}
Resistance to wear	$M_{DE}20$
Acid-soluble sulphate content: aggregates other than air-cooled blast-furnace slag air-cooled blast-furnace slag	$AS_{0.2}$ $AS_{1.0}$
Total sulphur:aggregates other than air-cooled blast-furnace slag air-cooled blast-furnace slag	</ = 1% by mass. </ = 2% by mass.
Volume stability of blast-furnace and steel slags:air-cooled blast-furnace slag steel slag	Free from dicalcium silicate and iron disintegration (BS EN 13242, (BSI, 2003), 6.4.2.2). V_5
Leaching of contaminants	Blast furnace slag and other recycled materials should meet the requirements of the Environment Agency Waste Acceptance Criteria for inert waste when leachate tested in accordance with BS EN 12457,3 (BSI, 2002a).

(c) Impermeable membrane characteristics

These should typically be manufactured from HDPE, polypropylene or EPDM and should be:

- durable, robust and able to withstand construction and operational loads
- resistant to puncture, multi-axial stresses and strains associated with movement and environmental stress cracking
- unaffected by potential pollutants
- installed with fully watertight joints and discharge outlets; welded joints should be tested to ensure the integrity of the system and provide a more robust jointing method. The membrane must be able to resist the punching stresses caused by sharp points of contact from the aggregate sub-base. It must also have sufficient strength to resist the imposed tensile forces from traffic or other loading. Consideration can be given to protecting membranes with geotextile fleeces where the risks associated with puncture are particularly high.

Additional guidance on specifications is given in Appendix C.

Material sustainability principles are presented in Section 3.6.

12.4 PRE-TREATMENT/INLETS

Where runoff from adjacent areas is accepted into the facility it is advisable to release any additional waters either onto the surface of the pervious construction, or accept it via a silt/debris trap. This should be done to prevent clogging of the pavement.

12.5 OUTLETS

The type of outlet used depends on site conditions and whether infiltration storage or storage for non-potable use of the collected stormwater is required. Typically, outflow from a pervious pavement construction can be achieved by:

1. Directing water from the structure to a drainage network from the bottom of the permeable sub-base, which conveys it to a suitable outfall or disposal point.
2. Allowing water entering the pervious surface to infiltrate down into the groundwater through the base of the construction. Excess water can be discharged via a high level overflow pipe.
3. Storing water in the construction for suitable non-potable use, any excess water being disposed off via a high level overflow pipe.

A well-protected observation well consisting of a 150 mm perforated pipe, or equivalent, should be placed at the downstream end of the facility. The well can be used to measure the actual emptying times of the pavement system and a record kept of performance with time.

12.6 VEGETATION

Small trees or woody shrubs have to be selected carefully and, preferably, should not be planted within 5 m of a pervious pavement to prevent root damage to the liner and to reduce the risk of surface clogging from leaf fall.

12.7 LANDSCAPING

Wherever possible, it is suggested that landscaped areas in and around pervious pavements should have a top soil level that is at least 50 mm below the top of the kerb adjacent to the pervious pavement. Preferably, the landscaped areas should slope away from the pervious pavement (see Figure 12.12). Where landscaped areas drain onto a pervious pavement, the landscaped surfaces should be stabilised so that the mobilisation of silt and other fine debris is minimised.

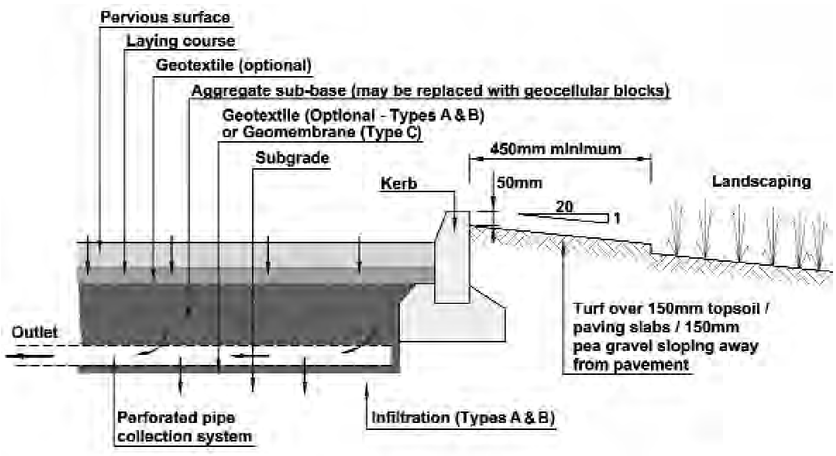

Figure 12.12 *Landscaping detail for pervious pavement (adapted from Wilson* et al*, 2004)*

12.8 OPERATION AND MAINTENANCE REQUIREMENTS

Regular inspection and maintenance is important for the effective operation of pervious pavements. Maintenance responsibility for a pervious pavement and its surrounding area should be placed with an appropriate responsible organisation. Before handing over the facility to the client, it should be inspected for clogging, litter, weeds and water ponding and all failures should be rectified. After handover, the facility should be inspected regularly, preferably during and after heavy rainfall to check effective operation and to identify any areas of ponding.

Pervious surfaces need to be regularly cleaned of silt and other sediments to preserve their infiltration capability. Experience in the UK is limited, but advice issued with permeable precast concrete paving has suggested a minimum of three surface sweepings per year. Manufacturers' recommendations should always be followed.

A brush and suction cleaner, which can be a lorry-mounted device or a smaller precinct sweeper, should be used and the sweeping regime should be as follows:

1. End of winter (April) – to collect winter debris.
2. Mid-summer (July/August) – to collect dust, flower and grass-type deposits.
3. After autumn leaf fall (November).

Care should be taken in adjusting vacuuming equipment to avoid removal of jointing material. Any lost material should be replaced.

The likely design life (or period before pavement rehabilitation is required) has yet to be established for the UK. However, it should be no different from standard paving assuming that an effective maintenance regime is in place to minimise risks of infiltration clogging.

If reconstruction is necessary, the following procedure should be followed:

1. Lift surface layer and laying course.
2. Remove any geotextile filter layer.
3. Inspect sub-base and remove, wash and replace if required.
4. Renew any geotextile layer.
5. Renew laying course, jointing material and concrete block paving.

The reconstruction of failed areas of concrete block pavement should be less costly and disruptive than the rehabilitation of continuous concrete or asphalt porous surfaces due to the reduced area that is likely to be affected. Materials removed from the voids or the layers below the surface may contain heavy metals and hydrocarbons and may need to be disposed of as controlled waste. Sediment testing should be carried out before disposal to confirm its classification and appropriate disposal methods. Guidance on waste management is provided in Chapter 23.

Maintenance plans and schedules should be prepared during the design phase. Specific maintenance needs of the pervious pavement should be monitored and maintenance schedules adjusted to suit requirements. Additional detail on the preparation of maintenance specifications and schedules of work is given in Chapter 22.

Table 12.12 *Pervious pavement operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Brushing and vacuuming.	Three times/year at end of winter, mid-summer, after autumn leaf fall, or as required based on site-specific observations of clogging or manufacturers' recommendations.
Occasional maintenance	Stabilise and mow contributing and adjacent areas.	As required.
	Removal of weed.	As required.
Remedial actions	Remediate any landscaping which, through vegetation maintenance or soil slip, has been raised to within 50 mm of the level of the paving.	As required.
	Remedial work to any depressions, rutting and cracked or broken blocks considered detrimental to the structural performance or a hazard to users.	As required.
	Rehabilitation of surface and upper sub-structure.	As required (if infiltration performance is reduced as a result of significant clogging).
Monitoring	Initial inspection.	Monthly for 3 months after installation
	Inspect for evidence of poor operation and/or weed growth. If required take remedial action.	3-monthly, 48 h after large storms.
	Inspect silt accumulation rates and establish appropriate brushing frequencies.	Annually.
	Monitor inspection chambers.	Annually.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken.

12.9 CONSTRUCTION REQUIREMENTS

The following guidance should be considered when constructing a pervious pavement structure:

1. Any sub-grade soft spots should be excavated and back-filled with suitable well compacted material. The formation should be prepared by trimming to level and compacting in accordance with Specification for Highways Works, to a tolerance of +20 to – 30 mm. If sub-grade improvement is employed, testing will be needed to demonstrate that the design CBR values have been consistently achieved.
2. Any impermeable membrane must be correctly specified, installed and treated with care to ensure that it is not damaged during construction
3. The fines in a conventional impermeable material help to bind the different size particles together, and act to restrict the passage of water. In the case of permeable pavement materials which lack fines, there is potential for segregation during the transportation and construction process. Care should be taken to avoid segregation but, if this occurs, corrective action must be taken. This can be minimised by using an angular, crushed material with high surface friction.

Unlike material for conventional pavements, those for permeable pavements must not be compacted to minimise voids. This could result in surface movement when construction traffic passes over. It may be desirable to undertake site trials to determine the appropriate construction methodology.

The sub-base should be laid in 100–150 mm layers and compacted to ensure that the maximum density is achieved for the particular material type and grading, without crushing the individual particles, or reducing the void ratio below the design value, within a tolerance of +20 mm to –15 mm of the design level.

4. Geotextiles should be laid in accordance with manufacturers' instructions and with overlaps between adjacent strips of 300 mm without any folds or creases. It is recommended that specialist advice be sought from the manufacturer or supplier of the geosynthetic filter.
5. Generally, concrete block pavements should be constructed in accordance with BS 7533: Part3: 2005, Code of Practice for laying precast concrete paving blocks and clay pavers for flexible pavements, the technical sections for which are available for download on the Interpave website at www.paving.org. Advice should be sought from the specific manufacturer on any product specific requirements, laying and jointing materials, block patterns and block laying procedures. In accordance with good practice, the block surface layer should be fully compacted and jointed to within 1 m of the laying face at the end of each day. Other pavement surfaces should be constructed according to the relevant British Standards and/or the surface manufacturer's guidance.

Preventing impermeable contaminants such as soil and mud from entering the pavement surface and sub-base both during and after construction is imperative to ensure that the pavement remains permeable throughout its design life. Construction equipment should be kept away from the area and silt fences, staged excavation works and temporary drainage swales which divert runoff away from the area should all be considered to manage these risks. Landscaping activities should be carefully designed and carried out to prevent deposition of topsoil, turf and other materials on the surface of the pavement. Infiltration surfaces must not be compacted and should be protected at all times.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Additional detail on construction and the programming of construction is provided in Chapter 21.

12.10 REFERENCES

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Geocellular/modular systems 13

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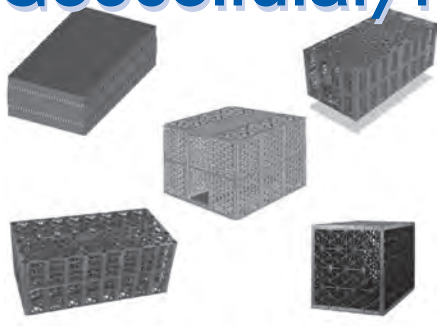
Geocellular/modular systems 13



Description

Modular plastic geocellular systems with a high void ratio that can be used to create a below ground infiltration (soakaway) or storage structure.

KEY DESIGN CRITERIA

- standard storage design using limiting discharges to determine storage volumes
- structural design to relevant standards for appropriate surface loadings
- appropriate geotextile/geomembrane for wrapping.

ADVANTAGES

- modular and flexible
- dual usage ie infiltration and/or storage
- high void ratios (up to 96%) providing high storage volume capacity
- lightweight, easy to install and robust
- capable of managing high flow events
- can be installed beneath trafficked or non-trafficked areas (providing structural performance is proven to be sufficient)
- long-term physical and chemical stability
- can be installed beneath public open spaces, eg play areas.

DISADVANTAGES

- no water quality treatment.

PERFORMANCE:

Peak flow reduction:	Good
Volume reduction (storage only)	Poor
Volume reduction (with infiltration)	Good
Water quality treatment:	Poor
Amenity potential	Poor
Ecology potential:	Poor

TREATMENT TRAIN SUITABILITY:

Source control:	Yes
Conveyance:	Possible
Site system:	Yes
Regional system:	Yes

SITE SUITABILITY:

Residential:	Yes
Commercial/Industrial:	Yes
High density:	Yes
Retrofit:	Yes
Contaminated sites/sites above vulnerable groundwater (with liner)	Yes

COST IMPLICATIONS:

Land-take:	Low
Capital cost:	Low
Maintenance burden:	Low

POLLUTANT REMOVAL:

Total suspended solids:	Low
Nutrients:	None
Heavy metals:	Low

KEY MAINTENANCE REQUIREMENTS

- regular inspection of silt traps, manholes, pipework and pre-treatment devices, with removal of sediment and debris as required.

13.1 GENERAL DESCRIPTION

The modular nature of geocellular systems means that they can be tailored to suit the specific requirements of any site. They can be used to control and manage runoff either as a soakaway or as a storage tank. In addition, they can be used for storing roof/rainwater before recycling.

Traditionally, stone-filled soakaways with a void ratio of around 30 per cent were used for infiltration, and storage was achieved by the construction of *in-situ*, concrete tanks or vaults. More recently, the much more efficient, versatile and easy-to-install, geocellular systems have been developed which allow a structure of almost any configuration to be installed, depending on the area available. The systems can be designed to withstand traffic loads, which means that they can be installed under roads and car parks as well as recreational areas and other public open space. They also tend to be more cost effective than traditional alternatives.

Geocellular systems can contribute to stormwater source control in both of the following ways:

1) By facilitating infiltration – through the provision of a storage structure that is wrapped in permeable geotextile and which allows the stormwater to infiltrate into the ground.
2) By creating storage volumes – through the provision of a structure that is wrapped in a suitably robust impermeable geomembrane (generally protected by a geotextile fleece) that provides temporary storage for stormwater runoff. This option is appropriate where ground conditions are not suitable for a soakaway. The storage tank can be designed as either on- or off-line.

Geocellular systems generally fall into two basic categories:

(a) "Modular Box" systems with inlet/outlet pipework connected to the sides of the completed structure.
(b) "Honeycomb" structures with perforated distribution pipework running under or through the tank. At a critical flow threshold, water is forced out of the pipework, through the gravel (see figures), into the storage blocks.

Typical sections through modular box systems for both infiltration and storage/attenuation application modes are presented in Figures 13.1 and 13.2.

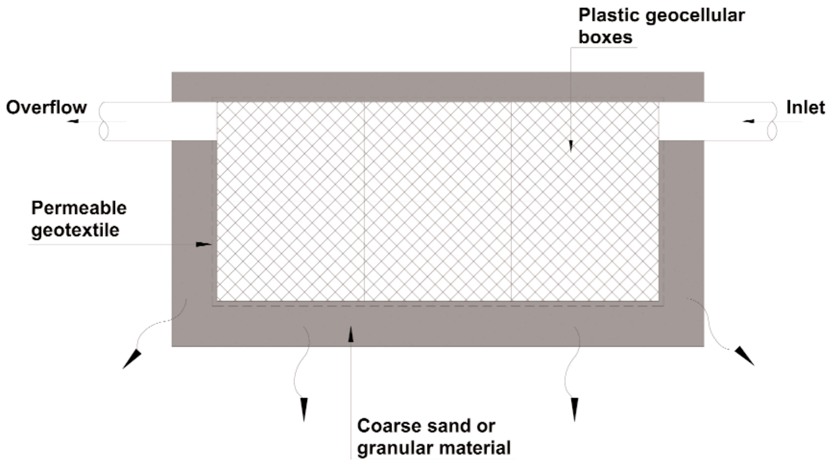


Figure 13.1 *Schematic of modular box system in soakaway mode*

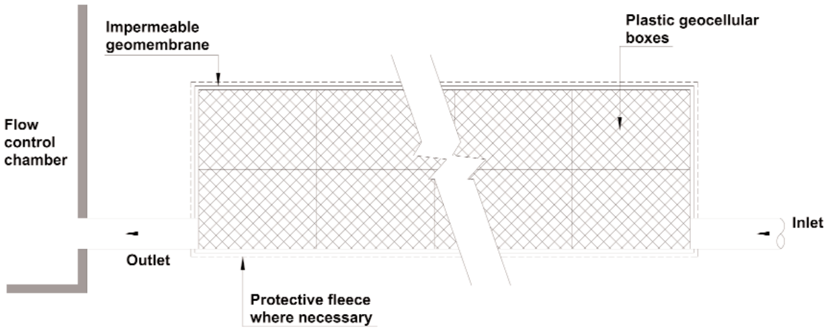


Figure 13.2 *Schematic of modular box system in storage/attenuation mode*

Typical sections through a honeycomb system for both infiltration and storage/attenuation application modes are presented in Figures 13.3 and 13.4.

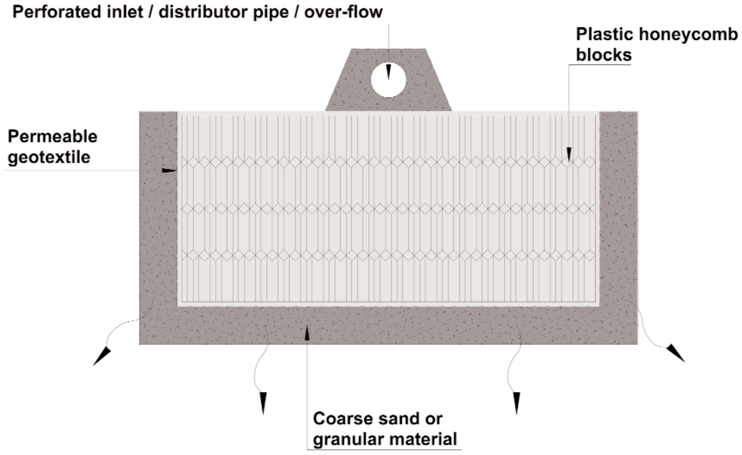


Figure 13.3 *Schematic of honeycomb system in soakaway mode*

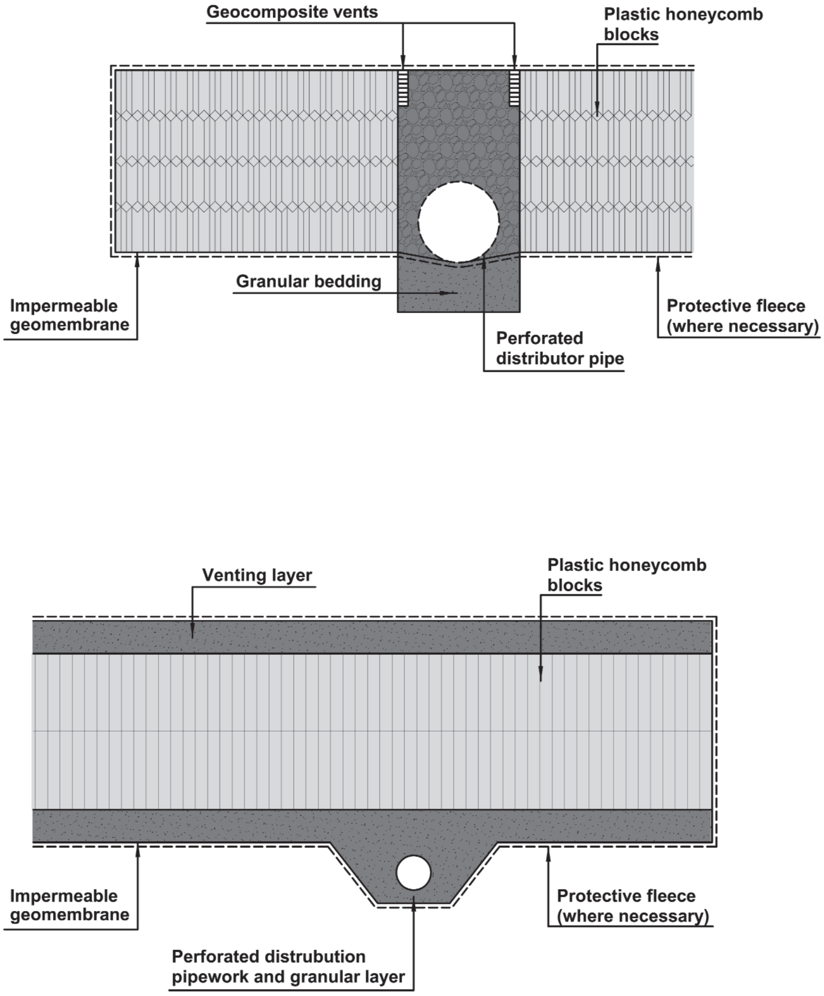


Figure 13.4 *Schematics of honeycomb systems in storage/attenuation mode*

13.2 SELECTION AND SITING OF GEOCELLULAR SYSTEMS

Geocellular systems generally can be used for any site requiring surface water drainage, providing that the system is proved to function satisfactorily both in terms of hydraulic ability and structural performance. Geocellular systems offer significant flexibility to the designer because of their modular nature and their ability to be used for either infiltration or storage. Table 13.1 outlines the main issues that should be considered to ensure site-specific suitability.

Table 13.1 *Considerations for using geocellular systems*

Drainage area	Modular geocellular systems can be designed to manage stormwater from almost any size of drainage area. Effective upstream pre-treatment is an important consideration and, to limit the impact of silt accumulation, it is recommended that the area drained to a tank should be as small as practical for any given site. This may require the use of several smaller tanks rather than one large one.
Space required	As modular systems are sited underground, they can be accommodated on most sites and will be attractive where space is limited above ground.
Siting	Modular systems can be sited in most locations. However when used for infiltration the infiltrating water must not affect building foundations or other infrastructure. Site requirements will tend to determine the location of the systems, ie storage systems are likely to be at or close to the lowest point on the site.
Site slope & stability	Storage systems generally should not be sited on unstable ground unless specialist advice has been sought. Ground stability should always be verified by assessing site soil and groundwater conditions.
Subsurface soils and groundwater	Where modular systems are designed for infiltration, the seasonally high groundwater table must be more than 1 m below the base of the facility and the design must comply with the environmental regulator's policy on infiltration and groundwater protection. Infiltration design methods are described in Chapter 4. Where a storage tank is to be installed either close to or below the groundwater table, the possibility of floatation must be prevented by ensuring that the weight of the soil over the top of the units is greater than the uplift force of the buoyancy of the groundwater. Alternatively, specialist geotechnical advice should be sought on possible anchor systems. In areas containing contaminated soils or contaminated groundwater an appropriate risk assessment should first be undertaken. Any excavation or earthmoving processes required must be assessed to ensure that mobilisation of contamination does not occur.

13.3 HYDRAULIC AND WATER QUALITY DESIGN

The hydraulic design of on- or off-line storage using pipes or tanks should be in accordance with Sewers for Adoption, 6th Edition (WRc, 2006) or Sewers for Scotland, 2nd Edition (Scottish Water, in preparation).

Infiltration systems should be designed to comply with current guidelines (BRE 365 (BRE, 1991) or CIRIA publication R156 (Bettess, 1996)), and storage systems should be designed using standard routing methods. Chapter 4 provides details of these design methods.

To achieve water quality treatment, these systems will need to form part of a SUDS management train, with appropriate sediment management and pollution control devices installed.

13.4 PHYSICAL SPECIFICATIONS

For details of relevant specification of the geocellular units and ancillaries, the proprietary manufacturers should be contacted directly. The structural design of tanks and pipes should be in accordance with relevant standards, eg *Sewers for Adoption*, 6th Edition (WRc, 2006), BSEN 1295 (BSI, 1998) *Structural design of buried pipelines under various conditions of loading, Highways Agency specification for highway works* (Highways Agency *et al*, 1998).

13.5 MATERIALS/STRUCTURAL DESIGN

Modular geocellular systems must be designed as structural components, using structural design theory. Imposed loads (eg dead and live loadings from overlying fill and vehicles, lateral loadings from earth and water pressures, and temperature variations) can cause deflection, bending and creep, and where poor design practice is employed, there is a risk of structural failure and system collapse. Designs must be based on sound structural analysis and clear laboratory test results and must consider not only collapse but also deflections and the effects these may have on overlying surface materials. The type and depth of cover should be suitable:

- to spread the loading across the cellular storage blocks so that their maximum loading limits are not exceeded
- for the expected loading (eg block paving may not be appropriate for high speed or heavy traffic).

Most cellular stormwater tanks are manufactured using plastic (usually polypropylene or polyethylene) and are complex structures in their own right. Designers should request from the manufacturer a complete set of independent test results for a proposed system including, as a minimum, stress/strain curves for vertical and lateral compression, and creep tests under sustained long-term loads. This should allow the ultimate compressive strength and deflection performance of the units to be determined (Wilson *et al*, 2004). Care must be taken to ensure that the strength derived from testing is representative of the likely system performance under the design assumptions.

Some systems use the individual units or columns to form tanks with an open internal void. This means the units are subject to bending stresses. Analysis using simple compression tests can underestimate the ultimate strength and deflections that may occur. Bending of this type of structure is shown in Figure 13.5. In this situation, tests to determine the bending resistance are required to allow a more rigorous structural analysis of these structures.

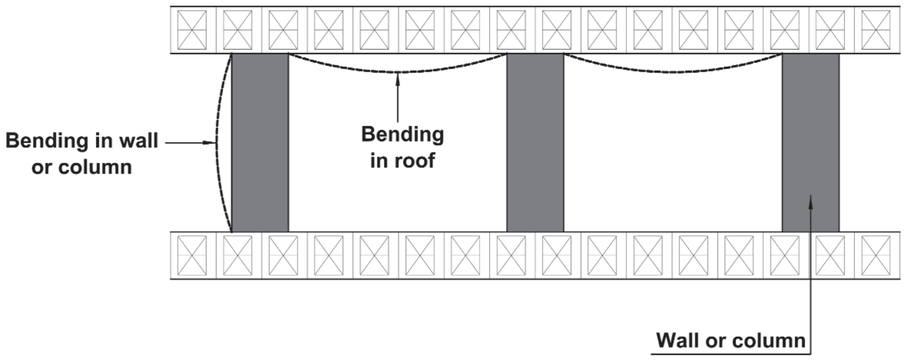


Figure 13.5 *Bending in box structure with an internal void (Wilson* et al*, 2004)*

Creep and fatigue can have a significant effect on the long-term performance of plastic structures and need careful consideration in design. The results from an example creep test are shown in Figure 13.6. CIRIA publication C609 (Wilson *et al*, 2004), suggests that creep test data should not be extrapolated in time to more than two orders of magnitude. This means, for example, that using the results of a 90 day test, the maximum design life that should be assumed is 20 years.

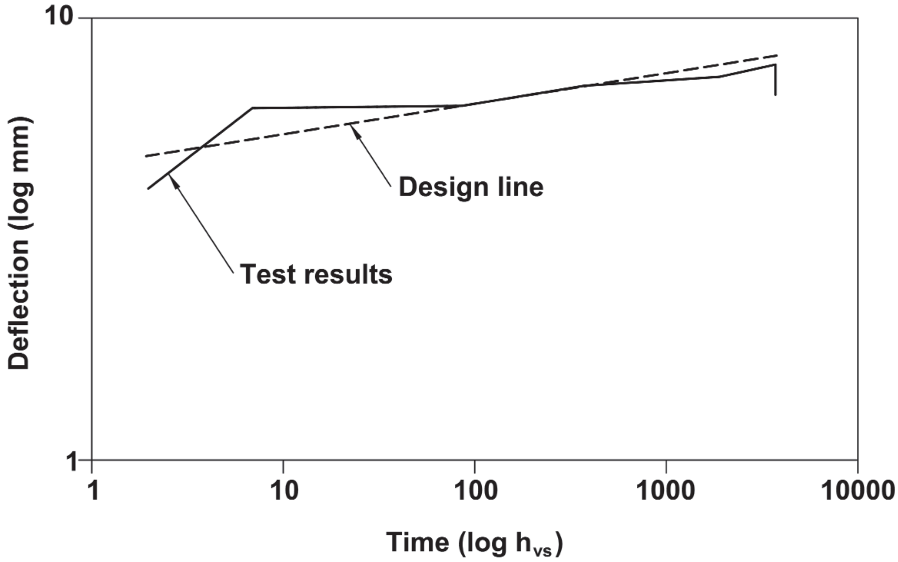


Figure 13.6 *Example creep test results (Wilson* et al*, 2004)*

Where very shallow cover depths are proposed, heavy loads are to be applied, or unusual configurations proposed, the design may be confirmed by instrumented, full-scale testing of the geocellular structure and overlying construction. This should give increased confidence in the predicted performance of the system.

Key structural design considerations are listed in Box 13.1.

Box 13.1 *Key structural design considerations for geocellular structures (adapted from C609, Wilson* et al*, 2004)*

KEY STRUCTURAL DESIGN CONSIDERATIONS

1 The bearing capacity and settlement characteristics of the underlying soil

Service dead and live loads.

2 Dead loads should include any fill material placed over the units and any other permanent or long-term loads.

3 Live loads should include distributed loads and point loads from temporary sources (typical vehicular loadings). Wheel loads from vehicles can impose very high concentrated loads on the units. Analysis is required to determine the thickness of overlying material that is needed to distribute these loads evenly and prevent overloading or excessive deflection of the units (see Figure 13.7).

4 Construction plant such as excavators, cranes and compaction plant can impose significant loads on the systems before they are provided with final cover. Therefore the deformations that could occur during construction should also be considered.

5 Earth and water pressures impose lateral loads. These should be assessed and allowed for.

6 Flotation can occur if tanked systems are located below the water table.

7 Risk of damage by chemical or biological attack from stormwater runoff or from contaminants present in the surrounding soils.

8 The effects of temperature variations on the plastic materials (especially in respect of creep).

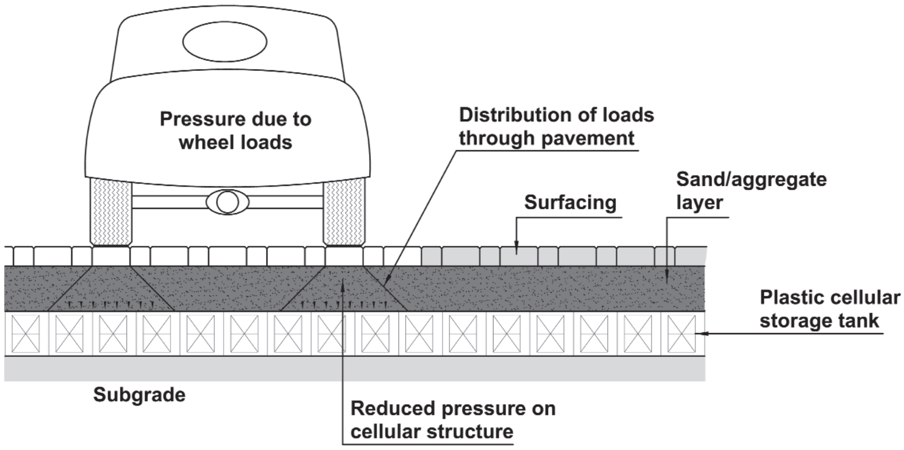


Figure 13.7 *Spread of a load below a wheel (Wilson* et al*, 2004)*

Limit state design methods can be used to design these tanks and this approach is described in Box 13.2 (CIRIA, 2004). However, geocellular system manufacturers should generally provide the designer with all the information required to design the system and limited additional calculations are likely to be required.

Box 13.2 *Limit state design of geocellular structures (Wilson* et al*, 2004)*

The philosophy of limit state design should be used so that the structures remain safe and suitable for use throughout their design life. A limit state is defined as "a limiting condition beyond which the structure stops fulfilling its intended function" (Day, 1997). The concept of limit state design is to consider the probability distributions of all parameters (applied loads and material strength and stiffness) to provide better control over risk and improved consistency compared with traditional designs based on permissible stress or lumped factors of safety.

The load and material factors used for the structural design of concrete or steel are derived to achieve a target probability of failure and are specific to particular load and material types.

The two most common limit states that should be considered are:

- ultimate limit state – the structure should not collapse under foreseeable overload – the main consideration is strength
- serviceability limit state of deflection – in this case, deflections under anticipated loadings should be at acceptable levels (for example to prevent cracking in the overlying surfacing).

Loads

Characteristic loads are a best estimate of the load likely to be placed on a structure during its design life. To allow for various factors, the characteristic load is multiplied by a partial factor of safety to produce a design load. This allows for:

- statistical variations in load
- increased loads due to tolerance in construction
- unforeseen load conditions.

The partial factors depend on the consequences of the limit state and the probability of particular combinations of load occurring at the same time. The loads that are applied to plastic tank structures are the same as those applied to other structures (for example traffic loads applied to bridges) and the probability of occurrence will be the same. Therefore the guidance from structural design codes for other materials (for example BS 8110, BSI, 1997) can be used to determine the partial load factors for plastic tank design. The most common combination of loads will be dead load plus live load.

Box 13.2 *Limit state design of geocellular structures (continued)*

Partial load factors from BS 8110, Part 1 (BSI, 1997) (dead and live load combination)

Load type	Ultimate limit state	Serviceability limit state
Dead load	1.4	1.0
Live load	1.6	1.0

The consequences of collapse are more serious than of cracking occurring in the surfacing. Thus a higher factor is used for the ultimate limit state so that the risk of the limit state being achieved is lower. Lorries can also impose very high dynamic loads on the boxes depending on their speed, and factors should be applied to allow for this in design.

Surfacing and allowable deflections

The type of surfacing overlying the storage tanks determines the levels of deflection that are acceptable under loading. The nature of the deflections also needs to be considered as they are elastic and will be repeated during the lifetime of the structure. Block paving is a relatively flexible material that can tolerate elastic defections up to about 1.5 mm without adverse effects.

To take account of factors such as variations during manufacture, variability and uncertainties in material strength (eg due to extrapolation of data), damage during installation and environmental effects, the design strength should be obtained by applying a material partial factor of safety ãm appropriate to the material and limit state. This also allows for the effects of fatigue (reduced strength as a result of repeated application of load).

The only readily-available guidance on choice of material factors for thermoplastic materials in load bearing applications is for geogrids used in earth reinforcement applications. BS 8006 (BSI, 1995) and Ingold, 1994 should be referenced for detail on this matter.

When considering the published "void ratio" for the system, it is important to differentiate between the total ("internal") void ratio, and the "external" void ratio. The "internal" value will determine the proportion of the structure available for storage (generally >90 per cent), but the "external" value describes the proportion of the structure's surface that is in contact with the surrounding material (ie the porosity of the external surface).

Geotextiles suitable for use as wrapping include needle punched filter fabric. Geotextiles and geomembrane specifications are provided in Appendix C. Material sustainability principles are presented in Section 3.6.

Design for maintenance and safety

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

If there is a likelihood of siltation within any associated pipework, it would be appropriate to provide access for inspection and maintenance (eg rodding) at appropriate points. Access may also be provided for inspection and maintenance of the modular system itself via gaps in the components.

Any associated pipework should be laid to achieve self-cleansing velocities wherever possible. For storage structures, the risk of siltation may be reduced by designing the tank off-line. As with all systems, it is critical that construction sediments are not allowed to enter the structure.

13.6 PRE-TREATMENT/INLETS

A sediment sump (or other pre-treatment device) should be included within the design immediately upstream of the tank. The device should not be allowed to overfill, as this may cause silt to be carried into the distribution pipework.

13.7 OUTLETS

When used for storage, the structure must have an outlet connecting to the downstream drainage system or watercourse. Modular systems can be designed to include an emergency or bypass system to safely pass flows that exceed the design event, but care should be taken that extreme flood discharges do not affect downstream buildings and structures.

13.8 OPERATION AND MAINTENANCE REQUIREMENTS

Regular inspection and maintenance is required to ensure the effective long-term operation of below ground modular storage systems. Maintenance responsibility for systems should be placed with a responsible organisation. Maintenance requirements for modular systems are described in Table 13.2.

Maintenance plans and schedules should be developed during the design phase. Specific maintenance needs of the system should be monitored, and maintenance schedules adjusted to suit requirements. Additional detail on the preparation of maintenance specifications and schedules of work is given in Chapter 22.

Table 13.2 *Modular systems – operation and maintenance requirements*

Maintenance schedule	Required action	Recommended Frequency
Regular maintenance	Inspect and identify any areas that are not operating correctly. If required, take remedial action.	Monthly for 3 months, then six monthly
	Debris removal from catchment surface (where may cause risks to performance)	Monthly
	Where rainfall infiltrates into blocks from above, check surface of filter for blockage by silt, algae or other matter. Remove and replace surface infiltration medium as necessary.	Monthly (and after large storms)
	Remove sediment from pre-treatment structures	Annually, or as required
Remedial actions	Repair/rehabilitation of inlets, outlet , overflows and vents	As required
Monitoring	Inspect/check all inlets, outlets, vents and overflows to ensure that they are in good condition and operating as designed	Annually and after large storms

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken.

13.9 CONSTRUCTION REQUIREMENTS

In addition to appropriate design, it is critical that the ground preparation and system installation are carried out to appropriate quality control conditions. Guidance should be sought from individual manufacturers on system-specific best practice.

Post installation, and in untrafficked situations, excavations can generally be backfilled with selected, as-dug material that does not contain large particles or sharp materials. It should then be well compacted. In trafficked areas, the use of well compacted backfill and cover is particularly important and the material should, typically, be selected in accordance with standard Highway works specifications (eg Highways Agency *et al*, 1996). Use of poor quality backfill can significantly increase lateral earth pressures and cause collapse. Running heavy plant over constructed tanks or stockpiling material over them during construction, when such loads have not been included within design calculations, can also cause collapse, especially if temporary cover during site works is less than the final design cover depth. Where the system is being used as a storage tank, the geomembrane wrapping may need to be protected from the backfill by a geotextile fleece in some instances. In all cases, advice should be sought from individual manufacturers regarding specific recommended installation and cover depths.

Runoff should be prevented from entering the modular blocks during construction. Alternatively, and only if the design allows, a flushing operation may be required prior to commissioning to ensure all sediments have been removed from the system.

All storage tanks should be fully sealed in accordance with waterproofing standards (ie welded joints rather than adhesive taped) and the integrity of the seal checked through the use of non-destructive testing, to ensure it is leak-proof. Care needs to be taken during installation against damage of both the modular structure and the geotextile and/or geomembrane wrapping. Follow-on trades can also cause damage and put the integrity of the structure at risk.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Additional detail on construction and the programming of construction is provided in Chapter 21.

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Sand filters

14

Contents

Sand filters

14

Description

Sand filters are single or multi-chambered structures designed to treat surface water runoff through filtration using a sand bed as the primary filter medium. The filters can be designed with an impervious lining, or to allow infiltration, depending on the soil type. Temporary storage of runoff is achieved through ponding above the filter layer. They are used where particularly high pollutant removal is required.

KEY DESIGN CRITERIA

- filter area to spread design water quality treatment volume to maximum depth of 150 mm
- pre-treatment volume >25% of water quality treatment volume (40% for high sediment loads)
- filter depths of 0.45 – 0.6 m
- sand sizes of 0.5 – 1.0 mm
- combined volume of sedimentation and filter chamber should provide >75% of treatment volume in temporary storage before filtration
- space for maximum head should be twice the average water level above the filter
- min sedimentation chamber length:width ratio 2:1.

ADVANTAGES

- flexibility of design
- efficient in removing a range of urban runoff pollutants
- suitable for retrofits and in tightly constrained urban locations.

DISADVANTAGES

- not recommended for areas with high sediment content in runoff
- long detention times can support algae growth and lead to filter clogging
- minimum hydraulic head of 1.2 m required (0.3 m for perimeter filters)
- negative aesthetic appeal/possible odour problems
- nitrate generation from sand filters has been observed
- not suitable for large catchment areas
- high capital cost and maintenance burden.

PERFORMANCE

Peak flow reduction:	Poor
Volume reduction:	Poor
Water quality treatment:	Good
Amenity potential:	Poor
Ecology potential:	Poor

TREATMENT TRAIN SUITABILITY

Source control:	No
Conveyance:	No
Site system:	Yes
Regional system:	Yes

SITE SUITABILITY

Residential:	Yes
Commercial/industrial:	Yes
High density:	Yes
Retrofit:	Yes
Contaminated sites/sites above vulnerable groundwater (with liner)	Yes

COST IMPLICATIONS

Land-take:	Low
Capital cost:	High
Maintenance burden:	High

POLLUTANT REMOVAL

Total suspended solids:	High
Nutrients:	Low
Heavy metals:	High

KEY MAINTENANCE REQUIREMENTS

- regular inspection for reductions in performance
- litter/trash/debris removal
- inlet/sedimentation basin cleaning
- replacement or rehabilitation of top filter layer
- vegetation management around filter.

14.1 GENERAL DESCRIPTION

Sand filters are structural controls that pass runoff through a filter bed of sand. The filtered runoff is typically collected and returned to the drainage system, or infiltrated into the surrounding soil, where conditions allow. Sand filters can be above ground, partially buried, or underground structures. They are relatively easy to fit into any type of urban setting and are also suitable for retrofitting. They are used for stormwater treatment in parts of the USA, but are much less common in the UK. There are many variations of filters, and alternative filter materials may be gravel, peat, compost or a combination. More recently, zeolite filters, which consist of microporous crystalline solids, have been employed in some areas.

Sand filters should be designed for ease of maintenance, and should consist of the components shown in Table 14.1.

Table 14.1 *Sand filter components*

Sand filter component	Function
1. Flow diverter	As a minimum, diverts the water quality treatment volume from the conveyance system into the filter.
2. Pre-treatment and sediments.sedimentation chamber	Removes floating debris and heavy.
3. Filtration chamber	Removes finer suspended solids, hydrocarbons, metals, BOD and bacteria through filtration of the runoff through the filter media bed.
4. Outflow mechanism	Collects the treated stormwater and directs it back to the conveyance system. If soil and groundwater conditions allow, the treated stormwater can also be partially or fully infiltrated.

The different types of filter are described below, and presented in the following figures.

(A) Surface sand filter

The surface sand filter is a ground level, open structure consisting of a pre-treatment sedimentation forebay and a filter bed chamber. This system tends to be designed as an off-line drainage component. It can be designed as an excavation with earth embankments, or as a concrete or block structure.

Figure 14.1 *Surface sand filter*

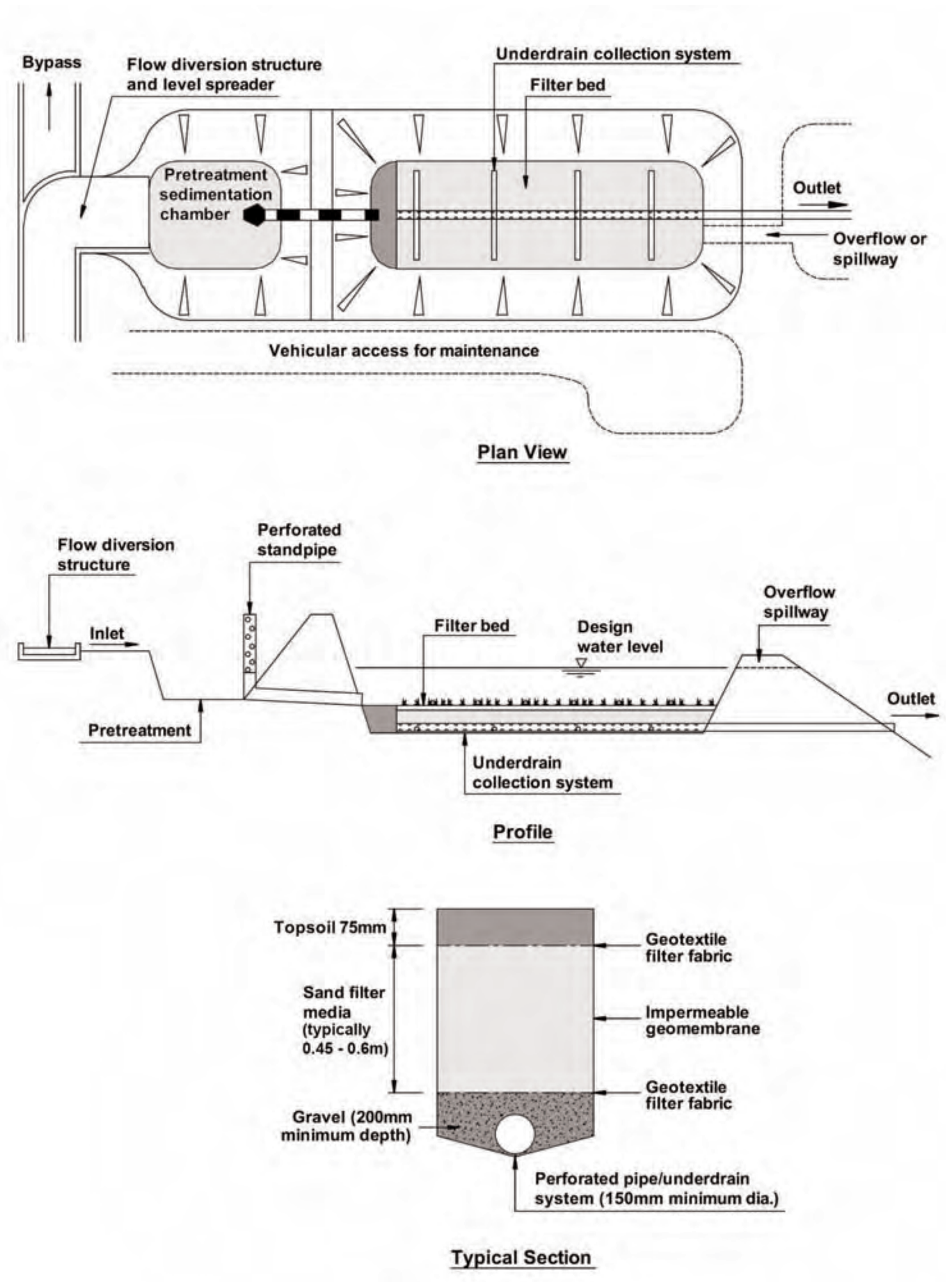

Figure 14.2 *Schematic of surface sand filter (adapted from CWP* et al*, 2000)*

(B) Perimeter sand filter

A perimeter sand filter is an enclosed filter system typically constructed just below ground level along the edge of an impervious area such as a car park. The system consists of a sedimentation chamber and a sand bed filter. Runoff generally flows into the structure from above through a series of inlet grates.

Figure 14.3 *Perimeter sand filter*

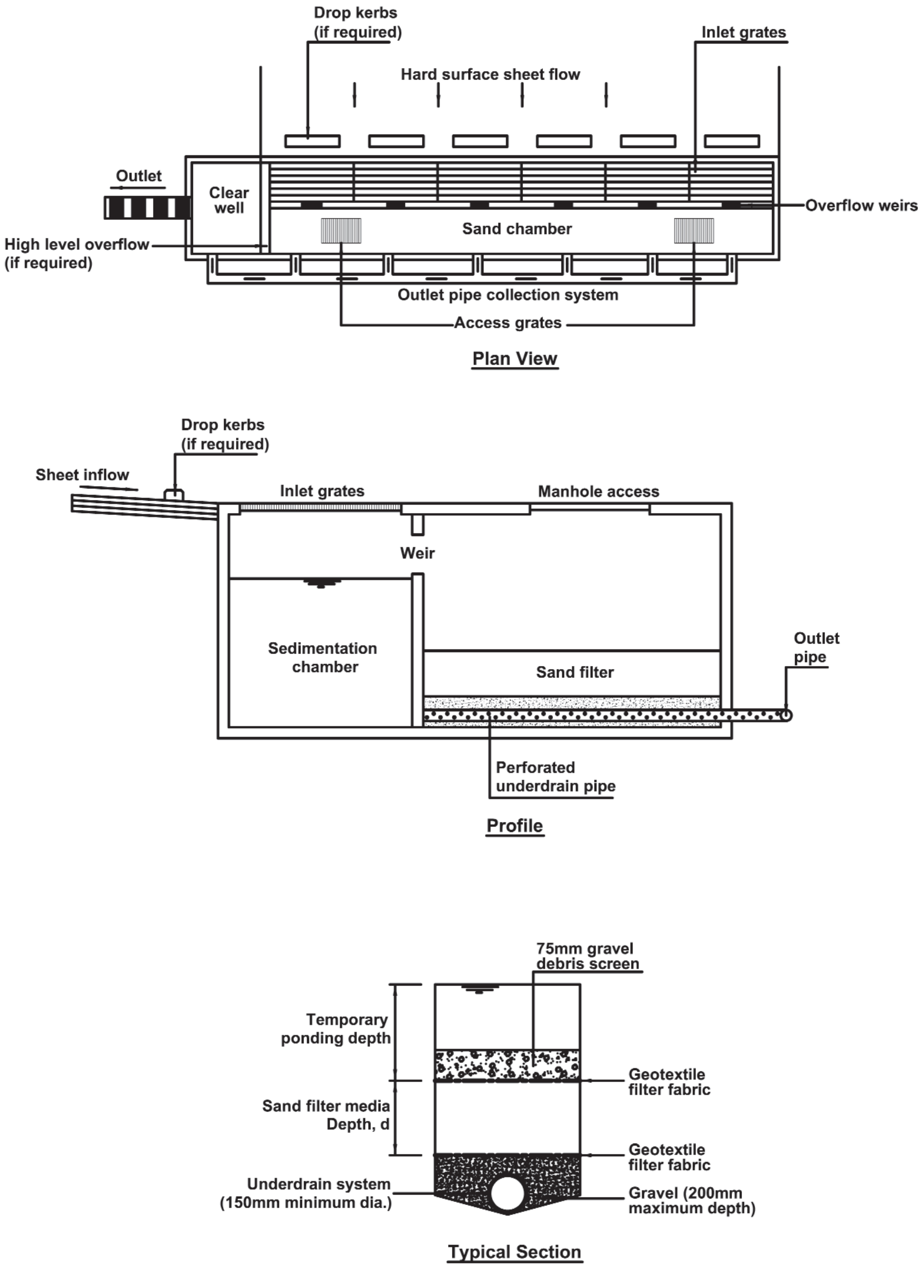

Figure 14.4 *Schematic of a perimeter sand filter (adapted from CWP* et al*, 2000)*

(C) Underground sand filter

This type of filter is intended primarily for extremely space-limited, high-density areas. Maintenance demands are more complex due to access arrangements.

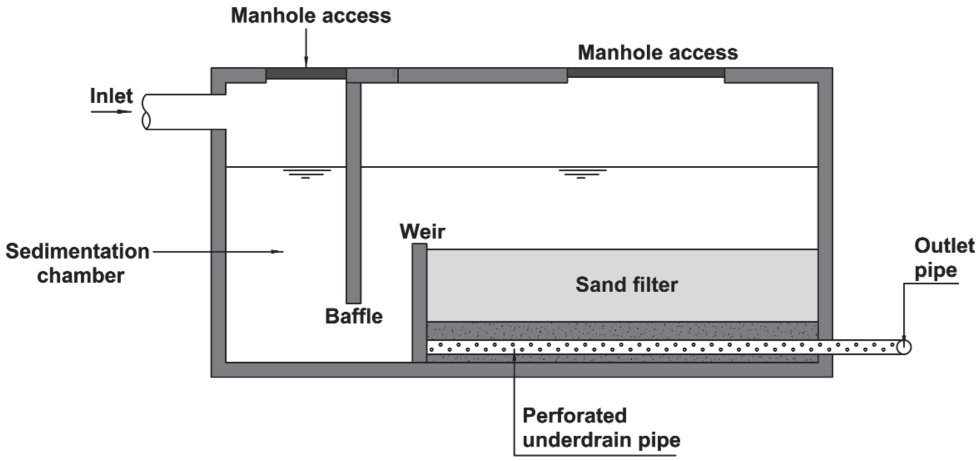

Figure 14.5 *Schematic of an underground sand filter (adapted from CWP* et al*, 2000)*

14.2 SELECTION AND SITING OF SAND FILTERS

Sand filters are generally applicable to most types of new development and redevelopment, and can be used in both residential and non-residential areas. They are particularly well-suited to highly impervious areas where land available for structural control is limited. Excessive content of fine sediments in stormwater or lack of the minimum required hydraulic head may preclude their use for certain development areas.

The criteria presented in Table 14.2 should be evaluated to ensure the suitability of a sand filter for meeting drainage objectives at a particular site.

Table 14.2 *Considerations for using sand filters*

Drainage area	Surface sand filters are appropriate for most catchment sizes providing appropriate pre-treatment and flow management systems are implemented.
Space required	Sand filters can be surface or underground, and can therefore be accommodated on most sites.
Siting	Sand filter systems are designed for intermittent flow and must be allowed to drain and re-aerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources. The catchment draining to the filter must not have earthen channels or unstabilised areas that may contribute high sediment loads to the runoff. A filter should not be installed in a location where leaves can accumulate in the filter basin. Caution is also required in approving them for use in residential areas, unless maintenance can be guaranteed. They should not be used for individual houses because of the maintenance requirements.
Site slope & stability	The site slope across the filter system should be less than 6%. The elevation difference needed at a site from the inflow to the outflow of the filter structure to achieve the necessary hydraulic head is a minimum of 1.2 m (typically 1.5 to 2.5 m) for surface filters and 0.3 m (typically 0.6 to 0.9 m) for perimeter sand filters. Sand filters should not be sited on unstable ground and ground stability should be verified by assessing site soil and groundwater conditions.
Subsurface soils and groundwater	Where sand filters are designed for infiltration, the seasonally high groundwater table must be more than 1 m below the base of the facility and the design must comply with the environmental regulator's policy on infiltration and groundwater protection. Infiltration tests should be undertaken in accordance with BRE Digest 365 (BRE, 1991) (see Chapter 4). Where infiltration is not required, the seasonally high groundwater level should be below the filter underdrain. Unlined filters should not be used on brownfield sites unless it has been clearly demonstrated that the risk posed by leaching of contaminants is acceptable.

14.3 HYDRAULIC AND WATER QUALITY DESIGN

Sand filters should be designed to manage the water quality treatment volume, and should be used in conjunction with additional downstream controls to provide extreme flood protection.

The sedimentation and filter chamber combined should provide a total volume equal to at least 75 per cent of the water treatment volume in temporary storage before it flows through the filter. This may be reduced if detailed analysis of the rainfall and outflow from the system shows a lower volume is acceptable. Unless detailed modelling is undertaken of the system that reflects the pass forward flow during the event, a pass forward flow of zero should be assumed.

The distribution of the treatment volume among the various components is shown in Figures 14.6 and 14.7.

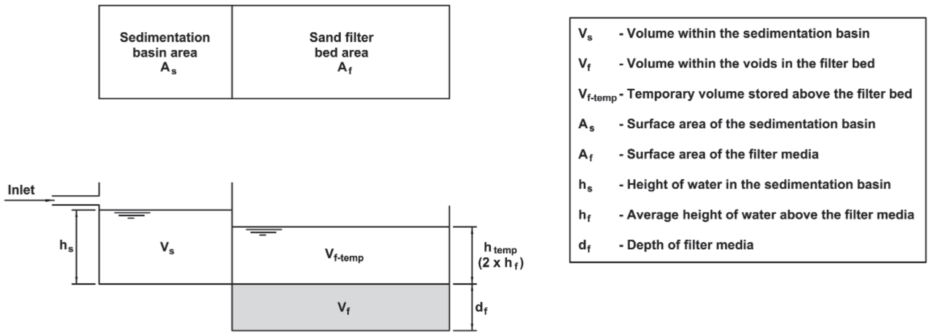

Figure 14.6 *Surface sand filter volumes (adapted from Claytor and Schueler, 1996)*

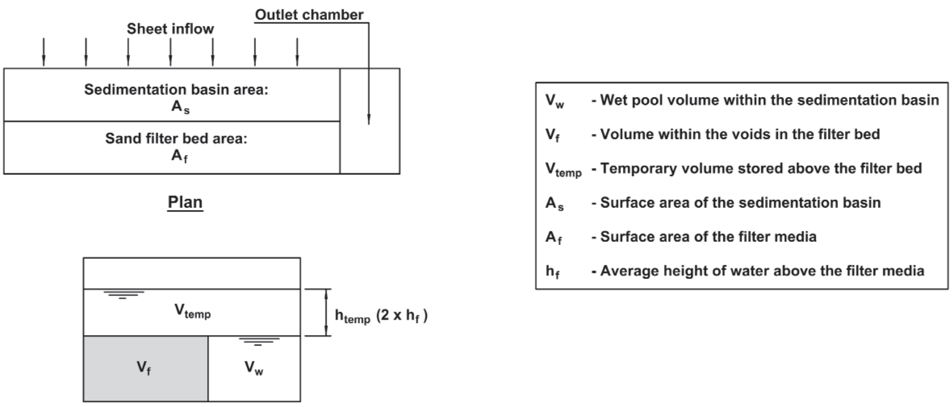

Figure 14.7 *Perimeter sand filter volumes (Claytor and Schueler, 1996)*

The filter area should be sized to completely drain in 40 hours or less, based on the principles of Darcy's Law (see Box 14.1). Filter bed depths should be between 0.45 and 0.6 m.

To prevent backflow of water in the system, the maximum head of water that can develop in the sedimentation chamber must at least be twice the average height of water above the filter device. In locations with insufficient hydraulic head for gravity flow, the design may be augmented to include pumps and stilling wells. However, these would have significant cost and long-term maintenance implications.

Box 14.1 *Darcy's Law for design of sand filter systems*

$$A_f = \frac{V_t(L)}{k(h + L)t}$$

Where:

A_f	=	surface area of filter bed (m^2)
V_t	=	water quality treatment volume (m^3)
L	=	filter bed depth (m) (typically 0.45–0.6 m)
k	=	coefficient of permeability of filter medium for water (m/s)
	=	0.001 (approx) for 0.5 mm sand
	=	0.006 (approx) for 1.0 mm sand
h	=	average height of water above filter bed (half maximum height, where hmax is typically ≤2 m) (m)
t	=	time required for water quality treatment volume to percolate through filter bed(s) (40 hours recommended)

14.4 PHYSICAL SPECIFICATIONS

The geometric design of media filters can vary considerably and they can be designed to take up minimal development space. However, there are a number of geometric ratios and minimum physical requirements that should be observed for adequate pollutant removal, ease of maintenance and good safety practice.

Geometry

The filter should consist of a layer of washed medium sand (0.45 – 0.6 m) over the underdrain system. Surface filters may, if required, have a layer of topsoil or gravel of approximately 75 mm depth.

Filter design should include a 150 mm diameter perforated PVC pipe underdrain in a gravel layer, which must have a minimum slope of 1 per cent. The perforation holes should be of the order of 10 mm in diameter and spaced at approximately 150 mm. The underdrain should have at least two lateral drainage pipes, and the spacing between pipes should not exceed 3 m.

The length to width ratio of the sedimentation chamber should ideally be a minimum of 2:1. However, this is usually achievable only for surface filters in locations where there are no space constraints. Inlet and outlet should be located at opposite ends of the chamber.

Materials

The structure of a surface filter may be constructed of impermeable material such as concrete, or through the use of excavations and earth embankments. When constructed with earth embankments, filter fabric should be used to line the bottom and side slopes of the structures before installation of the underdrain system and filter media.

Permeable filter fabric should be placed both above and below the sand bed to prevent clogging of the filter and underdrain system. The pore size and permeability should be specified to suit the flows required and the likely particle size requiring retention. Underdrain gravel should be clean, washed aggregate with a grain size of typically 10 to 20 mm diameter. The void space should be approximately 40 per cent. Alternatively, geocellular units may be used for the underdrain.

The sand provided in the filter should be specified to meet the required design criteria. A sand with grain sizes of between 0.5 and 1 mm often gives the best compromise between hydraulic capacity and pollutant removal. However, other specifications have been used, such as the one provided in Table 14.3.

Table 14.3 *Example sand specification*

Sieve size (mm)	Percentage passing
9.5	100
6.3	95–100
3.17	80–100
1.5	50–85
0.8	25–60
0.5	10–30
0.25	2–10

Design for maintenance and safety

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

The design should allow for easy access for maintenance. There may be a need to remove heavy wet sand from the system, usually by hand, and the access should be designed to facilitate this.

A maintenance access ramp should be provided for each chamber. All access points into perimeter and underground filters must be made safe from unauthorised entry. Inspection/cleanout wells should be provided to the underdrain.

14.5 PRE-TREATMENT/INLETS

Pre-treatment is an integral component of the filter system. It improves pollutant removal and also reduces the maintenance requirements for the filter bed. Pre-treatment can be achieved using upstream SUDS components, or in a sedimentation chamber that precedes the filter bed. The following guidelines apply:

1. For surface filters: the pre-treatment facility should be sized equal to 25 per cent of the water quality volume for the catchment. For areas with high sediment loads, the sizing should be increased to 40per cent. The sedimentation system can be wet or dry. However inflow into the chamber must not cause re-suspension of previously deposited sediments.
2. For perimeter filters: the pre-treatment facility should be sized equal to 50 per cent of the water quality volume for the catchment. Sedimentation systems for this filter type (and for underground filters) tend to have a permanent wet pool with a water depth of 0.6 – 0.9 m.

The most common method of calculating the area of the sedimentation chamber is to use the Camp-Hazen equation:

Box 14.2 *Camp-Hazen equation for calculation of sand filter surface area*

$$A_s = -(Q_o/W)1n(1-E)$$

Where:

A_s = Surface area (m^2)
Q_o = Discharge rate from basin (water quality volume/detention time) (m^3/s)
W = particle settling velocity (m/s) (0.00101 m/s for impervious area<75%; 0.000122 for impervious areas ≥75%)
E = Removal efficiency – typically assumed to be 90% (0.9)

A detention period of the order of 24 hours is appropriate.

Consideration should be given to including energy dissipaters at the inlet, as exit velocities from the sedimentation chamber should be non-erosive. Flow velocities in the sedimentation area should be low (less than 0.25 m/s) and the design should aim to avoid flow short-circuiting. This could be achieved using baffles to lengthen the flow path or to provide flow resistance at the inlet.

A typical inlet pipe from the sedimentation basin to the filter media basin of a surface filter is shown in Figure 14.8.

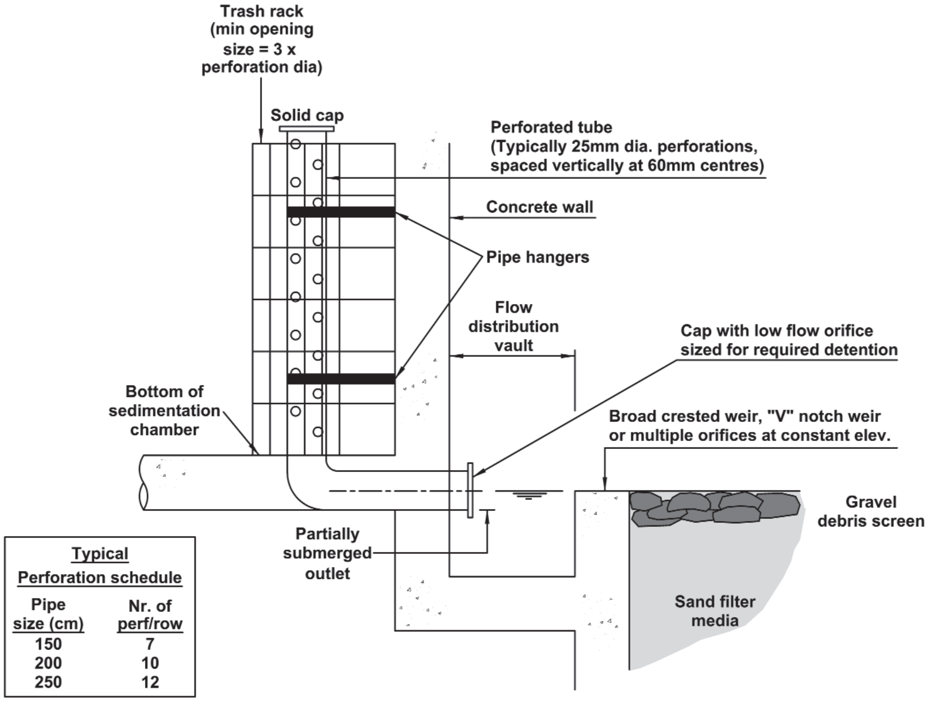

Figure 14.8 *Typical sand filter inlet detail (adapted from Claytor and Schueler, 1996)*

14.6 OUTLETS

An outlet pipe has to be provided from the underdrain system to the point of discharge of the facility. Because of the slow rate at which water percolates through the filter, specific outlet protection is usually not necessary (except for emergency overflows and spillways).

Surface filters should include an emergency or bypass spillway to pass flows that exceed the design storm flows safely. The spillway should prevent filter water levels from overtopping any embankments and causing structural damage. It should be designed such that spillway discharges do not affect downstream buildings and structures.

14.7 LANDSCAPING AND VEGETATION

Vegetation can enhance the appearance of surface filters, stabilise side slopes and prevent erosion, and temporarily conceal unsightly litter and debris. Vegetation also aids in pollutant removal and in preventing clogging. Surface filters that are covered with topsoil should be planted with species that will not inhibit infiltration, are capable of withstanding frequent periods of inundation and drought, and are low maintenance.

In the vicinity of the filter, deciduous trees and shrubs should be avoided, as their leaves can be washed into the filter structure and increase the risks of blockage. Filters can be fenced to prevent access. Inlet and access grates to perimeter sand filters should also be locked.

Wherever possible, sand filters should be visible and signed so that they are recognised as components of a SUDS scheme. Additional information on landscaping is provided in Chapter 22.

14.8 OPERATION AND MAINTENANCE REQUIREMENTS

Regular inspection and maintenance is critical for the effective operation of sand filter. Maintenance responsibility for a filter should be placed with a responsible organisation.

Adequate access must be provided to the sand filter for inspection and maintenance, including for appropriate equipment and vehicles. Operation and maintenance requirements for sand filters are described in Table 14.4.

Table 14.4 *Sand filters operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Inspect and identify any areas that are not operating correctly, if required take remedial action.	Monthly.
	Litter/trash/debris removal.	Monthly.
	Check surface of filter for blockage by algae or other matter. Remove and replace surface filter medium as necessary.	Monthly.
	Grass cutting and weeding.	Monthly or as required.
	If permanent water level is present (perimeter sand filter), ensure that the chamber does not leak and take remedial action, if required.	Monthly.
	Remove sediment.	Annually or as required.
	General filter rehabilitation.	Annually or as required.
Occasional maintenance	Replace top layers of filter media (50–75 mm of sand and, if present, topsoil).	3–5 years.
Remedial actions	Repair of erosion (surface filters) or other damage.	As required.
	Repair/rehabilitation of inlets, outlet and overflows.	As required.
	Replace compacted/clogged filter bed (Note: where filter beds become compacted to less than 0.75 of the original filter depth, they should be reinstated to the original design thickness).	As required.
	Replace all blocked filter fabrics.	As required.
Monitoring	Inspect/check all grates, inlets, outlets and overflows to ensure that they are in good condition and operating as designed.	Monthly.
	Check for odours indicating presence of anaerobic conditions.	Monthly.
	Record dewatering time of the filter to determine if maintenance is necessary.	6 monthly.
	Check for evidence of deterioration, spalling and/or cracking of concrete	Annually.
	Check that sedimentation chamber is <50% full (or filled to <300 mm depth, whichever is the smaller). Check that filter bed has <15 mm surface sediment accumulation.	Annually.
	Check filter casing for material failure.	Annually.

Sediments excavated from sand filters that receive runoff from residential or standard road and roof areas are generally not toxic or hazardous material and can therefore be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation to determine its classification and appropriate disposal methods. For industrial site runoff, sediment testing will be essential. In the majority of cases, it will be acceptable to distribute the sediment on site if there is an appropriate safe and acceptable location to do so. Additional detail on waste management is provided in Chapter 23.

Maintenance plans and schedules should be developed before maintenance contracts are commissioned. Specific maintenance needs of the sand filter should be monitored and maintenance schedules adjusted to suit requirements. Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken.

Additional detail on the preparation of maintenance specifications and schedules of work is given in Chapter 22.

Perlite/zeolite filter should be maintained in accordance with manufacturers' instructions, with major maintenance expected about once every 1–4 years.

14.9 CONSTRUCTION REQUIREMENTS

Sand filters should not receive any runoff until vegetation in the system is fully established and construction at the site has reached a state where sediment concentrations in the runoff will not cause clogging. If sediment from construction work accumulates on a sand filter surface, it should be cleared and the filter fully rehabilitated before the drainage system is adopted by the organisation carrying out the maintenance.

It is important that the top of the filter bed is constructed completely level, otherwise filtration will be localised and early failure may occur.

In areas where groundwater protection is a concern, the completed tank structure (concrete or membrane) should be filled with water for 24 hours to ensure that there is no leakage.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Additional detail on construction and the programming of construction is provided in Chapter 21.

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Infiltration basins

15

Contents

Infiltration basins 15

Description

Infiltration basins are vegetated depressions designed to store runoff and infiltrate it gradually into the ground.

KEY DESIGN CRITERIA

- effective pre-treatment required to remove sediments and fine silts prior to infiltration
- designed to infiltrate the water quality treatment volume, as a minimum
- infiltration should not be used where groundwater is vulnerable or to drain pollution hotspots.

ADVANTAGES

- reduces the volume of runoff from a drainage area
- can be very effective at pollutant removal via filtering through the soils
- contributes to groundwater recharge and baseflow augmentation
- simple and cost-effective to construct
- changes in performance easy to observe

DISADVANTAGES

- Potentially high failure rates due to improper siting, poor design and lack of maintenance, especially if appropriate pre-treatment is not incorporated
- comprehensive geotechnical investigations required to confirm suitability for infiltration
- not appropriate for draining pollution hotspots where high pollution concentrations are possible
- requires a large, flat area.

PERFORMANCE

Peak flow reduction:	Average
Volume reduction:	Good
Water quality treatment:	Good
Amenity potential:	Good
Ecology potential:	Good

TREATMENT TRAIN SUITABILITY

Source control:	No
Conveyance:	No
Site system:	Yes
Regional system:	No

SITE SUITABILITY

Residential:	Yes
Commercial/industrial: (probably roofs only)	Yes
High density:	No
Retrofit:	No
Contaminated sites/sites above vulnerable groundwater	No

COST IMPLICATIONS

Land-take:	High
Capital cost:	Low
Maintenance burden:	Low

POLLUTANT REMOVAL

Total suspended solids:	High
Nutrients:	Medium
Heavy metals:	High

KEY MAINTENANCE REQUIREMENTS

- regular inspections for signs of deterioration in performance, clogging and other blockages
- litter/trash removal
- inlet/outlet cleaning
- vegetation management
- regular removal of sediment from pre-treatment.

15.1 GENERAL DESCRIPTION

Infiltration basins are designed as depressions that store runoff for infiltration into the subsurface soils. They facilitate the recharge of groundwater resources and the replenishment of surface water baseflows, and remove stormwater pollutants via filtration processes occurring within the unsaturated soils beneath the system. Careful implementation is required to ensure that groundwater is not put at risk, that the site is suitable for infiltration, and that the system is not likely to clog due to the blockage of soil pores by sediments and fine silts.

In general, infiltration basins should be designed to treat only small storms (ie for water quality and groundwater recharge). Therefore, ideally they should be designed "off-line" using a diversion structure upstream of the system. Infiltration basins tend to be used to drain runoff from a number of properties but should not be used as regional solutions due to the increased risk of sediment loadings and pollution events from large contributing areas. In all cases, effective pre-treatment is required to ensure long-term performance of the basin.

Schematics for infiltration basins are shown in Figures 15.1 and 15.2.

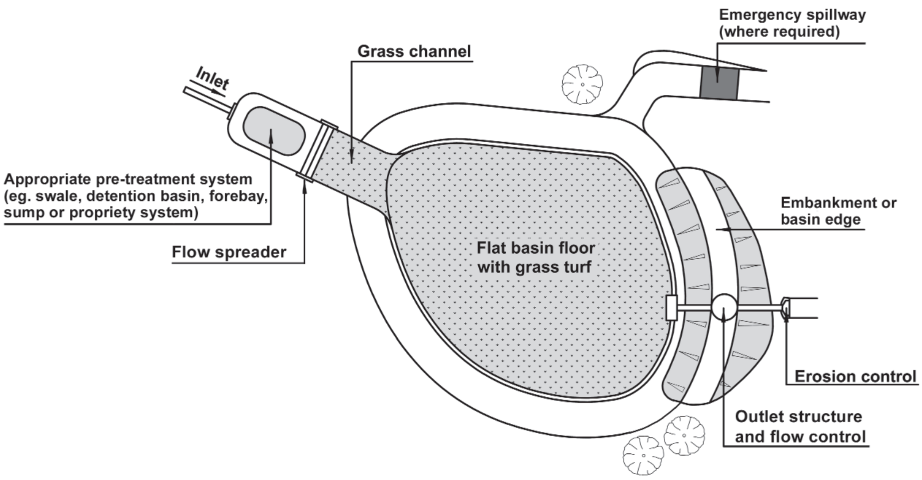

Figure 15.1 *Plan view of infiltration basin*

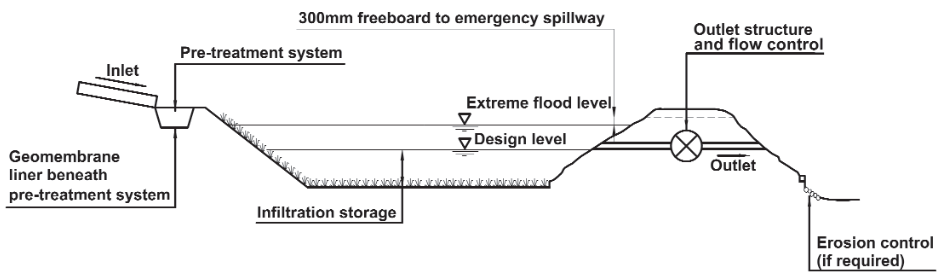

Figure 15.2 *Elevation of infiltration basin*

15.2 SELECTION AND SITING OF INFILTRATION BASINS

Infiltration basins should be implemented only where site and runoff conditions allow, and after geotechnical testing to confirm that infiltration is an appropriate method of disposal of runoff.

The criteria presented in Table 15.1 should be evaluated to ensure the suitability of infiltration basins for meeting drainage objectives at a particular site.

Table 15.1 *Considerations for using infiltration basins*

Drainage area	Appropriate for any drainage area providing appropriate pre-treatment via a SUDS management train has been implemented upstream.
Space required	They are relatively high land-take devices, and it is not possible to use the basins for other purposes, due to the risk of deterioration of the performance of the infiltration surface.
Siting	Infiltration basins require a large accessible area which is relatively flat and highly pervious. Account should be taken of other natural site features that might be used as additional temporary storage areas or conveyance routes when the basin's capacity is exceeded during extreme events.
Site and slope stability	The basin floor should be as level as possible to maximise the infiltration surface and minimise risks of erosion. Infiltration basins should not be sited on unstable ground and ground stability should be verified by assessing site soil and groundwater conditions. Infiltration basins should not be used in locations where infiltrating water may cause slope stability or foundation problems, eg areas of landslides, at the top of cutting or embankment slopes, or close to building foundations, unless a full assessment of the risks has been carried out by a suitably qualified geotechnical engineer or engineering geologist.
Subsurface soils and groundwater	The seasonally high groundwater table must be more than 1 m below the base of the facility and the design must comply with the environmental regulator's policy on infiltration and groundwater protection (see Section 2.4). Infiltration tests should be undertaken in accordance with BRE Digest 365 (BRE, 1991) (see Appendix B). Infiltration basins should not be used on brownfield sites unless it has been clearly demonstrated that the risk posed by leaching of contaminants is acceptable. Any excavation or earthmoving processes required must be assessed to ensure that mobilisation of contamination does not occur. Infiltration basins should not be used to treat runoff from pollution hotspots.

15.3 HYDRAULIC AND WATER QUALITY DESIGN

Guidance on sizing the Water Quality Treatment Volume (Vt) and other storages, and on infiltration design methods is given in Chapter 4. Infiltration is always beneficial to flood and pollution control and infiltration opportunities should be maximised wherever possible. Consideration should be given to events in excess of those that can be managed via infiltration, and these should be routed safely to downstream drainage components.

Shallow side-slopes and benching will help mitigate safety risks. The basin should also be designed to half empty in 24 hours, to ensure that adequate storage is available for multiple storms and to minimise the risks of water damaging the vegetation and compacting the surface soils.

15.4 PHYSICAL/GEOMETRIC SPECIFICATIONS

The form and aesthetic appearance of the facility will depend on specific site characteristics, local public concerns, and development design criteria.

Geometry

The bottom of the basin should be graded as flat as possible to provide uniform ponding and infiltration of the runoff across the surface. The side slopes of the basin should be no steeper than 1 in 4 to allow for vegetative stabilisation, mowing, access and for public safety reasons.

Materials

If an embankment is required to impound the water then the embankment fill material should use inert natural soils that will not leach contaminants into the stored runoff. Embankments should be designed to be stable and watertight, and the detailed guidance contained within the CIRIA publication R161 *Small embankment reservoirs* (Kennard *et al*, 1996) should be followed.

Design for maintenance and safety

Side slopes of the facility should not usually exceed 1 in 4 unless special site and/or safety arrangements allow for steeper slopes. Slopes should be no steeper than 1 in 4 wherever mowing is required, to reduce the risks associated with maintenance activities. Flatter slopes tend to improve the aesthetics, at the expense of additional land take. There should always be appropriate access to the infiltration basin for maintenance activities such as grass cutting and rehabilitation of the infiltration surface.

The rate of inflow and rise in water levels should be sufficiently slow as not to present a hazard. A risk assessment should be undertaken of the frequency of flooding to a range of inundation depths in order that public safety is not put at risk.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

All embankments should be designed in accordance with best practice, as described in CIRIA report R161 (Kennard et al, 1996). Those storing more than 25,000 m3 must also meet the 1975 Reservoir Act (DoE, 1975) requirements (see Section 2.5.6).

Design for ecology

The ecological value of the system can be enhanced by including bioretention areas (see Chapter 11) and other planting (see Chapter 20, Landscaping).

15.5 PRE-TREATMENT/INLETS

Infiltration basins are susceptible to high failure rates because of sediment clogging, and therefore require effective pre-treatment (see Chapter 7) to remove as much of the suspended solids and fine silts from the runoff as possible, before it enters the basin. To ensure that pre-treatment mechanisms are as effective as possible, designs should ideally incorporate “multiple pre-treatment”, using practices such as swales, sediment basins and filter strips in series upstream of the infiltration basin.

Infiltration basins can be designed as off-line devices, with high flows being conveyed around the basin to prevent system damage during extreme events.

Inlet channels should be stabilised using appropriate erosion control, eg rip rap, and a level spreader should be provided at the inlet to the basin from the pre-treatment system to promote shallow sheet flow into the basin which will maximise pollutant removal opportunities, and reduce the risks of erosion.

15.6 OUTLETS

Where infiltration basins have to be implemented as on-line devices, they must have an emergency spillway capable of passing runoff from large storms without damage to the impounding structure, and full consideration should be given to the safe management of events that exceed the infiltration basin’s capacity.

15.7 LANDSCAPING AND VEGETATION

Immediately following basin construction, the base and side-slopes should be stabilised with a dense turf of water-tolerant grass. Plants in an infiltration basin should be able to withstand periods of ponding and dry periods and, ideally, maintain or enhance the pore space in the underlying soils via deep rooting systems. In order to reduce maintenance requirements, planting with wild flower meadow mixes can be considered (see Chapter 20).

Infiltration basins are typically grassed structures, but some additional vegetation can enhance the appearance of the basin, stabilise side slopes and prevent erosion, serve as wildlife habitat, and partially conceal unsightly litter and debris. It also increases the effectiveness of infiltration by slowing the flows across the basin.

Fencing is generally not desirable as it may reduce the amenity benefits provided by the infiltration facility, provide a barrier to easy maintenance, and provide a trap where litter and dead vegetative material could collect. Where fences are required, they should be low (toddler-proof), but facilitate movement of wildlife. Gentle slopes can contribute to minimising public safety risks. Community engagement is discussed in Chapter 24 and landscaping and planting best practice is presented in Chapter 20.

Inlet and outlet pipes/culverts should not be accessible by small children. The headwalls of large pipes should be fenced to prevent accidents and deter access. Grilles should also be considered to prevent entry into the pipe but these tend to clog rapidly, triggering more regular maintenance requirements and potentially affecting hydraulic performance.

Education boards should be provided to inform the public of the function of the basin, especially where the basin has a dual-use.

15.8 OPERATION AND MAINTENANCE REQUIREMENTS

Regular inspection and maintenance is important for the effective operation of infiltration basins as designed. Maintenance responsibility for an infiltration basin and its surrounding area should be placed with a responsible organisation.

Regular mowing in and around infiltration basins is required only along maintenance access routes, amenity areas (eg footpaths), across embankments and across the main storage area. The remaining areas can be managed as "meadow", unless additional management is required for landscaping purposes.

Adequate access should be provided to the infiltration basin for inspection and maintenance, including for appropriate equipment and vehicles, eg mowing equipment. Operation and maintenance requirements for infiltration basins are described in Table 15.2.

Table 15.2 *Infiltration basin operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Litter, debris and trash removal.	Monthly.
	Grass cutting – for landscaped areas and access routes.	Monthly (during growing season), or as required.
	Grass cutting – meadow grass in and around basin.	Half yearly (spring – before nesting season, and autumn).
	Manage other vegetation and remove nuisance plants.	Monthly (at start, then as required).
Occasional maintenance	Re-seed areas of poor vegetation growth.	Annually, or as required.
	Prune and trim trees and remove cuttings.	As required.
	Remove sediment from pre-treatment system when 50% full.	As required.
Remedial actions	Repair of erosion or other damage by re-seeding or re-turfing.	As required.
	Realignment of rip-rap.	As required.
	Repair/rehabilitation of inlets, outlets and overflows.	As required.
	Rehabilitate infiltration surface using scarifying and spiking techniques if performance deteriorates.	As required.
	Re-level uneven surfaces and reinstate design levels.	As required.
Monitoring	Inspect inlets, outlets and overflows for blockages, and clear if required.	Monthly.
	Inspect banksides, structures, pipework, etc for evidence of physical damage.	Monthly.
	Inspect inlets and pre-treatment systems for silt accumulation. Establish appropriate silt removal frequencies.	Half yearly.
	Inspect infiltration surfaces for compaction and ponding.	Monthly.

Sediments excavated from infiltration basins that receive runoff from residential or standard road and roof areas are generally not toxic or hazardous material and can therefore be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation to determine its classification and appropriate disposal methods. For industrial site runoff, sediment testing will be essential. In the majority of cases, it will be acceptable to distribute the sediment on site if there is an appropriate safe and acceptable location to do so. Further information on waste management is provided in Chapter 23.

Maintenance plans and schedules should be developed before maintenance contracts are commissioned. Specific maintenance needs of the basin should be monitored and maintenance schedules adjusted to suit requirements. Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken.

Additional detail on the preparation of maintenance specifications and schedules of work is given in Chapter 22. Provided preventive maintenance measures are conscientiously undertaken, the need for corrective maintenance should rarely arise.

15.9 CONSTRUCTION REQUIREMENTS

Ideally, construction of the infiltration basin should take place after the site has been stabilised in order to minimise the risk of premature failure of the basin from deposition of sediments from disturbed ground. If this is not possible, then initial excavation should be carried out to within 450 mm of the basin floor and final excavation should be delayed until after stabilisation. Checks should be made that any embankments meet their design criteria.

All excavation and levelling should be performed by equipment with tracks exerting very light pressures to prevent compaction of the basin floor, which may reduce infiltration capacity. Before and after construction, other vehicular movements should be prevented.

The base of the basin should be carefully prepared to an even grade with no significant undulations. The surface soils within the basin should not be smeared or compacted during construction. After final grading, the basin floor should be tilled to a depth of 150 mm to provide a well-aerated, porous surface texture.

Backfilling against inlet and outlet structures needs to be controlled to minimise settlement and erosion. The topsoils used to finish the side slopes need to be suitably fertile, porous and of sufficient depth to ensure healthy vegetation growth.

It is essential that infiltration basins should not be used to manage construction runoff and trap construction sediments.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Additional detail on construction and the programming of construction is provided in Chapter 21.

15.10 REFERENCES

BRE (Buildings Research Establishment) (1991)
Digest 365: *Soakaway Design*.
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Detention basins

16

Contents

Detention basins 16

Description

Detention basins are surface storage basins or facilities that provide flow control through attenuation of stormwater runoff. They also facilitate some settling of particulate pollutants. Detention basins are normally dry and in certain situations the land may also function as a recreational facility.

KEY DESIGN CRITERIA

- detention volume to manage design storms via constrained outflow
- minimum length:width ratio of 2:1
- maximum side slopes of 1:4 for maintenance and safety reasons, unless the situation allows steeper slopes to be used
- bioretention and/or wetland/micropools at outlets is desirable for enhanced pollution control.

ADVANTAGES

- can cater for a wide range of rainfall events
- can be used where groundwater is vulnerable, if lined
- simple to design and construct
- potential for dual land use
- easy to maintain
- safe and visible capture of accidental spillages.

DISADVANTAGES

- little reduction in runoff volume
- detention depths may be constrained by system inlet and outlet levels.

PERFORMANCE

Peak flow reduction:	Good
Volume reduction:	Poor
Water quality treatment:	Medium
Amenity potential:	Good
Ecology potential:	Medium

TREATMENT TRAIN SUITABILITY

Source control:	No
Conveyance:	No
Site system:	Yes
Regional system:	Yes

SITE SUITABILITY

Residential:	Yes
Commercial/industrial:	Yes
High density:	Yes
Retrofit:	Yes
Contaminated sites/sites above vulnerable groundwater (with liner)	Yes

COST IMPLICATIONS

Land-take:	Medium
Capital cost:	Low
Maintenance burden:	Low

POLLUTANT REMOVAL

Total suspended solids:	Medium
Nutrients:	Low
Heavy metals:	Medium

KEY MAINTENANCE REQUIREMENTS:

- litter/trash removal
- inlet/outlet cleaning
- vegetation management
- sediment monitoring and removal when required.

16.1 GENERAL DESCRIPTION

Detention basins are dry basins that attenuate stormwater runoff by providing temporary storage and controlled release of detained runoff. They are normally vegetated depressions that are mainly dry, except during and immediately after storm events. They may be designed with a small permanent pool at the outlet to help prevent re-suspension of sediment particles by high intensity storms and to provide enhanced water quality treatment for frequent events.

For maximum pollutant removal effectiveness, flows should be distributed across the full width of the basin. However, where there are concerns about keeping a proportion of the base of the basin dry, a proportion of the basin can be lowered to constrain frequent events within a specified area. Low flow channels are not recommended. Any "lowered" areas should be as wide as practicable. Where there are high groundwater levels, the use of a wetland base can create an attractive feature and provide additional treatment.

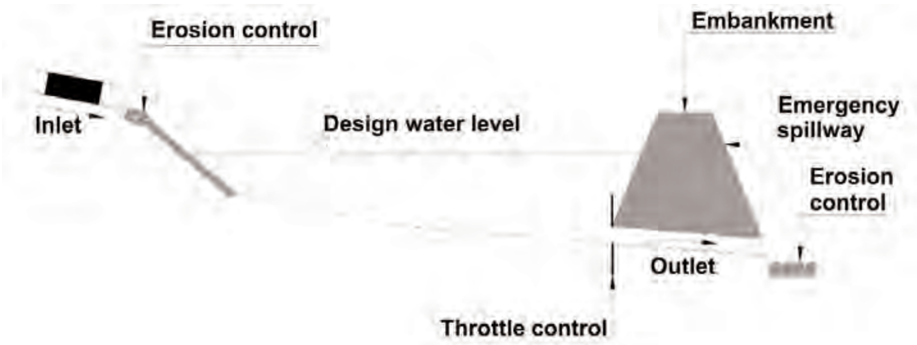

Figure 16.1 *Schematic of simple detention basin profile*

Detention basins may be constructed as on-line or off-line facilities. On-line facilities have surface runoff routed through them during storm events. They have a restricted outflow that allows the basin to fill, thus attenuating flows. Off-line facilities usually receive runoff via a flow diverter or overflow, by which flows in excess of a threshold value are diverted from the main flow path into the detention basin and temporarily stored. The water from the detention basin is passed back into the main system when the inflow falls below the diversion threshold. Off-line detention basins should be avoided where treatment of the runoff is important.

Detention basins may be constructed to serve more than one purpose, and can be used as car parks, playgrounds or sports fields. When constructed for dual purposes, the detention basin should be usable for the function other than stormwater detention for most of the time. Where dual use is intended, the recreational area should have a relatively low flooding frequency eg 1 to 5 year return period, depending on its use. Signage indicating that the area is liable to flooding would also be required. Further information can be found in CIRIA publication C635 (Balmforth *et al* 2006)

Detention facilities are frequently used for temporary sediment control during construction. It is essential that they are reinstated or reconstructed at the end of construction and before adoption by the maintaining authority.

Figures 16.2 and 16.3 provide a typical plan view and more detailed profile for the design of a detention basin.

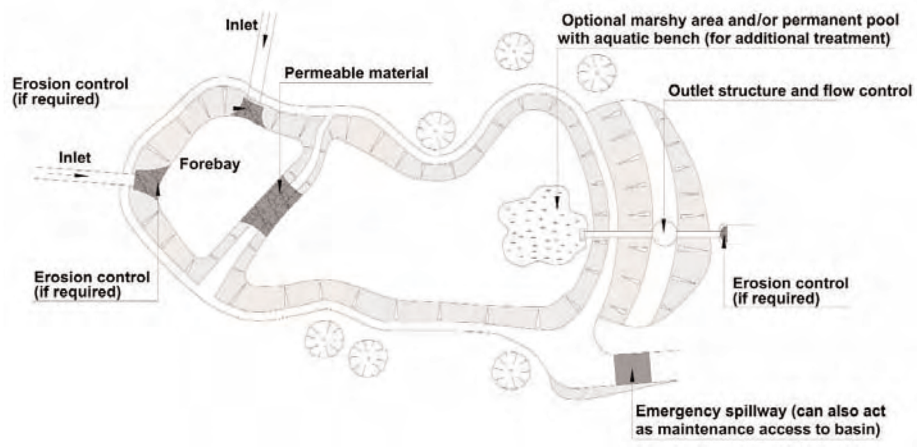

Figure 16.2 *Plan view of detention basin*

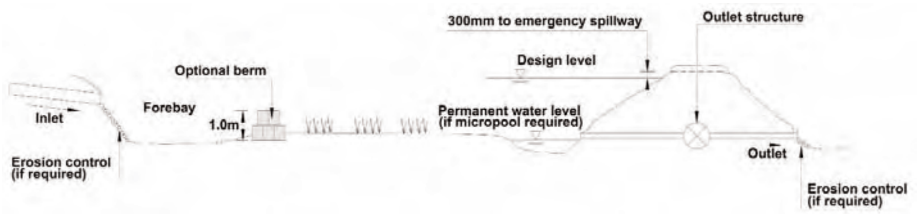

Figure 16.3 *Elevation of detention basin*

16.2 SELECTION AND SITING OF DETENTION BASINS

Detention basins are generally applicable to most types of development, and can be used in both residential and non-residential areas. They can be used for both large site and regional controls, and are also appropriate for use in retrofit situations (where existing drainage network levels allow).

The criteria presented in Table 16.1 should be evaluated to ensure the suitability of detention basins for meeting drainage objectives at a particular site.

Table 16.1 *Considerations for the use of detention basins*

Drainage area	For catchments of less than three hectares, outlet throttle diameters may have to be very small (ie <150 mm diameter)to achieve pre-development outflow rates. This may mean that they risk clogging and special attention should be given to the design of the outlet area. There is no maximum catchment area beyond which detention basins cannot be used.
Space required	Through imaginative site design, detention basins can be constructed for dual purposes.
Siting	Detention basins should be integrated into the site planning process and take into account the location and use of other site features and undisturbed natural areas.
Site slope & stability	The basin floor should be as level as possible to minimise flow velocities, maximise pollution removal efficiencies, and minimise risks of erosion. Detention basins should not be sited on unstable ground and ground stability should be verified by assessing site soil and groundwater conditions.
Subsurface soils and groundwater	Historic groundwater level records should be checked to ensure that during periods of high groundwater, the storage capacity of the detention basin is retained. If a liner is used, then there is a risk that the liner may "float" during periods of high groundwater levels. A seasonally high groundwater table may not always impede the proper functioning of the facility, but can result in a muddy base that may be considered unattractive if not developed into a permanent wetland feature. Unlined detention basins should not be used on brownfield sites unless it has been clearly demonstrated that there is no risk of groundwater pollution. Any excavation or earthmoving processes required must be assessed to ensure that mobilisation of contamination does not occur. Unlined detention basins should not be used to treat runoff from hotspots if there is a risk of groundwater pollution. Where a micropool at the outlet is required, the soil below the pool area should be sufficiently impermeable to maintain the permanent pool, unless a continuous baseflow or high groundwater table is present. In highly permeable strata, a liner will be required to prevent the pool from drying out.

16.3 HYDRAULIC AND WATER QUALITY DESIGN

Guidance on hydraulic criteria is given in Chapter 3 and methods for sizing the storages are presented in Chapter 4. The detention basin should be sized to provide flood attenuation for all events to meet the site standard of service criteria – up to the 10, 30 or 100 year, if required, with discharges being constrained to the equivalent greenfield rates. Consideration should be given to larger events which must be routed safely downstream. Basin volumes may require increasing if long-term storage criteria cannot be met.

Although, in the past, extended detention of the water quality treatment volume was thought to provide enhanced water quality performance, current research suggests that there is little evidence to support such a conclusion. Effective sediment control and management, together with use of the vegetated basin base for filtration of small, frequent events has been shown to provide a reasonable level of treatment. Where contributing catchment pollution risks are particularly high and/or the receiving watercourse is particularly sensitive, then several components should be used in series to minimise risks of damaging the environment. Sections 1.3.2 and 3.3.3 address the implementation of the SUDS management train philosophy.

16.4 PHYSICAL/GEOMETRIC SPECIFICATIONS

The form and aesthetic appearance of the facility will depend on specific site characteristics, local public concerns, and development design criteria. However, there are a number of geometric ratios and limiting depths that should be observed to maximise pollutant removal, ease of maintenance and good safety practice.

Geometry

The maximum depth of water in the basin should not normally exceed 3 m. However, many authorities will require a much lower maximum depth, for safety reasons.

The bottom of the basin should be fairly flat with a gentle slope (no more than 1 in 100) towards the outlet, to maximise contact of runoff with the vegetation and to prevent standing water conditions from developing. Areas above the normal high water elevations of the detention facility should also be sloped toward the basin to allow effective drainage.

The recommended length/width ratio for online detention basins is between 2:1 and 5:1. Inlets and outlets should be placed to maximise the flow path through the facility. Contoured bases can be used effectively to define areas that are likely to be wetted regularly.

Materials

A liner may be required to maintain the water level in a micropool, prevent infiltration of runoff from pollution hotspots, and/or to protect an underlying aquifer. Liner (geomembrane) specifications are discussed in Appendix C.

If an embankment is required to impound the water then the embankment fill material should use inert natural soils that will not leach contaminants into the stored runoff. Embankments should be designed to be stable and watertight, and the detailed guidance contained within the CIRIA publication R161 *Small embankment reservoirs* (Kennard *et al*, 1996) should be followed.

Design for maintenance and safety

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

All embankments should be designed in accordance with best practice, as described in CIRIA publication R161 (Kennard *et al*, 1996). Those storing more than 25 000 m^3 must also meet the 1975 Reservoir Act requirements (DoE, 1975) (see Section 2.5.6).

Side slopes of the facility should not usually exceed 1 in 4 unless special site and/or safety arrangements allow for steeper slopes. Slopes should be no steeper than 1 in 4 wherever mowing is required, to reduce the risks associated with maintenance activities. Flatter slopes tend to improve the aesthetics, at the expense of additional land take.

There should always be appropriate access to the detention basin for maintenance activities such as grass cutting and sediment removal.

Design for ecology

The ecological value of the system can be enhanced by including micropools or wetland zones at the base. Relevant guidance is given in Chapter 17.

16.5 PRE-TREATMENT/INLETS

For basins serving large developments, a sediment forebay or upstream pre-treatment component will improve the water quality performance of a detention basin and reduce long-term maintenance requirements. The plan area of the sedimentation bay should be at least 10 per cent of the total basin area and could consist of a separate basin or be formed by building an earth berm, stone/rock-filled gabion or rip rap across the upstream portion of the basin. For systems with multiple inlets, pre-treatment should be provided for each inlet that is likely to contribute a significant sediment load.

Consideration should be given to installing a fixed sediment depth marker in the forebay to measure sediment deposition with time. This will assist with the development of appropriate future maintenance schedules.

The energy of incoming flows should be dissipated to minimise the risk of scouring and erosion. This can be achieved by stabilising inflow channels using rip-rap or other erosion control systems. The design of inlets is described in Chapter 19.

16.6 OUTLETS

Outlets should be built into a dyke or berm with easy access for maintenance. A manhole-type outlet structure can accommodate a variety of outlet control mechanisms. Trash racks are not recommended, but where grilles are necessary to prevent access into the pipework, they must be designed so that debris does not obstruct or reduce design flow rates unduly.

When discharging to a receiving water, detention basins will generally require a non-clogging variable flow rate control structure at the outlet, together with an emergency overflow to pass an extreme flood flow downstream safely. Low flow controls are generally provided via orifices, which can then be combined with overflow channels and overflow weir sections and/or culverts for larger events. Multiple orifices or pipe outlets can be used to achieve the same objectives. For more detail on outlet infrastructure, see Chapter 19.

A micropool at the outlet reduces the risk of re-suspension of sediment and of the outlet clogging. Rip raps, plunge pools or pads, or other energy dissipators should be placed at the end of the outlet prevent scouring and erosion if the basin discharges to a watercourse.

Drawdown valves may be included as a precaution in case the outlet structure becomes blocked. Seepage control in the form of collars may need to be provided for outlet pipes through embankments.

16.7 LANDSCAPING AND VEGETATION

Detention basin design should take account of the local landscaping and environment. It should be site specific and individual designs should be developed using “soft” geometries with curved boundaries and undulating margins, rather than straight lines and hard edges. Community engagement is discussed in Chapter 24 and landscaping and planting best practice is presented in Chapter 20.

Detention basins are, typically, grassed structures, and other planting schemes are not generally implemented. Some additional vegetation can enhance the appearance of the basin, stabilise side slopes and prevent erosion, serve as wildlife habitat, and partially conceal unsightly litter and debris. It also increases the effectiveness of sediment settling by slowing the flows across the basin.

Fencing is generally not desirable as it may reduce the amenity benefits provided by the detention facility, provide a barrier to easy maintenance, and provide a trap where litter and dead vegetative material can collect. Where fences are required, they should be low (toddler-proof), but allow movement of wildlife. Gentle slopes and appropriate planting can contribute to minimising public safety risks.

Inlet and outlet pipes/culverts should not be accessible by small children. The headwalls of large pipes should be fenced to prevent accidents and deter access. Grilles should also be considered to prevent entry into the pipe but these tend to clog rapidly, triggering more regular maintenance requirements and potentially affecting hydraulic performance.

Lifesaving equipment should be provided where the potential water depth in the basin can exceed 1.2 m. Education boards should be provided to inform the public of the function of the basin, especially where the basin has a dual use.

16.8 OPERATION AND MAINTENANCE REQUIREMENTS

Regular inspection and maintenance is important for the effective operation of detention basins as designed. Maintenance responsibility for a detention basin and its surrounding area should be placed with a responsible organisation.

Regular mowing in and around detention basins is required only along maintenance access routes, amenity areas (eg footpaths), across embankments and across the main storage area. The remaining areas can be managed as “meadow”, unless additional management is required for landscaping purposes.

Where a detention basin has a micropool at the outlet, its submerged and emergent aquatic vegetation should be managed as for ponds or wetlands. Plant management, to achieve the desired habitat effect, should be specified clearly in a maintenance schedule.

Adequate access must be provided to the detention basin for inspection and maintenance, including for appropriate equipment and vehicles, eg mowing equipment. Operation and maintenance requirements for detention basins are described in Table 16.2.

Table 16.2 *Detention basin operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Litter and debris removal.	Monthly.
	Grass cutting – for spillways and access routes.	Monthly (during growing season), or as required.
	Grass cutting – meadow grass in and around basin.	Half yearly (spring - before nesting season, and autumn).
	Manage other vegetation and remove nuisance plants.	Monthly (at start, then as required).
	Tidy all dead growth before start of growing season.	Annually.
	Remove sediment from inlets, outlet and forebay.	Annually (or as required).
	Manage wetland plants in outlet pool – where provided.	Annually.
Occasional maintenance	Re-seed areas of poor vegetation growth.	Annually, or as required.
	Prune and trim trees and remove cuttings.	2 years, or as required.
	Remove sediment from forebay, when 50% full and from micropools if volume reduced by > 25%.	3 – 10 years (or as required).
Remedial actions	Repair of erosion or other damage by re-seeding or re-turfing.	As required.
	Realignment of rip-rap.	As required.
	Repair/rehabilitation of inlets, outlets and overflows.	As required.
	Re-level uneven surfaces and reinstate design levels.	As required.
Monitoring	Inspect inlets, outlets and overflows for blockages, and clear if required.	Monthly/after large storms.
	Inspect banksides, structures, pipework, etc for evidence of physical damage.	Monthly/after large storms.
	Inspect inlets and facility surface for silt accumulation. Establish appropriate silt removal frequencies.	Half yearly.
	Check penstocks and other mechanical devices.	Half yearly.

Sediments excavated from detention basins that receive runoff from residential or standard road and roof areas are generally not toxic or hazardous material and can therefore be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation to determine its classification and appropriate disposal methods. For industrial site runoff, sediment testing will be essential. In the majority of cases, it will be acceptable to distribute the sediment on site if there is an appropriate safe and acceptable location to do so. Additional information on waste management is given in Chapter 23.

Maintenance plans and schedules should be developed during the design phase. Specific maintenance needs of the basin should be monitored and maintenance schedules adjusted to suit requirements. Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken. Additional detail on the preparation of maintenance specifications and schedules of work is given in Chapter 22. Provided preventive maintenance measures are conscientiously undertaken, the need for corrective maintenance should rarely arise.

Many of the maintenance activities for detention basins can be undertaken as part of landscape maintenance and, if landscape management is already required at site, should have marginal cost implications.

16.9 CONSTRUCTION REQUIREMENTS

The bottom and side slopes of the basin should be carefully prepared to ensure that they are structurally sound and checks should be made that any embankment structures meet their design criteria. The preparation should also ensure that the basin will satisfactorily retain the surface water runoff without significant erosion damage.

Backfilling against inlet and outlet structures needs to be controlled to minimise settlement and erosion. The soils used to finish the side slopes need to be suitably fertile, porous and of sufficient depth to ensure healthy vegetation growth. If an impermeable liner is used, care should be taken to ensure that it is not damaged during construction.

During the SUDS establishment phase, runoff from bare soils should be minimised. For example:

- vegetative on slopes should be rapidly established
- base-of-slope trenches should be introduced to retain the inevitable runoff of sediments
- construction should be timed to avoid autumn and winter when high runoff rates are to be expected.

Detention basins may be used to manage construction runoff and trap construction sediments, providing they are fully rehabilitated to original design formation levels before handover.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Additional detail on construction activities and the programming of construction activities is provided in Chapter 21.

16.10 REFERENCES

DETR (1994)
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Small embankment reservoirs (R161)
CIRIA, London.

Ponds

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Contents

Ponds

17

Description

Ponds can provide both stormwater attenuation and treatment. They are designed to support emergent and submerged aquatic vegetation along their shoreline. Runoff from each rain event is detained and treated in the pool. The retention time promotes pollutant removal through sedimentation and the opportunity for biological uptake mechanisms to reduce nutrient concentrations.

KEY DESIGN CRITERIA

- permanent pool volume for water quality treatment
- temporary storage volume for flow attenuation
- sediment forebay or upstream pre-treatment
- length:width ratio between 3:1 and 5:1
- minimum depth for open water areas of 1.2 m
- maximum depth of permanent pool of 2 m
- side slopes <3:1 for slopes.

ADVANTAGES

- can cater for all storms
- good removal capability of urban pollutants
- can be used where groundwater is vulnerable, if lined
- good community acceptability
- high potential ecological, aesthetic and amenity benefits
- may add value to local properties.

DISADVANTAGES

- no reduction in runoff volume
- anaerobic conditions can occur without regular inflow
- land take may limit use in high density sites
- may not be suitable for steep sites, due to requirement for high embankments
- colonisation by invasive species could increase maintenance
- perceived health & safety risks may result in fencing and isolation of the pond.

PERFORMANCE

Peak flow reduction:	Good
Volume reduction:	Poor
Water quality treatment:	Good
Amenity potential:	Good
Ecology potential:	Good

TREATMENT TRAIN SUITABILITY

Source control:	No
Conveyance:	No
Site system:	Yes
Regional system:	Yes

SITE SUITABILITY

Residential:	Yes
Commercial/industrial:	Yes
High density:	Unlikely
Retrofit:	Unlikely
Contaminated sites/sites above vulnerable groundwater (with liner)	Yes

COST IMPLICATIONS

Land-take:	High
Capital cost:	Medium (High with liner)
Maintenance cost:	Medium

POLLUTANT REMOVAL

Total suspended solids:	High
Nutrients:	Medium
Heavy metals:	High

KEY MAINTENANCE REQUIREMENTS:

- litter/debris removal
- inlet/outlet cleaning
- vegetation management
- sediment monitoring and removal when required.

17.1 GENERAL DESCRIPTION

Ponds are widely used as a cost-effective SUDS technique. Well-designed and maintained ponds can offer important aesthetic, amenity and wildlife benefits to development sites.

Ponds are basins that have a permanent pool of water. They can be created by using an existing natural depression, by excavating a new depression, or by constructing embankments. Existing natural water bodies should not be used as a means by which to dispose of surface water runoff due to the risk that pollution events and poorer water quality might disturb/damage the natural ecology of the system.

Each time it rains, the runoff entering the pond is detained and treated by settling out sediments and biological uptake until it is displaced by runoff from the next storm.

To meet the required design criteria (see Chapter 3), the pond should be designed for ease of maintenance, and should contain several zones:

1. **The sediment forebay (optional)** Effective pre-treatment should ideally be implemented via appropriate source control and upstream SUDS management train components (see Chapter 7). Where there are residual sediment risks, or where a sediment forebay is the only suitable management option at the site, then the pond can be split to allow coarse sediments to settle in the forebay before the runoff enters the permanent pool. The forebay allows sediment build-up to be monitored easily, and concentrates any required sediment removal activities within a small area, thereby minimising potential damage to the rest of the pond.
2. **The permanent pool t**hat will remain throughout the year (less any evaporation and infiltration during extended periods of dry weather). The pool acts as the main treatment zone and helps to protect fine deposited sediments from re-suspension. The top water level for this volume should be at the invert level of the outlet structure, unless an "infiltration depth" is included (ie a depth between outlet invert level and top elevation of liner over which infiltration is encouraged to take place).
3. **The temporary storage volume** provides flood attenuation for the required events.
4. **The shallow zone (aquatic bench)** along the edge of the permanent pool to support wetland planting. This acts as a biological filter and provides ecology, amenity and safety benefits.

Additional pond design features should include an emergency spillway, maintenance access, a safety bench, and appropriate landscaping.

A pond should preferably be divided into a multiple pond system that provides water quality and quantity volume storage in several independent cells. These can create increased attenuation flood control, longer pollutant removal pathways, an easier maintenance regime, and more varied ecology. They also allow:

- enhanced biodiversity via the provision of several systems of improving water quality levels, where the lower ponds are well protected from accidental pollution spills or high toxicity events
- a more environmentally effective maintenance programme to be developed, through staggered programmes for each of the ponds.

Figures 17.1 and 17.2 provide example plan view and profile schematics for the design of a pond system. Figure 17.3 gives details of typical pond edge details.

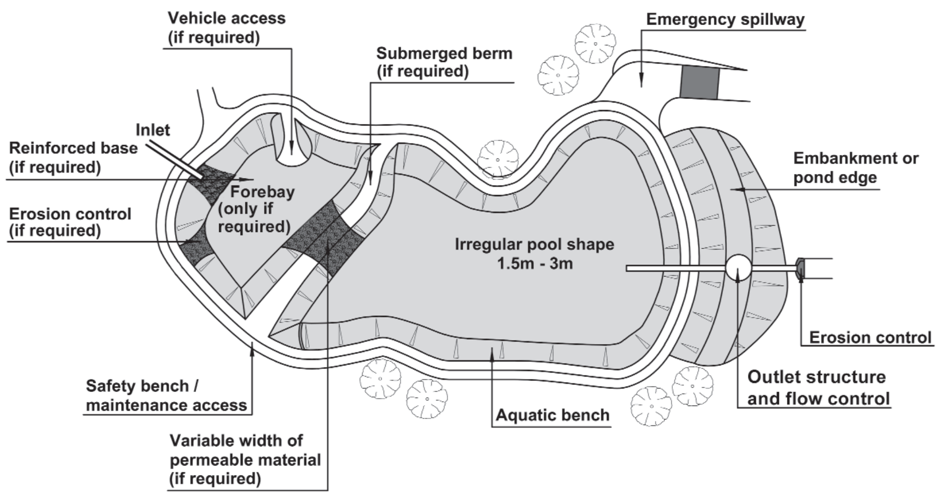


Figure 17.1 *Plan view of pond details*

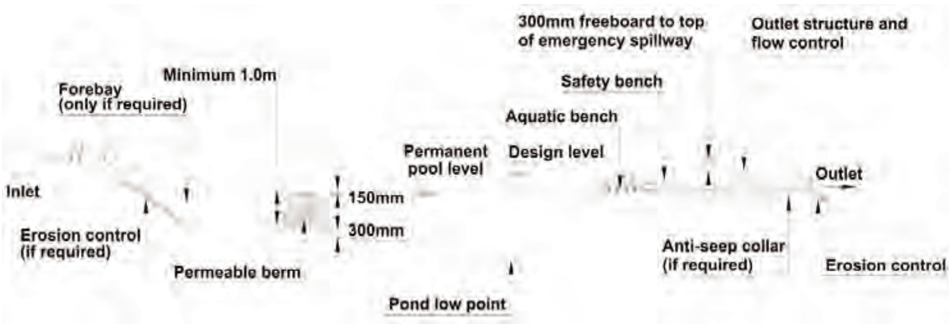


Figure 17.2 *Profile of pond details*

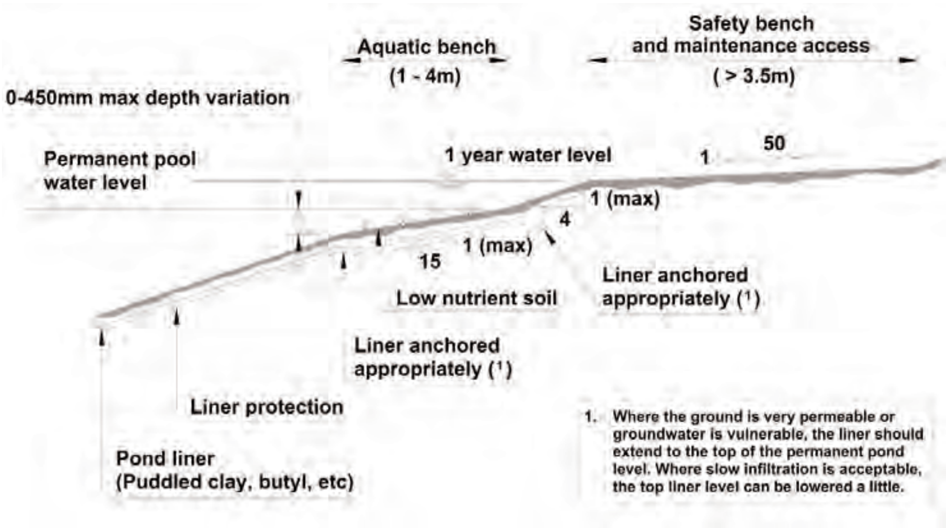


Figure 17.3 *Typical pond edge geometry*

17.2 SELECTION AND SITING OF PONDS

Generally, ponds are applicable to most types of new development and redevelopment, and can be used in both residential and non-residential areas. Ponds can be used for both site and regional controls, and are also appropriate for use in retrofit situations where land is available at a suitable point near the outlet of the drainage system. Land-take requirements may preclude their suitability for high-density development areas.

The criteria presented in Table 17.1 should be evaluated to check the suitability of a pond for meeting drainage objectives at a particular site.

Table 17.1 *Considerations for using ponds*

Drainage area	There is no specific constraint on drainage area although if ponds are too small their amenity benefits will be limited, they may be difficult to maintain and there may be risks of drying out during extended dry weather (unless water will seep to the pond from eg groundwater sources). In all cases, an appropriate SUDS management train should be implemented upstream so removing the need for large downstream ponds.
Space required	Typically, 3–7% of the upstream catchment area will be required for the pond.
Siting	Ponds are normally located at a position that can receive all the site runoff (ie at the lowest point in the site), generally at minimum excavation (or construction) cost. Their location should allow safe routing of events greater than the design event, with any risks from embankment failure given full consideration and mitigation. If a purpose of the pond is to protect the watercourse during floods, then the system should not be located in the floodplain, where there is a risk that the detention storage will be lost through inundation at the critical time. River flood waters also tend to carry high sediment and debris loads that will be deposited in any on-line storage areas necessitating additional maintenance. Wherever possible, ponds should be located in, or adjacent to, non-intensively managed landscapes where natural sources of native species are likely to be good.
Site slope & stability	It may be difficult to site a pond on steeply sloping sites, and ponds should not be sited on unstable ground. Ground stability should be verified by assessing site soil and groundwater conditions. Ponds should not be built on waste fill materials, uncontrolled fill or non-engineered fill.
Subsurface soils and groundwater	The soil below a wet pond should be sufficiently impermeable to maintain the water levels within the permanent pool at the required level, unless a continuous upstream baseflow can be guaranteed. In permeable strata, a liner (or other impermeable material such as puddled clay) will be required to prevent the pond drying out. Evaluation of soils should be based upon soils investigations and permeability tests. In areas containing contaminated soils or contaminated groundwater (brownfield sites), ponds can be used providing the system is fully sealed, preventing exchange of water between pond and groundwater. Any excavation or earthmoving processes required must be assessed to ensure that mobilisation of contamination does not occur. If used on a site with a sensitive underlying groundwater zone, or if used to treat runoff from a potential pollution hotspot, a hydrogeological risk assessment will generally be required to determine an appropriate separation distance between the bottom of the pond and the elevation of the annual maximum water table unless a liner is proposed. Any permeability of the subsurface soils will require the use of a liner (or other impermeable material such as puddle clay). Where the groundwater table is close to the base of the pond, the operation of the outfall should be confirmed for the annual maximum water table level. The maximum expected groundwater level should be beneath the temporary detention zone.

17.3 HYDRAULIC AND WATER QUALITY DESIGN

The SUDS management train philosophy recommends that ponds are used as site/regional controls with upstream components used as primary treatment and, particularly, sediment management components. Implementing this approach is described in detail in Sections 1.3.2 and 3.3.3.

Where the pond is the first or only component of the treatment train, then the permanent pool should be sized to treat the Water Quality Treatment Volume multiplied by an appropriate factor. Detailed guidance on water quality criteria is given in Section 3.3 and methods for sizing the treatment volume are described in Section 4.5.6. A summary of the range of factors is given in Table 17.2.

Table 17.2 *Water quality treatment volume factors for permanent pool sizing*

Factor	Receiving watercourse sensitivity	Contributing catchment pollution risk	Upstream treatment devices	Notes
<1	Low	Low	Yes	Factor can be reduced depending on treatment volumes provided in upstream devices.
1	Low	Low	No	Minimum factor required where pond provides main treatment component and pollution risks are low.
>1	Low High	High Low	Possibly	Where watercourse sensitivity is high and/or risks of pollution from the contributing catchment are significant. A factor of between 2 and 4 should be agreed with the environmental regulator, depending on the estimated risks. This can be reduced if upstream components are included.

Guidance on hydraulic criteria is given in Section 3.3 and methods for sizing storages are presented in Chapter 4. The temporary detention zone (flood control volume or attenuation storage) should be sized to provide flood attenuation for all events to meet the site standard of service criteria – up to the 30/100/200 year, if required, with discharges being constrained to the equivalent greenfield rates. Storage volumes may need to be increased if long-term storage criteria cannot be met elsewhere.

17.4 PHYSICAL SPECIFICATIONS

The form and aesthetic appearance of the pond will depend on specific site characteristics, local public concerns, and development design criteria. However, there are a number of geometric ratios and limiting depths for pond design that should be observed for adequate pollutant removal, ease of maintenance and good safety practice.

Geometry

Inlets and outlets should be placed to maximise the flow path through the facility. The ratio of flow path length to width should be at least 3:1 to avoid hydraulic short-circuiting. If there are multiple inlets, the length-to-width ratio should be based on the flow-weighted, average flow path length for all inlets.

Ponds should be wedge-shaped in plan where possible so that flow enters the pond and gradually spreads out. This improves the sedimentation process. Baffles, pond shaping and islands can be added within the permanent pool to increase the flow path and maximise water quality treatment processes.

Maximum depth of the permanent pool should not exceed 2 metres to avoid stratification and anoxic conditions. Very shallow ponds may be at risk of algal blooms and high biological activity during summer months. Greater depths near the outlet will reduce the risk of sediment re-entrainment, will tend to yield cooler bottom water discharges that may mitigate downstream thermal effects, and will facilitate draw-down.

An aquatic bench should be provided that extends inwards from the normal pond edge and has a maximum depth of 0.45 metres below the normal pool water surface elevation. The width can be varied depending on the size of the pond and extent of vegetation required for safety and aesthetic purposes, but would normally be at least 1 m wide.

Materials

A liner may be required to maintain the permanent pool water level, prevent infiltration of runoff from pollution hotspots, and/or to protect an underlying aquifer. Liner (geomembrane) specifications are discussed in Appendix C.

If an embankment is required to impound the water then the embankment fill material should use inert natural soils that will not leach contaminants into the stored runoff. Embankments should be designed to be stable and watertight, and the detailed guidance contained within the CIRIA publication R161, *Small embankment reservoirs* (Kennard *et al*, 1996) should be followed. Material sustainability is discussed in Section 3.6.

Design for maintenance and safety

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

All embankments should be designed in accordance with best practice, as described in CIRIA R161 (Kennard *et al*, 1996). Those storing more than 25 000 m^3 must also meet the 1975 Reservoir Act requirements (DoE, 1975) (see Section 2.5.6). Consideration should be given to the safe routing of floodwater when the design event is exceeded and to mitigating the risks of potential embankment failure.

Safety benches and maintenance access routes should be provided at an appropriate level above the permanent pond. A suitable width for a safety bench is 3.5 m, with a cross-fall of less than 1 in 15, although this will depend on land availability and the type of maintenance equipment required for the pond. Side slopes to the pond between the aquatic and safety bench should not be steeper than 1 in 3 for both public safety and maintenance though a maximum gradient of 1 in 4 is preferred. The aquatic bench should be at least 1 m wide and designed to have vegetation to dissuade access to the water. Where internal pond slopes are steeper than 1:3 a minimum transitional 1 m width beyond the aquatic bench should be provided at a gradient less than 1:3.

High fencing tends to isolate pond systems and reduce amenity benefits. Toddler-proof fencing, if thought necessary, combined with barrier planting strategies and effective landscaping can be used to deter public access to open water areas and facilitate the movement of wildlife. Section 20.4.6 provides recommendations on barrier planting and Section 24.5 sets out advice on managing health and safety risks for open water areas. Hard edges tend to encourage public access, but may be required for access in confined locations.

Children should not be able to gain access to spillways, and all vertical drops exceeding 1.2 m (eg headwalls above pipe inlets/outfalls) should be fenced. Wherever possible, vertical drops should be avoided or graded to shallow slopes to minimise health and safety risks.

Education boards should be provided to inform the public of the function of the pond, and also to provide information on the local flora and fauna that the system supports. Warning signs should be posted to prohibit swimming or fishing in the water. Lifesaving equipment should also be provided. Chapter 24 provides detail on public education and awareness-raising strategies.

Design for ecology

Pond designs can be improved for ecology by developing the pond system in two phases: Phase 1 establishes the basic shape and structure of the pond with a follow-up

Phase 2 (1–2 years later) to undertake fine-tuning of the scheme. Examples of small-scale refinement that can be incorporated in Phase 2 which add considerably to the habitat value of sites include:

- addition of small scale topographic features (eg re-profiling of pond margins to increase the extent of seasonal water level variations)
- maximising the potential of unplanned habitats that occur on most sites, such as runoff from grassed slopes and natural seepages.

Ecological value is enhanced by creating small pools around the margins of larger ponds which are fed by clean surface runoff from non-intensively managed grassland, scrub or woodland on the basin sides. These pools should be located above the level of the main SUDS pond. If some ponds, or parts of basins, are not exposed to the main pollutant burden, this may allow a wider range of animals and plants to exploit some parts of the site. In addition to enhancing biodiversity, such a design approach should ensure rapid re-colonisation following a spill event. This type of benefit may also be achieved through the use of multiple ponds in series, where water quality improves through the train. The development of mosaics of marginal plants should be encouraged (rather than single species stands) to maximise habitat structural diversity. The development of open, lightly shaded and densely shaded areas or pools should also be encouraged as this will add to the diversity of habitats available.

In contaminated systems, shallow water and wetland areas can support a range of wildlife that is less vulnerable to the effects of pollutants than submerged aquatic plants and those animals which live permanently under the water (such as mayfly larvae, dragonfly larvae and fish). Consideration should be given to setting aside such areas for wildlife. Additional information on maximising the ecological benefits of SUDS is given in *Maximising ecological benefits of SUDS* (HR Wallingford, 2003).

17.5 PRE-TREATMENT/INLETS

All ponds require a sediment forebay or other form of upstream pre-treatment system (See Chapter 7). This is to remove the majority of incoming sediment from the runoff before it is more widely dispersed within the larger permanent pool. Sediment can be managed more effectively when it is contained in a separate zone. The forebay can either be an area within the pond, separated by an acceptable barrier (eg berm), or a separate structure upstream of the main pond.

A pre-treatment system should be provided for each inlet, unless contributing sediment loads are known to be insignificant. The pre-treatment volume is part of the total water quality volume and can be subtracted from the water quality volume for permanent pond storage sizing.

Consideration should be given to installing a fixed sediment depth marker in forebays where high sediment loads are expected, to measure sediment deposition with time. This will assist with the development of appropriate future maintenance schedules. The base of the forebay can be reinforced to facilitate sediment removal. If a membrane liner is used without protection, great care must be taken during sediment removal operations.

The energy of the incoming flows should be dissipated to minimise the risk of scouring and erosion, and to prevent disturbance to the permanent pool volume. This can be achieved by stabilising inflow channels using rip-rap or other erosion control systems, or by partially or fully submerging the inlet pipe.

Safety grilles may be required if inlet pipe diameters allow public entry, but they tend to increase the risks of blockage and can present a hazard in themselves so, wherever possible, inlet infrastructure should be designed so that they are not required. Chapter 19 provides detail on inlet and outlet designs.

17.6 OUTLETS

Outlets are usually built into an embankment with easy access for maintenance. A manhole-type outlet structure can accommodate a variety of outlet control mechanisms. Grilles are not recommended, but where they are necessary to prevent access into the pipework, they should be designed so that debris does not obstruct higher flows. Ponds will generally require a variable flow rate control structure at the outlet, together with an emergency overflow. Low flow controls can be provided using perforated riser pipes or orifices, which can then be combined with overflow channels and overflow weir sections and/or culverts for larger events. Multiple orifices or pipe outlets can be used to achieve the same objectives.

Emergency spillways or flood routes should be provided to pass floods that exceed the pond design capacity safely and/or to convey flows should outlet blockage occur. They should be designed to prevent overtopping of any embankment which might cause structural damage, and spillways should be located so that downstream people and property are not put at risk. A freeboard of 300 mm for the design event is usually sufficient, but where risks are high an additional allowance should be agreed with the environmental regulator or other authority. Detail on the design of outlet infrastructure is provided in Chapter 19.

The outlet area should be the deepest point to provide final settling and prevent re-suspension of sediments, and to facilitate total drawdown of the pond. Consideration should be given to energy dissipation at the point of discharge of overflows using rip-rap, plunge pools or scour pads.

17.7 LANDSCAPING AND VEGETATION

Pond design should take account of the local landscaping and environment and community requirements. A summary of the recommendations made following a survey of public opinion at residential SUDS pond sites across the UK, is presented in Table 17.3 (HR Wallingford, 2003b).

Table 17.3 *Summary of recommendations for enhancing public perception of pond sites (HR Wallingford, 2003b)*

Recommendations for design characteristics	• make the pond as natural in appearance as possible • introduce marginal vegetation • introduce adjacent vegetation (native to the area) • introduce wildlife and protection of existing species • shallow bank side slopes and shallow water depths adjacent to bank • introduce natural barriers (eg planting) • introduce signs warning of deep water • introduce benches and picnic tables • create child playgrounds • create walkways • introduce fish.
Recommendations for operation & maintenance	• frequent litter removal • removal of silt • cleaning up of the inlets & outlets of the pond to avoid blockages • maintenance of marginal vegetation.
Recommendations for education	• provision of pre-purchase information to householders • application of educational campaigns to local communities or other target groups • introduction of interpretation boards.

Ponds should be developed to mimic natural forms, using "soft" geometries with curved boundaries and undulating margins, rather than straight lines and hard edges. Vegetation can enhance the appearance of the pond, stabilise side slopes and prevent erosion, serve as wildlife habitat, and temporarily conceal unsightly litter and debris. Aquatic vegetation provides some nutrient uptake and increases sediment settling effectiveness by slowing the flows across the pond. A vegetated aquatic bench can help prevent children from entering open-water areas and discourage the use of adjacent grassed areas by geese. Plants should therefore be encouraged along the aquatic bench, the safety bench and side slopes, and within shallow areas of the pool itself.

Dense planting of marginal floating-leaved and aquatic plant species help the pond colonise rapidly should be avoided and the pond should be left to colonise as naturally as possible. Over-planting initially tends to fill space that could otherwise be exploited by self-colonising local species, and in doing so reduces the potential ecological value of the pond.

The selection of species should also consider the risks of children not being observed if they get into difficulties as a result of being hidden by vegetation. The plants should not restrict visibility of the water's edge or hinder adult supervision, particularly in amenity areas (see Chapter 20).

Figure 17.4 shows a typical vegetation profile across a pond.

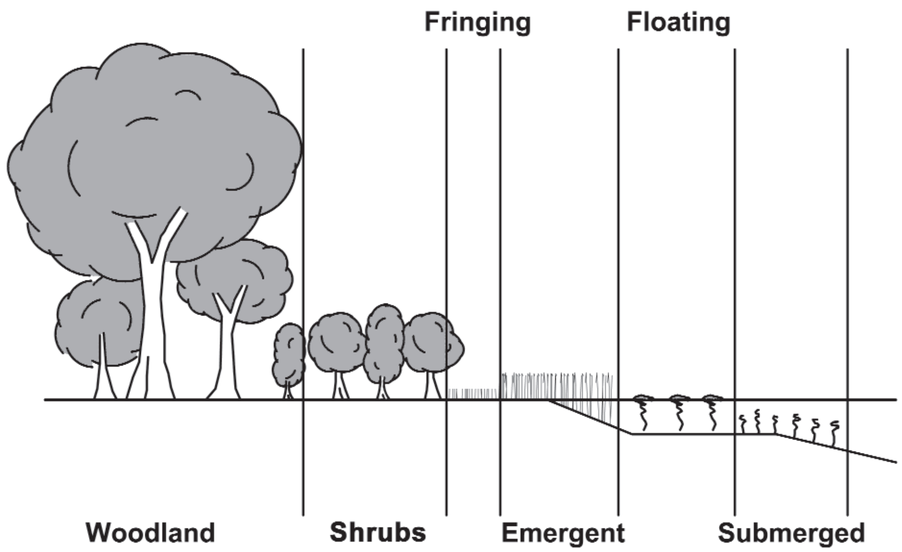


Figure 17.4 *Typical vegetation profile across a retention pond*

Pond designers should develop an appropriate local plant list comprising species found within 30 km of the development site. Such lists can easily be compiled in most areas from relevant county floras.

Community requirements are discussed in Chapter 24 and landscaping and planting best practice is presented in Chapter 20.

17.8 OPERATION AND MAINTENANCE REQUIREMENTS

Regular inspection and maintenance is important for the effective operation of ponds as designed. Maintenance responsibility for a pond and its surrounding area should always be placed with a responsible organisation.

A maintenance access way (or "easement") should be provided to the pond from a public or private road. An assessment should be made at the planning stage regarding the maintenance and associated access requirements. Ideally, access should be at least 3.5 metres wide, have a maximum cross fall of 1 in 15, and be sufficiently robust to withstand maintenance equipment and vehicles. However temporary access routes for infrequent operations could be considered where permanent routes are not appropriate. The access should extend to the forebay, safety and aquatic benches, inlet and outlet infrastructure. Consideration should be given as to whether maintenance vehicles will need to turn around.

Operation and maintenance requirements for ponds are described in Table 17.4.

Table 17.4 *Ponds operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Litter removal.	As required
	Grass cutting – public areas.	Monthly (during growing season)
	Grass cutting – meadow grass.	Half yearly (spring, before nesting season, and autumn)
	Inspect vegetation to pond edge and remove nuisance plants (for first 3 years).	Monthly (at start, then as required)
	Hand cut submerged and emergent aquatic plants (at minimum of 0.1 m above pond base; include max 25% of pond surface).	Annually
	Remove 25% of bank vegetation from waters edge to a minimum of 1 m above water level.	Annually.
	Tidy all dead growth before start of growing season.	Annually.
	Remove sediment from forebay.	1–5 years, or as required.
	Remove sediment from one quadrant of the main body of ponds without sediment forebays.	2–10 years.
Occasional maintenance	Remove sediment from the main body of big ponds when pool volume is reduced by 20%.	>25 years (usually).
Remedial actions	Repair of erosion or other damage.	As required.
	Aerate pond when signs of eutrophication are detected.	As required.
	Realignment of rip-rap or other damage.	As required.
	Repair/rehabilitation of inlets, outlets and overflows.	As required.
Monitoring	Inspect structures for evidence of poor operation.	Monthly/after large storms.
	Inspect banksides, structures, pipework etc for evidence of physical damage.	Monthly/after large storms.
	Inspect water body for signs of eutrophication.	Monthly (May–October).
	Inspect silt accumulation rates and establish appropriate removal; frequencies.	Half yearly.
	Check penstocks and other mechanical devices.	Half yearly.

Sediments excavated from ponds or forebays that receive runoff from residential or standard road and roof areas are generally not toxic or hazardous material and can therefore be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation to determine its classification and appropriate disposal methods. For industrial site runoff, sediment testing will be essential. In the majority of cases, it will be acceptable to distribute the sediment on site if there is an appropriate safe and acceptable location to do so. Additional detail on waste management is provided in Chapter 23. If ponds are to be drawn down, care should be taken to prevent downstream discharge of sediments and anoxic water. The environmental regular should be notified prior to such activities.

New ponds may become rapidly dominated by invasive native plants, particularly Common Bulrush *(Typha latifolia)*. As it is not desirable for all new ponds to be bulrush dominated, it should be ensured that in the first five years, while vegetation is establishing, certain plant growth is controlled. After this period, ponds can usually be allowed to develop naturally, recognising that, unless the margins are occasionally managed, they are likely to become dominated by trees and shrubs.

Eutrophication of SUDS ponds can occur during the summer months. Eutrophication is best alleviated by controlling the nutrient source or providing a continuous baseflow to the pond. Unless eutrophication is severe, aeration can be used as a stop-gap measure to save aquatic animal species and reduce risks to receiving waters. However, the addition of barley straw bales, dredging or rendering the nutrients inactive by chemical means can also be successful.

Maintenance plans and schedules should be developed during the design phase. Specific maintenance needs of the pond should be monitored and maintenance schedules adjusted to suit requirements. Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken. Additional detail on the preparation of maintenance specifications and schedules of work is given in Chapter 22. Provided preventive maintenance measures are conscientiously undertaken, the need for corrective maintenance should rarely arise.

17.9 CONSTRUCTION REQUIREMENTS

The bottom and side slopes of the pond, including any benches, should be carefully prepared to ensure that they are structurally sound. Any embankments should be checked to ensure that they meet their design criteria. The preparation should also ensure that the basin will satisfactorily retain the surface water runoff without significant erosion damage.

Backfilling against inlet and outlet structures needs to be controlled to minimise settlement and erosion. The soils used to finish the side slopes of the pond above the retained level need to be suitably fertile, porous and of sufficient depth to ensure healthy vegetation growth. If an impermeable liner is used, care should be taken to ensure that it is not damaged during construction.

During the SUDS establishment phase, runoff from bare soils should be minimised. For example:

- vegetative cover be rapidly established
- base-of-slope trenches should be introduced to retain the inevitable runoff of sediments
- construction should be timed to avoid autumn and winter when high runoff rates are to be expected.

Ponds can be used to manage construction runoff and trap construction sediments, providing they are fully rehabilitated to original design formation levels before handover. It is recommended that planting schemes are implemented once rehabilitation measures have been carried out.

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Additional detail on construction and the programming of construction is provided in Chapter 21.

17.10 REFERENCES

DETR (1994)
Construction (Design and Management) Regulations
Department of Environment, Transport and the Regions, HMSO, London

DoE (1975)
Reservoirs Act
HMSO, London

HR Wallingford (2003a)
Maximising the ecological benefits of sustainable drainage schemes
SR 625

HR Wallingford, UK

HR Wallingford (2003b)
An assessment of the social impacts of sustainable drainage schemes in the UK
SR 622
HR Wallingford, UK

KENNARD M F, HOSKINS C G AND FLETCHER M (1996)
Small embankment reservoirs (R161)
CIRIA, London.

Stormwater wetlands

18

Contents

Stormwater wetlands 18

Description

Wetlands provide both stormwater attenuation and treatment. They comprise shallow ponds and marshy areas, covered almost entirely in aquatic vegetation. Wetlands detain flows for an extended period to allow sediments to settle, and to remove contaminants by facilitating adhesion to vegetation and aerobic decomposition. They also provide significant ecological benefits.

KEY DESIGN CRITERIA

- water quality treatment volume, detained within or above the permanent water body
- shallow, temporary storage volume for attenuation
- sediment forebay or equivalent upstream pre-treatment
- continuous baseflow
- combination of deep and shallow areas (maximum depth <2 m)
- length:width ratio of greater than 3:1
- shallow side slopes.

ADVANTAGES

- good removal capability of urban pollutants
- if lined, can be used where groundwater is vulnerable
- good community acceptability
- high potential ecological, aesthetic and amenity benefits
- may add value to local property.

DISADVANTAGES

- land take is high
- requires baseflow
- limited depth range for flow attenuation
- may release nutrients during non-growing season
- little reduction in runoff volume
- not suitable for steep sites
- colonisation by invasive species would increase maintenance
- performance vulnerable to high sediment inflows
- perceived health and safety risks may result in fencing and isolation of wetland.

PERFORMANCE:

Peak flow reduction:	
Low frequency events	Good
Extreme events	Good
(if large wetland area available)	
Volume reduction:	Poor
Water quality treatment:	Good
Amenity potential:	Good
Ecology potential:	Good

TREATMENT TRAIN SUITABILITY:

Source control:	No
Conveyance:	Yes
Site system:	Yes
Regional system:	Yes

SITE SUITABILITY:

Residential:	Yes
Commercial/industrial:	Yes
High density:	Unlikely
Retrofit:	Unlikely
Contaminated sites/sites above vulnerable groundwater (with liner)	Yes

COST IMPLICATIONS:

Land-take:	High
Capital cost:	High
Maintenance cost: (once established)	Medium/Low

POLLUTANT REMOVAL:

Total suspended solids:	High
Nutrients:	Medium
Heavy metals:	High

KEY MAINTENANCE REQUIREMENTS:

- litter/trash/debris removal
- inlet/outlet cleaning
- vegetation management to retain high vegetation coverage, possibly requiring specialist equipment
- sediment monitoring and removal when required.

18.1 GENERAL DESCRIPTION

Wetlands are constructed shallow marsh systems with a range of deep and shallow water areas, designed to treat urban stormwater runoff. Well-designed and maintained wetlands can offer important aesthetic, amenity and wildlife benefits to an area. Stormwater wetlands are not normally designed to provide significant attenuation, but temporary storage may be provided above the permanent water level. Constructed wetlands require a continuous baseflow to support a plant-rich community including aquatic vegetation and micro-organisms. Without such baseflow, salts and algae can concentrate in the water column (potentially discharging at the start of a storm event) and may cause the wetland to die off. A comprehensive water budget analysis is necessary to ensure the viability of a wetland.

Wetlands should consist of the following elements:

a) Shallow, vegetated areas of varying depths.
b) Permanent pool or micropools.
c) Small depth range overlying the permanent pool, in which runoff control volumes are stored.
d) Sediment forebay, or equivalent (if required).
e) Emergency spillway.
f) Maintenance access
g) Safety bench.

Designs of wetlands can vary, each option differing in the relative amounts of shallow and deep water, and storage area above the wetland, and in the specific function that they perform. The options include:

1. Shallow wetland.
2. Extended detention shallow wetland.
3. Pocket wetland.
4. Pond/wetland system.
5. Submerged gravel wetlands.
6. Wetland channel.

Descriptions of each design variant are given below:

1. **Shallow wetland** – The majority of the water quality treatment volume is stored in shallow high marsh or low marsh depths (ie within the permanent water body). Deep portions of the facility are limited to the inlet forebay and the outlet micropool. Shallow wetlands therefore require a relatively large amount of land to store the water quality volume.
2. **Extended detention shallow wetland** – This is generally the same as the shallow wetland but part of the water quality treatment volume is provided as extended temporary detention above the surface of the marsh and released gradually. This technique can hydraulically control and treat a greater volume of stormwater in a smaller area than the shallow wetland design. For this technique, plants that can tolerate wet and dry periods need to be selected for the extended detention zone.
3. **Pocket wetlands** – Small wetland areas intended for smaller drainage areas. These either require excavation down to the water table or a reliable baseflow to support the wetland system. They can make use of smaller-scale design versions of option (1) or (2) described above.

4. **Pond/wetland systems** – The pond/wetland system has two separate cells: a wet pond and a shallow marsh. The design of the wet pond should follow the guidance given in Chapter 17. It will trap sediments (in the forebay) and attenuate storm flows which can then be discharged into the wetland in a more controlled manner, where they then receive additional treatment.

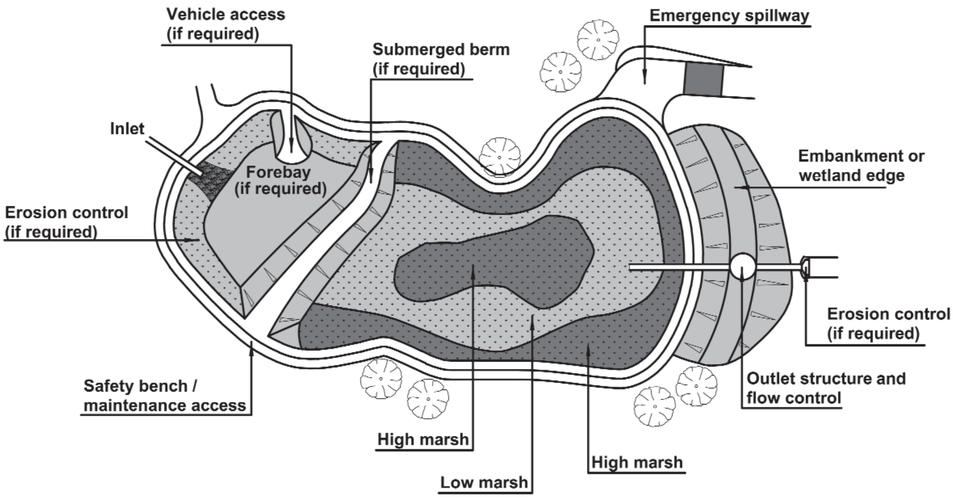


Figure 18.1 *Plan schematic of a shallow wetland*

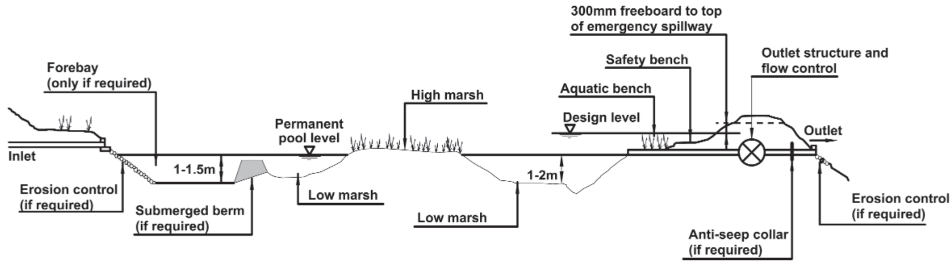


Figure 18.2 *Elevation schematic of a shallow wetland*

5. **Submerged gravel wetland system** – This wetland type consists of one or more treatment cells filled with crushed rock or gravel, and is designed to allow stormwater to flow through the facility beneath the surface. The outlet from each cell is set at an elevation to keep the rock or gravel submerged. Wetland plants are rooted in the medium, where they can directly take up pollutants. In addition, algae and microbes thrive on the surface area of the rocks, and the anaerobic conditions on the bottom of the filter promote de-nitrification. This technique has been widely used for wastewater treatment but not, to date, for stormwater management. The technique may be useful in retrofit situations were space is at premium, where additional treatment is required in a management train, or where safety concerns are particularly high.
6. **Wetland channel** – A wetland may be implemented within a man-made channel with a widened base. It may be used downstream of a larger facility to provide conveyance as well as water quality treatment during low flow conditions.

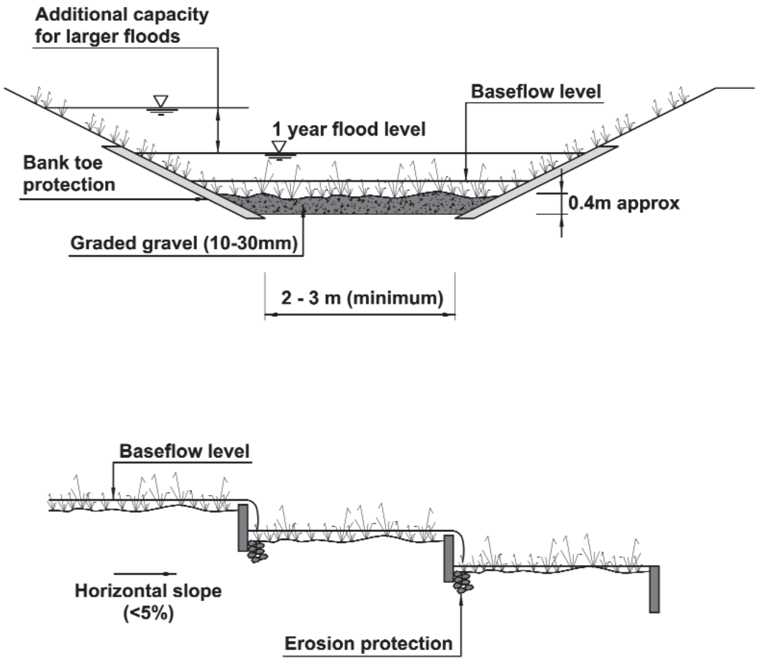


Figure 18.3 *Plan and elevation schematics of wetland channel*

Detailed guidance on the design, construction and management of constructed wetlands is provided in CIRIA publication *Review of the design and management of constructed wetlands*, R180 (Nuttall *et al,* 1997) and by the Environment Agency R&D Technical Report P2-159/TR1 *Constructed Wetlands and Links with Sustainable Drainage Systems* (Ellis *et al*, 2003).

18.2 SELECTION AND SITING OF WETLANDS

Stormwater wetlands are generally chosen to improve runoff quality, rather than for controlling large volumes of stormwater. Wetlands can be used for both site and regional controls, and are also appropriate for use in retrofitting. High land take requirements may preclude their suitability for high-density development areas and the need for a perennial baseflow may also be a constraining factor. The criteria presented in Table 18.1 should be evaluated to ensure the suitability of a wetland for meeting drainage objectives at a particular site.

Table 18.1 *Considerations for using wetlands*

Drainage area	Wetlands require a positive water balance, through continuous baseflow or groundwater seepage, so that permanently wet conditions can be sustained. They are therefore limited to areas where springs or land drainage provides baseflow during dry weather.
Space required	It is likely that a wetland will require more space than a pond.
Siting	Wetlands are normally located at a position that can receive all the site runoff (ie at the lowest point in the site), generally at minimum excavation (or construction) cost. Where the urban design of an area permits, the location of a wetland should take account of natural site features that might be used as additional temporary storage areas when the wetland capacity is exceeded during extreme events. If the wetland design criteria include protection of the watercourse during floods, then the system should not be located in the floodplain, where there is a risk that the detention storage will be lost through inundation at the critical time. River flood waters also tend to carry high sediment and debris loads which will necessitate additional wetland maintenance. Wherever possible, wetlands should be located in, or adjacent to, non-intensively managed landscapes where natural sources of native species are likely to be plentiful.
Site slope & stability	Wetland basins require a near-zero (almost horizontal) longitudinal slope, which can be provided using embankments, if required. Wetlands should not be sited on unstable ground and ground stability should be verified by assessing site soil and groundwater conditions. Wetlands should not be considered within or over waste fill materials, uncontrolled or non-engineered fill.
Subsurface soils and groundwater	The soil below a wetland must be sufficiently impermeable to maintain wet conditions, unless the wetland intersects the water table. In permeable strata, a liner (or other impermeable material such as puddle clay) will be required to prevent the wetland drying out. As the wetland evolves, loss of water should become negligible as the soils on the floor of the basin become more organic, reducing the potential for exfiltration. Loamy soils are needed in a wetland bottom to permit plants to take root. Assessment of soils should be based upon an actual subsurface analysis and permeability tests. In areas with contaminated soils or contaminated groundwater (brownfield sites), wetlands can be used providing the system is fully sealed, preventing exchange of water between the facility and groundwater. Any excavation or earthmoving processes required must be managed to ensure that mobilisation of contamination does not occur. If used on a site with a sensitive underlying groundwater zone, or if used to treat runoff from a potential pollution hotspot, a hydrogeological risk assessment will generally be required to determine an appropriate separation distance between the base of the wetland and the elevation of the annual maximum water table. Any permeability of the subsurface soils will require the use of a liner (or equivalent). Where the groundwater table is close to the base of the wetland, the operation of the outfall should be confirmed for the annual maximum water table level. The maximum expected groundwater level should be beneath the storage zone.

18.3 HYDRAULIC AND WATER QUALITY DESIGN

Wetlands design is site-specific but general design consideration includes a sediment forebay, maximised hydraulic retention time, elimination of dead zone and hydraulic short-circuiting, and selection and establishment of native wetland vegetation. Most of the design elements discussed in the pond section are applicable to wetlands. The exceptions are depth and distribution of aquatic vegetation. Low velocities (<0.1 m/s) for both wetland baseflows and water quality events should be targeted to ensure that retention times are adequate.

The permanent and temporary storage zones should be designed as for ponds (see Section 17.3). Ideally the temporary storage should empty within 24 hours to prevent damage to vegetation. However, in practice, it is likely that a trade off will be required between the need to maximise retention time for pollutant removal and the emptying of temporarily stored water. Multi-level outfall controls can be used to provide enhanced levels of control for different sizes of event. Inlet infrastructure can also be designed with flow bypass components that divert flows above a threshold away from the wetland, preventing wetland system damage, and improving wetland efficiency for lower flows.

Submerged wetland systems and wetland channels should be designed to convey the baseflow and water quality treatment event either below the surface or at very low water depths and velocities.

It is important to carry out a water balance calculation for wetlands to ensure that they will not dry out in a summer drought due to loss of water by evaporation. During the severe drought in summer 1976, no rain occurred in England and Wales for between 35 and 42 days. As a result, a 30-day drought resistance test is recommended, with appropriate assumptions made regarding inflows related to the site-specific location. A typical approach is given in Box18.1.

Box 18.1 *30-day drought resistance test for wetlands*

30 day inflow (m^3) (assuming zero rainfall) – evaporation rate during summer (m/day) x 30 days x wetland surface area (m^2)

> wetland surface area x acceptable water level drop during summer period

18.4 PHYSICAL SPECIFICATIONS

Wetland designs should be specific to the particular location. The form and aesthetic appearance of the wetland will depend on specific site characteristics, local public concerns, and development design criteria. However, there are a number of geometric ratios and limiting depths for wetland design that should be observed for optimum pollutant removal, ease of maintenance and good safety practice.

Geometry

Inlets and outlets should be placed to maximise the flow path through the wetland. The ratio of flow path length to width, to avoid hydraulic short-circuiting, depends on the type of wetland used, but should preferably be greater than 3:1. If there are multiple inlets, the length-to-width ratio should be assessed using the flow-weighted, average flow path length for all inlets. Baffles, wetland shaping and islands can be used to increase the flow path and maximise water quality treatment processes.

Stormwater wetlands should comprise a mixture of water depths. Water levels in excess of 1 m should not occur over more than 20 per cent of the wetland pond surface area (preferably limited to the forebay and outlet micropool zones) as deep water supports a relatively few number of plant species compared to shallow zones. The following bathymetry for the remainder of the wetland surface area is recommended:

0.5 – 1.0 m	30 per cent minimum
0.0 – 0.5 m	50 per cent minimum

Where wetlands are designed for flow attenuation, the depth of temporary storage above the permanent water level should not exceed 1.5 m.

Materials

Most constructed wetlands for stormwater treatment are surface flow wetlands. These consist of shallow water areas that are generally between 0.3 and 0.6 m depth, with water flowing above the support medium. The support medium is typically soil or aggregate, with the latter helping to reduce the risk of re-suspension of sediment during heavy storm events and providing an enhanced medium for supporting emergent macrophytes. Rock beds with 25 to 75 mm aggregate have also been shown to enhance nitrogen removal in wetlands. Wetlands can also be designed as subsurface flow systems where the water to be treated flows within the underlying support medium, which is typically gravel with high permeability. The plants rooted in the support medium grow hydroponically in the water as it flows past the roots. Further information on subsurface systems is provided in the CIRIA publication R180 (Nuttall *et al*, 1997).

The shallow nature of wetland stormwater treatment systems means that even a small alteration in water level can significantly affect the health of the aquatic plant community. It is therefore important to ensure that water levels remain as consistent as possible, apart from during storm events. This may necessitate the use of a clay or geotextile liner to maintain water levels.

Geotextile/geomembrane specifications are set out in Appendix C. Material sustainability principles are presented in Section 3.6.

Design for safety and maintenance

Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively.

All embankments should be designed in accordance with best practice, as described in CIRIA publication R161 (Kennard *et al*, 1996). Those storing more than 25 000 m^3 must also meet the 1975 Reservoir Act (DoE, 1975) requirements (see Section 2.5.6).

The criteria given in Section 17.4 for pond design are also appropriate for wetlands.

Design for ecology

Well-designed wetlands provide high value ecological habitat. To maximise the opportunities for ecological contributions, designers should follow guidance given in Section 17.4 (Design for ecology, for ponds) and Chapter 20 (Landscaping) of this report, and HR Wallingford, 2003 (Maximising the ecological benefits of sustainable drainage schemes).

18.5 PRE-TREATMENT/INLETS

If the wetland is to be constructed “off line”, then an upstream bypass structure can be used to divert the water quality storm and lower return period events into the wetland. Flows exceeding this will then bypass the system, reducing the potential for turbulence and mixing, and allowing optimum contaminant removal processes to occur.

Effective pre-treatment should ideally be implemented via appropriate source control and upstream SUDS management train components (see Chapter 7). Where there are residual sediment risks, or where a sediment forebay is the only suitable management option at the site, then the wetland can be split to allow heavier sediments to drop out of suspension before the runoff enters the main body of the system. The forebay allows sediment build-up to be monitored easily, and concentrates any required sediment removal activities within a small area, thereby minimising potential damage to the rest of the wetland.

Guidance on pre-treatment and inlet design should follow Section 17.5 (Pre-treatment/inlet design for ponds), Chapter 7 (Pre-treatment systems) and Chapter 19 (Inlet and outlet structures) of this report.

18.6 OUTLETS

Wetland outlet design considerations should follow Section 17.6 (Outlet design for ponds) and Chapter 19 (Inlet and outlet structures) of this report.

18.7 LANDSCAPING AND VEGETATION

The type of vegetation used in stormwater wetlands is of critical importance to its proper functioning. Vegetation promotes the settlement of suspended matter, stabilises the sediments in the base of the facility (thus preventing scour and re-suspension during heavy storms), and promotes nutrient uptake. Plant die-off in winter also provides a dense litter layer that promotes pollutant removal. Vegetation can enhance the appearance of the wetland, stabilise side slopes and prevent erosion, serve as wildlife habitat, temporarily conceal unsightly litter and debris and reduce safety risks associated with open water.

Planting density varies but typically ranges between four to eight plants per square metre. Planting of wetlands should take place between early April and mid-June so that the plants have a full growing season to develop the root reserves they need to survive through winter. Vegetation needs to be established quickly once stormwater flows are introduced to the system, to ensure pollutant removal levels and reduce the risk of bankside erosion.

Tall, emergent species should be planted on aquatic benches. Dense planting of marginal floating-leaved and aquatic plants should be avoided, and the wetland should be left to colonise as naturally as possible. Over-planting initially tends to fill space that could otherwise be exploited by self-colonising local species, and so reduces the potential ecological value of the wetland. Wetland plants must be tolerant of fluctuating water levels. Ideal species are those that offer a high density of stems in the submerged zone, maximising the contact between water and the surface on which micro-organisms grow, while providing uniform flow conditions. Wetland designers should develop an appropriate local plant list comprising species found within 30 km of the development site. All plant supplies should be accredited or plant sources known.

Wetland design should take account of the local landscaping and environment, together with community requirements. The guidance set out in Section 17.7 (landscaping and vegetation for ponds) should also be followed for wetlands. In addition, community requirements are presented in Chapter 24, and landscaping and planting best practice is presented in Chapter 20.

Where perimeter pool areas are deeper than 1 m, these should be surrounded by safety and aquatic benches similar to those of ponds (see Chapter 17), although the shallow nature of wetlands tends to reduce their safety liability potential. The wilder appearance of constructed wetlands and their minimal areas of open water will also tend to discourage casual use for swimming or boating. A risk assessment should, however, be undertaken for all SUDS sites.

18.8 OPERATION AND MAINTENANCE REQUIREMENTS

Regular inspection and maintenance is important for the effective operation of wetlands as designed. Maintenance responsibility for a wetland and its surrounding area should always be placed with a responsible organisation.

The guidance given in Section 17.8 (Operation and maintenance for ponds), should be followed regarding maintenance access and easements, and management practices for sediment, eutrophication and invasive plants. Maintenance requirements for wetlands will tend to be higher than for ponds while vegetation becomes established, and effective monitoring during these first years will be crucial to the success of the system.

Operation and maintenance requirements for wetlands are described in Table 18.2.

Table 18.2 *Wetlands operation and maintenance requirements*

Maintenance schedule	Required action	Frequency
Regular maintenance	Litter/trash/debris and surface scum removal.	Monthly.
	Grass cutting – public areas.	Monthly (during growing season).
	Grass cutting – meadow grass.	Half yearly (spring, before nesting season, & autumn).
	Inspect vegetation to wetland edge and remove nuisance plants (for first 3 years).	Monthly (at start, then as required).
	Hand cut submerged and emergent aquatic plants (at minimum of 0.1 m above wetland base; include max 25% of wetland surface). This activity may require a boat.	Annually, or as required.
	Remove 25% of bank vegetation from waters edge to a minimum of 1 m above water level. This activity may require a boat.	Annually, or as required.
	Tidy all dead growth before start of growing season.	Annually
	Remove sediment from one quadrant of sediment forebay.	Annually, or as required.
	Remove sediment from one quadrant of the main body of wetlands without sediment forebays.	2 – 5 years.
Occasional maintenance	Remove sediment from the main body of wetland when its volume is reduced by 20%.	>25 years (usually).
Remedial actions	Repair of erosion or other damage.	As required.
	Repair/rehabilitation of inlets, outlets and overflows.	As required.
	Supplement plants (to maintain at least 50% surface area coverage) if vegetation is not established after the second growing season.	One-off event.
Monitoring	Inspect structures for evidence of poor operation. Take remedial action if required.	Monthly/after large storms.
	Inspect banksides, structures, pipework etc for evidence of physical damage.	Monthly/after large storms.
	Inspect silt accumulation rates and establish appropriate removal frequencies.	Six monthly.
	Check penstocks and other mechanical devices.	Six monthly.

Sediments excavated from wetlands that receive runoff from residential or standard road and roof areas are generally not toxic or hazardous material and can therefore be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation to determine its classification and appropriate disposal methods. For industrial site runoff, sediment testing will be essential. In the majority of cases, it will be acceptable to distribute the sediment on site if there is an appropriate safe and acceptable location to do so. Additional detail on the management of wastes (eg contaminated plants and sediments) is given in Chapter 23. If wetlands are to be drawn down, care should be taken to prevent downstream discharge of sediments and anoxic water. If the wetland discharges to a stream, this activity should generally be undertaken during periods where high dilution in the receiving water is possible. The environmental regulator should be notified before draining a stormwater wetland.

Maintenance plans and schedules for the wetland should be developed during the design phase. Specific maintenance needs of the wetland should be monitored and maintenance schedules adjusted to suit requirements. Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Maintenance activities should be detailed in the Health and Safety Plan and a risk assessment should be undertaken. Additional detail on operation and maintenance activities, and the preparation of maintenance specifications and schedules of work is given in Chapter 22. The need for corrective maintenance should be minimised by ensuring that regular preventive maintenance measures are undertaken.

18.9 CONSTRUCTION REQUIREMENTS

The soils used to finish the side slopes of the wetland above the retained level need to be suitably fertile, porous and of sufficient depth to ensure healthy vegetation growth. If an impermeable liner is used, care should be taken to ensure that it is not damaged during construction.

The guidance provided in Section 17.9 (Construction requirements for ponds) should be followed for wetlands, although their use for the management of construction runoff is not recommended. Implementation of the CDM Regulations (DETR, 1994) and generic health and safety criteria are presented in Sections 2.5.10 and 3.4.2 respectively. Additional detail on construction and the programming of construction is provided in Chapter 21.

18.10 REFERENCES

DETR (1994)
Construction (Design and Management) Regulations
Department of Environment, Transport and the Regions, HMSO, London

DoE (1975)
Reservoirs Act
HMSO, London

ELLIS J B, SHUTES R B E and REVITT M D (2003)
Constructed wetlands and links with sustainable drainage systems
Technical Report P2-159/TR1
Environment Agency, Bristol, UK

HR Wallingford (2003)
Maximising the ecological benefits of sustainable drainage schemes
SR 625
HR Wallingford, UK

KENNARD M F, HOSKINS C G and FLETCHER M (1996)
Small embankment reservoirs (R161)
CIRIA, London

NUTTALL P M, BOON A G and ROWELL M R (1997)
Review of the design and management of constructed wetlands(R180)
CIRIA, London.

Inlets and outlets

19

Contents

Inlets and outlets 19

Hydraulic control is essential for adequate functioning of any SUDS component, regardless of type. Through the use of a sustainable drainage approach, however, stormwater should be managed in small, cost-effective landscape features, close to source, rather than large systems, eg ponds located at the bottom of drainage areas. In many cases, this should eliminate the need for large concrete structures and designs should instead require small control and conveyance structures appropriate for low flows and velocities. This chapter covers the issues of hydraulic control requirements.

In all cases, the hydraulic, structural and geotechnical design of inlet and outlet structures should be undertaken by competent persons. Textbooks, such as those by Chow (1959) and Henderson (1966) provide most of the theory relevant to the hydraulic design.

19.1 GENERAL DESIGN CONSIDERATIONS

SUDS designs should aim to reduce runoff by integrating stormwater controls throughout the site in small, discrete units. Through effective source control, the need for large flow attenuation and flow control structures should be minimised. As discussed in Chapter 6, SUDS designs should aim to reduce impervious surfaces (minimising the need for kerbs and guttering), and decrease the use of pipework and inlet structures through effective landscaping. Small, distributed control features also offer a major technical advantage as more of the systems can fail without undermining the overall integrity of the site control strategy.

Flow is conveyed to, from and between SUDS components either in open channels, across vegetated surfaces, or within pipework. This chapter describes the systems used to facilitate the transfer of stormwater between SUDS components and the associated conveyance networks. The definition of flow structures used in this chapter is as follows:

- ***an inlet structure*** conveys flow in to a SUDS component
- ***an outlet structure*** conveys flow out of a SUDS component
- ***a control structure*** restricts the rate of flow into or from an outlet structure.

All structures have both an entry and an exit. The details presented in this chapter for the exit from an inlet structure may also be adapted by the designer for the exit from an outlet structure into receiving waters downstream.

The structures described in this chapter are intended to apply to ponds only and detention basins that are smaller than the limit under the Reservoirs Act (DoE, 1975) and are not capable of impounding water more than approximately 1 m above the adjacent ground levels. Designers of large ponds and basins should check that their design lies outside the Reservoirs Act criteria of all reservoirs "designed to hold, or capable of holding" more than 25 000 m^3 of water "above the natural level of any part of the land adjoining the reservoir". Details of the Reservoirs Act are given in Section 2.5.6.

19.2 INLET AND OUTLET LAYOUT

SUDS systems such as ponds, basins and wetlands can generally be divided into three zones:

1. ***Inlet zone***, which includes appropriate design for velocity reduction and effective flow distribution across the width of the system. This may also include a sediment trapping and storage area.
2. ***Main treatment or storage area***.
3. ***Outlet zone,*** this may be deeper than the main area to prevent re-suspension of sediments, or may be designed as a shallow shelf with raised outfall for final polishing of the stormwater.

To maximise treatment processes, short-circuiting should be avoided. Dead storage areas (areas within the system that are bypassed by the flow regime and are therefore ineffective in the treatment process), should be minimised. Examples of ideal and poor configurations are presented in Figure 19.1. Where design shapes are fixed, baffles may be used to avoid such problems, as shown in Figure 19.2 below.

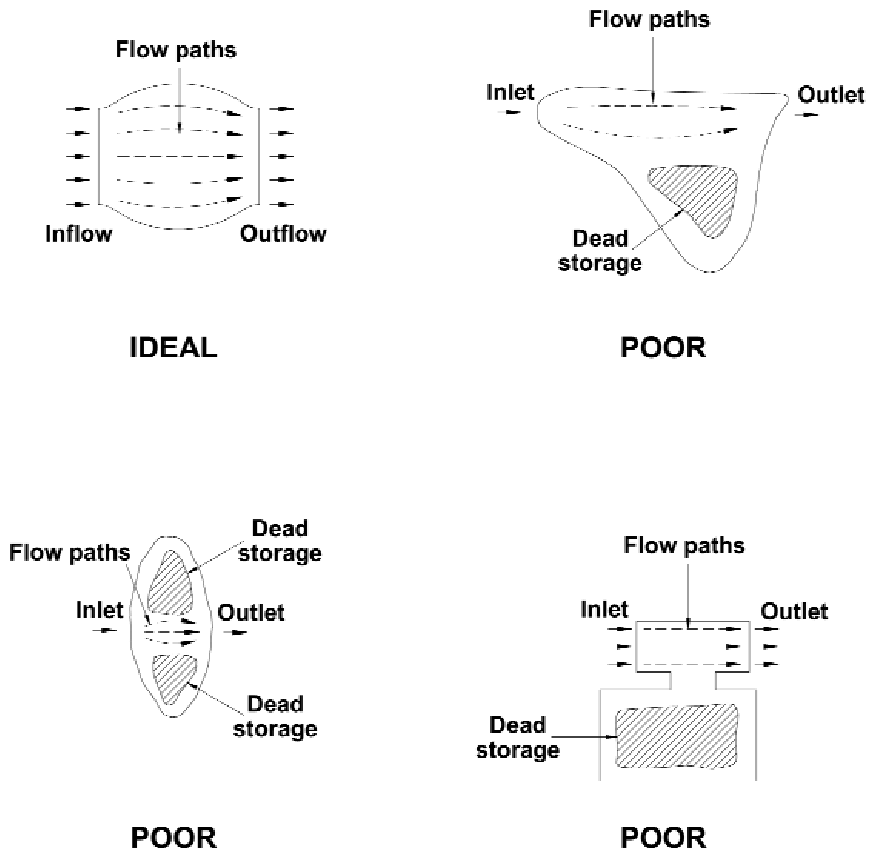


Figure 19.1 *Examples of ideal and poor inlet and outlet configurations*

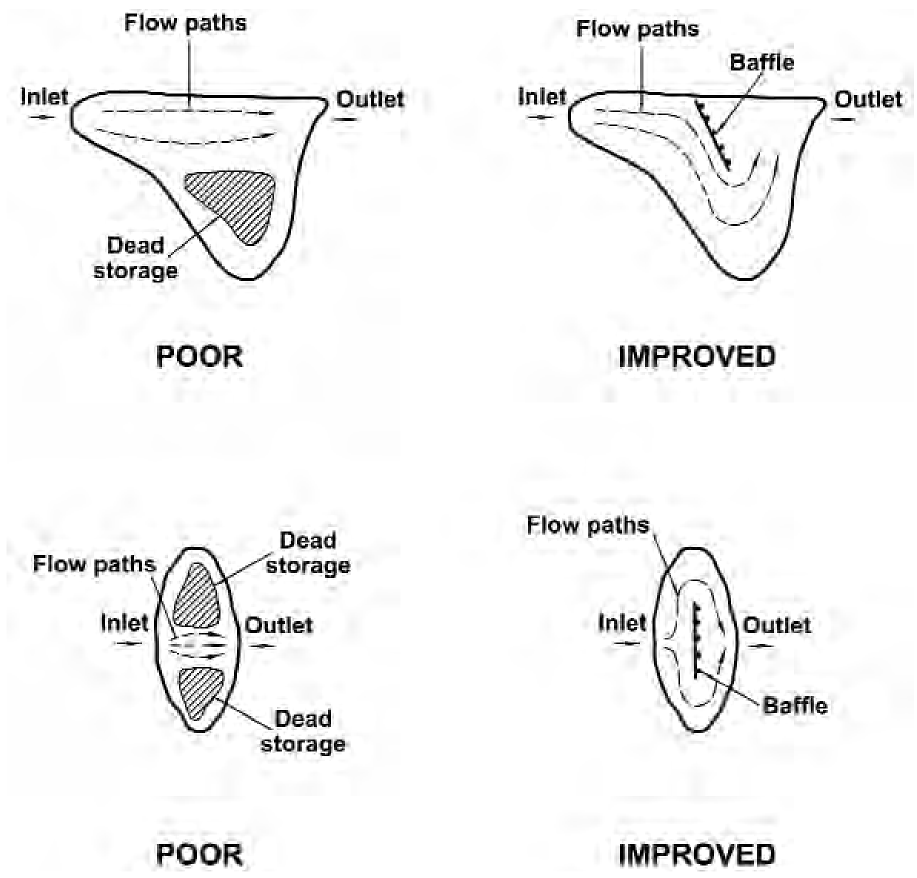


Figure 19.2 *Illustration of the use of baffles to avoid short-circuiting and dead storage areas*

19.3 SOFT AND HARD SOLUTIONS TO HYDRAULIC CONTROL

The basic principles of hydraulic analysis and design have been understood for many decades, and standard "hard" designs have been developed, usually constructed of concrete and/or steel sheet piling, which perform the necessary range of commonly-needed hydraulic functions for high flow, velocity and volume control. However, blockage, maintenance difficulties and vandalism have been regular problems in the past and a new design approach for SUDS provides the opportunity of implementing more sustainable solutions in the future.

In line with the principles of SUDS, "soft" options for hydraulic control structures are preferred. Softer solutions usually provide valuable amenity and ecological benefits, for the same degree of hydraulic control or safety. Only if such arrangements cannot be designed to operate in a satisfactory and safe manner, should "hard" alternatives be considered.

SUDS systems usually operate at relatively low pressures and velocities, and offer the opportunity to use environmentally sympathetic materials which are sufficiently durable and sustainable for use in control structures. Appropriate materials include timber, native plants, soils, gravels, stone and other materials that are often deployed for channel bank protection. By using such materials, these systems can be more easily integrated into the landscape and appear to be much more natural than "hard" systems. Their natural characteristics may also increase public acceptance of systems and the willingness of stakeholders to adopt and maintain them. It should be noted that the scope for using such materials may reduce with increasing water pressures and velocities.

Hard engineered hydraulic control structures can be made less intrusive, by disguising their presence or appearance with appropriate landscaping and other design features such as planting, the use of natural screening materials, and the use of stone and wood energy dissipation options. The use of stone indigenous to the area helps to blend the facility into its physiographic context. Good landscaping is discussed in detail in Chapter 20.

To better integrate the design of the inlet and outlet structures within the aesthetics of a natural landscape, consideration should be given to replacing concrete headwalls and wing walls with retaining walls constructed of natural stone and plant material that follows the bank profiles. Such structures can provide the necessary stability and erosion protection while affording the following benefits:

- reduced cost
- ease of construction
- aesthetic attractiveness
- habitat
- health and safety benefits.

To prevent stone removal or movement, it may be wise to contain such material within stainless steel baskets (these avoid zinc pollution) or else to use large stone boulders that cannot be lifted.

19.4 INLET SYSTEMS

The mechanisms by which runoff is collected and delivered to SUDS techniques will vary depending on the component type, the site layout and the site constraints. Pervious pavements and green roofs collect rainfall runoff directly without the need for inlets. Swales, filter strips, trenches and other systems should receive flow via unrestrained lateral inflows, but where point inflows from piped collection systems are unavoidable, sediment trapping and flow spreading systems will be required to avoid sediment build-up, erosion and flow channelling.

Concrete aprons and erosion protection systems can be replaced by deep pools and planted berms. Pools dissipate energy and moderate velocities which, in turn, aid in limiting the re-suspension of accumulated sediments in the forebay. Planted rock berms create low weirs that are resistant to breaching and accumulate debris allowing more efficient removal.

Specific inlet details for each SUDS component are set out in individual chapters. This chapter presents generic concepts, together with hydraulic control principles.

19.4.1 Inlet elevation

Inlets raised above any adjacent permanent water levels are generally recommended. Submerged inlets have the following significant potential drawbacks:

- surcharging or backwater effect on the upstream stormwater conveyance system
- scour/re-suspension of the pond bottom near the inlet
- clogging of the inlet by sedimentation near the inlet
- sediment deposition in the upstream conveyance system.

All concealed infrastructure is at risk from blockage or lack of maintenance.

The operational and failure risks associated with each device should be fully considered in the site management plan.

19.4.2 Inlet from an unrestricted piped collection system

Piped inlets should be designed to meet the following criteria:

- to deliver the required maximum flow rate freely from the upstream collection system
- to be simple, robust and easily maintained (ie easily mowable, cleanable, repairable and obvious to site managers)
- to resist blockage
- to prevent erosion
- to minimise hazard to people (ie no exposed vertical trip edges or drops, no open pipework accessible by small children)
- to minimise hazard to wildlife (ie no exposed sumps, traps, gullies or open inlets to sewers)
- to be visually interesting or neutral (ie no negative aesthetic effect)
- to minimise vandalism risks.

Components of a small, low flow inlet system are likely to comprise:

1. Conveyance pipe of suitable diameter to allow unrestricted flow, laid to appropriate fall, with bedding and surround.
2. Inlet protection to the pipe such as a mitred concrete headwall, stone-filled stainless steel basket or gabion protection.
3. Erosion control such as concrete pad, rip rap or other apron device to reduce energy within the inflow that may damage the SUDS component.

Inlet design should recognise the source of the upstream flow. Where the stormwater is discharged from a filter drain, or permeable pavement, there will be no debris to create a maintenance need and therefore a grille or stone protection would be acceptable. Where water is collected from an open system, eg a swale or hard surface, there is always a risk that silt, litter or vegetation could block the pipe and ease of maintenance must then be fundamental to the design.

A low flow intensity inlet structure that would be suitable for discharge into a pond or swale is shown in Figure 19.3. Where such inlets are within public open space, the pipe could be enclosed within a gabion basket. This minimises risk of blockage or vandalism, but is less obvious to maintenance staff.

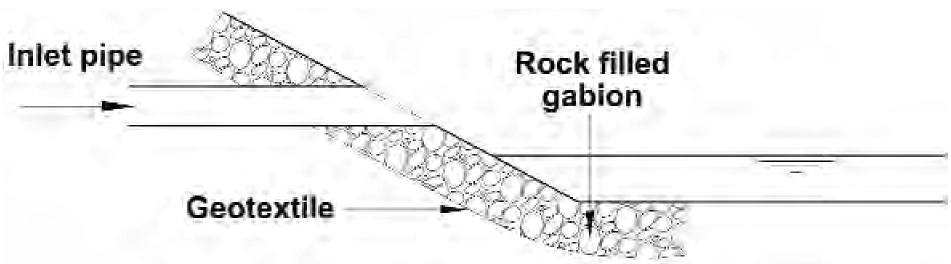


Figure 19.3 *Low flow intensity inlet structure to pond or swale: simple pipe discharge with stone protection*

Examples of current good practice are shown in the following photographs:

Figure 19.4 *Photographs of low-flow inlet pipes to SUDS systems (courtesy Robert Bray Associates)*

Where high flows are unavoidable and larger diameter pipes are involved, concrete head walls may be required. There may also be a need for safety/security screening of pipe outfalls. In such situations, the concrete should be carefully integrated with the adjacent landscaping to minimise aesthetic impact, safety risks (trip hazards) and facilitate maintenance. Such structures should be very carefully designed if they are to be acceptable from a maintenance, amenity and sustainability perspective. In particular, 90 degree concrete faces tend to exacerbate blockage risks.

Erosion control systems and more formal energy dissipation devices are described in Section 19.6. Issues concerned with trashracks and safety and security grilles are discussed in Section 19.8.

19.4.3 Lateral flow inlets

Where runoff from car parks and roads does not drain directly to a permeable pavement sub-base then it should, where possible, be conveyed in sheet flow to a filter strip, swale or filter drain via a lateral flow management device. This device should provide an appropriate "edge" detail to the pavement, while facilitating the transfer of water and minimising the risk of flow "channelling" that can cause deterioration in performance or failure of the downstream SUDS device.

Examples of the type of edge details that can be considered are:

- flush kerbs
- kerb outlets
- drop kerb channels
- open kerb edges.

In all cases, the width of opening must provide a sufficient width of flow to minimise risks of erosion and channelling. The edge should be flush with the runoff surface to prevent ponding and sedimentation. Kerb outlets (ie kerbs with rectangular outlets within the kerb, at regular spacings), have been shown to block easily and are not recommended where sediment and litter may accrue. An example of a drop kerb inlet system to a roadside drainage system is shown in the photograph in Figure 19.5.

Gravel strips can also be used to pre-filter and spread the flow downstream of kerb edges and upstream of SUDS systems. Silt is collected within such gravel strips, although such strips eventually tend to act only as flow spreaders as the silt cannot removed easily during operation and maintenance activities.

Figure 19.5 *Roadside drop kerb lateral filter drain inlets (courtesy Robert Bray Associates)*

It is important that grass growth is adequate at the edge of the detail. This will generally require topsoil depths of 100–150 mm, so kerb depths may need to be increased, or a revised edging required. In addition, the grass surface should be 20–25 mm below the kerb edge which is contrary to current landscaping practice.

19.4.4 Bypass structures/flow dividers

SUDS facilities can be designed as “flow-through” or “on-line” systems with flows above the water quality treatment event simply passing through the system at a lower pollutant removal efficiency. However, there will be some risk of damage to the water quality treatment system during flood events for such systems and it may be more acceptable (on both technical and economic grounds) to divert high flows to an alternative storage area (which may have dual use) using some form of flow control upstream of the SUDS system.

This scenario is presented in Figure 19.6.

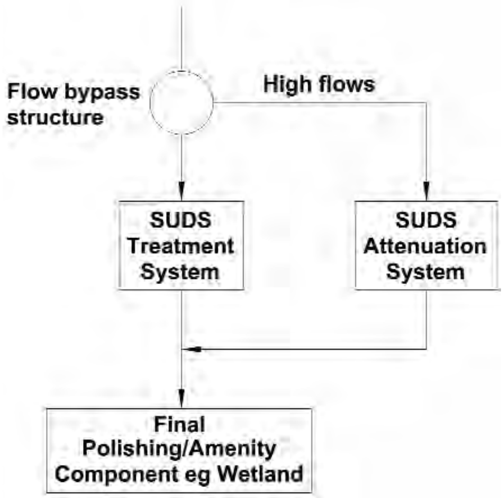


Figure 19.6 *Requirements for flow bypass structures*

In such cases, the inlet structure will normally include a means of controlling the flows which pass to the SUDS components. The complexity of the structure will depend on the level of flow control required. A crucial factor in designing flow dividing structures is to ensure that the correct low flow is retained on the main drainage path, and that above this rate, additional flows are diverted with minimal increase in head at the bypass structure to avoid surcharging the main drainage path under high flow conditions.

For surface flows, flow diversion structures can often be constructed through the use of appropriate landscaping alone eg for an off-line detention basin it may be possible to spill high flows over a low section of a channel bank into the detention, without any control on the flows passing on down the channel other than the channel capacity itself. Figure 19.7 illustrates such a system, with low/medium range flows passed downstream to a treatment wetland.

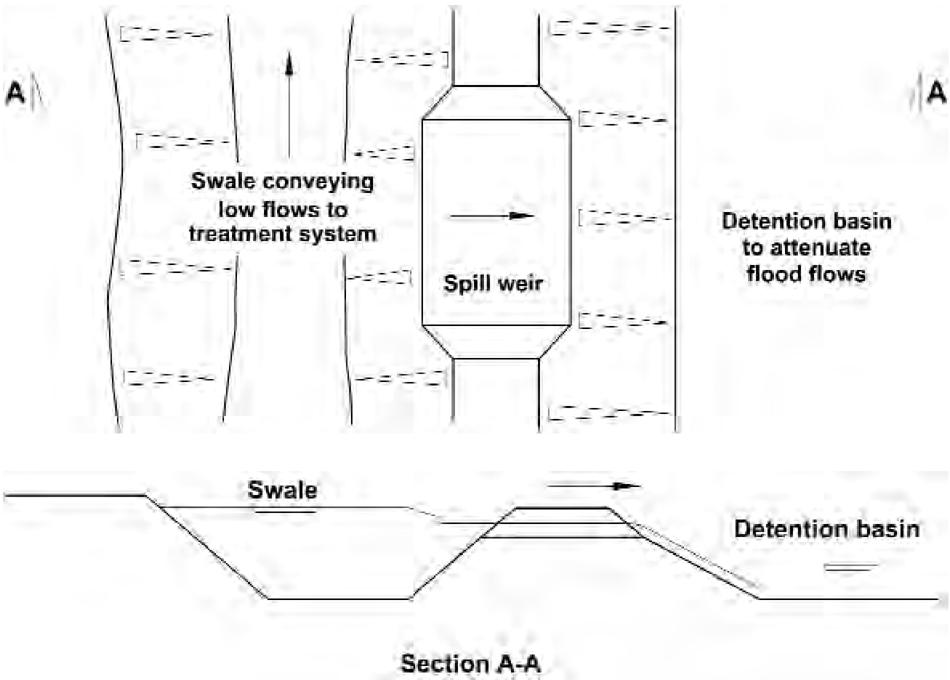


Figure 19.7 *Simple overflow inlet to detention basin; no control on flow passed downstream as shown but could be combined with orifice or culvert.*

Protection may be needed to the weir crest and face of detention basin to prevent erosion from the flow. This could take the form of gabion mattresses or cellular concrete blocks allowing the development of partial grass cover, although for occasional periods of discharge a well-grassed surface is likely to be adequate. The design of grass-lined spillways has been documented in CIRIA publication R116 (Hewlett *et al*, 1987).

Low flows can be deflected from highways into treatment zones (eg bioretention areas, swales and filter trenches), using systems such as those shown in Figure 19.8 and schematised in Figure 19.9. However any such designs would require agreement with the local highway authority. An alternative system is shown in Figure 19.10, where low flows are diverted into a small collection basin, which intercepts silt and spillages.

Figure 19.8 *Highway inlet deflector system (courtesy Robert Bray Associates)*

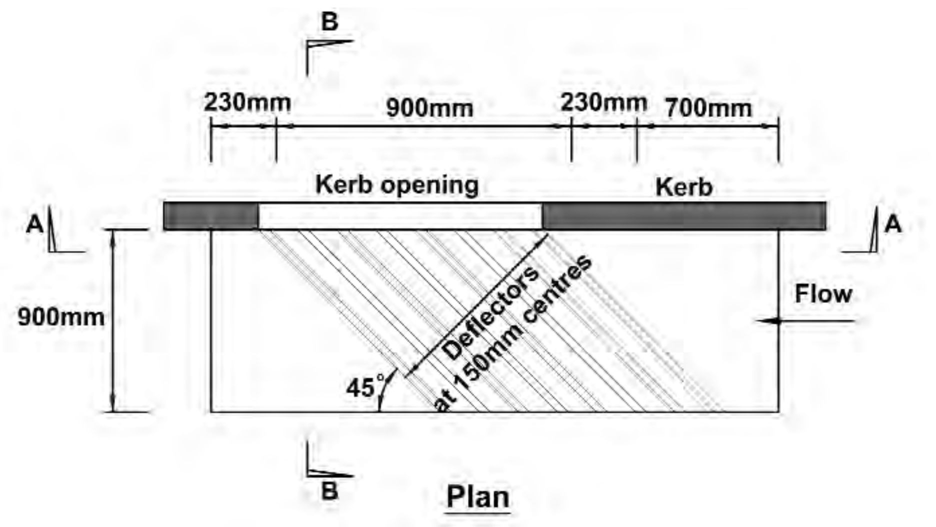


Figure 19.9 *Schematic of typical inlet deflector structure (adapted Wilson* et al*,2004)*

Figure 19.10 *Alternative inlet bypass structure with low and high flow routes, Orlando, Florida, (courtesy Robert Bray Associates)*

For piped flows, and where flows need to be tightly controlled, a "harder" structure may be required. This scenario is likely to be relevant only for heavily-urbanised, high-density development where the majority of the drainage infrastructure has to be below ground. Maintenance and safety issues should always be given full consideration.

Engineered, manhole flow dividers are likely to comprise one or two chambers with pipe or weir outlets (Figure 19.11).

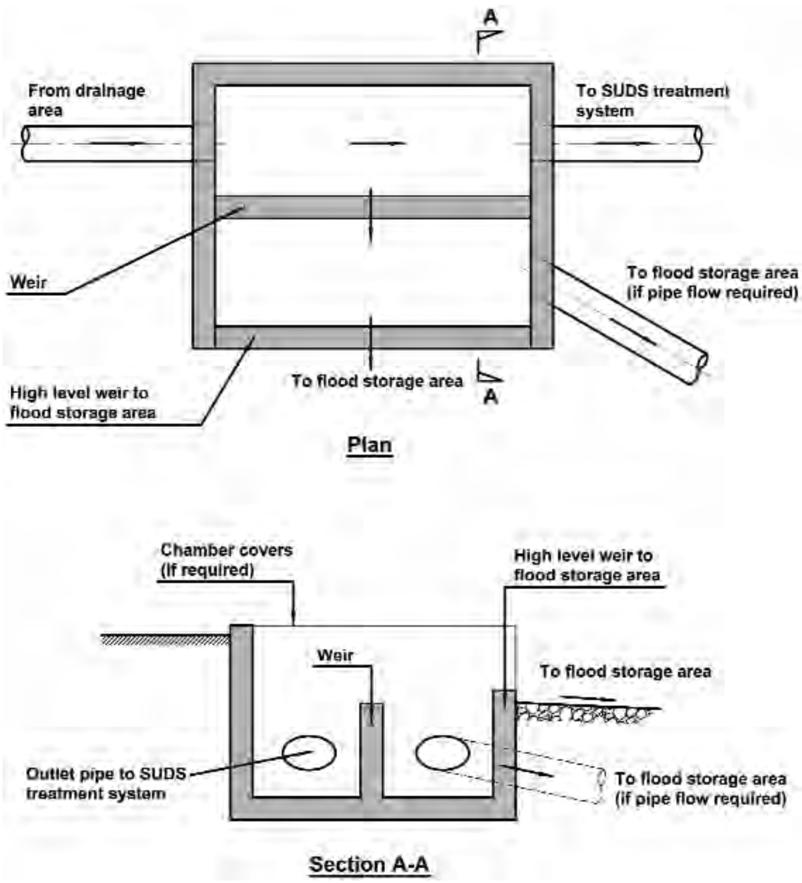


Figure 19.11 *Conceptual design for engineered inlet flow divider*

In cases where the normal and flood outflow routes from the chamber(s) are both via pipes, it is also advisable to include an "emergency" high-level weir, designed to deal with extreme floods and also to pass flows in the event of blockage of the pipe(s). The emergency weir may pass flood flows to a detention basin, or a bypass route, or possibly both.

The key features of the hydraulic design of the inlet structure are the need for appropriate design and sizing of the pipes and weirs to achieve the required discharge relationships, including the derivation of appropriate threshold water depths and levels which are compatible with the available hydraulic head.

There may be more than one inlet to a pond or detention basin. In such cases, consideration needs to be given to whether the economic and functional requirements can be met more effectively by combining the incoming pipe systems upstream of any inlet flow divider, or by providing a number of separate inlet divider structures. Care needs to be taken to ensure that there is no opportunity for any adverse short-circuiting between the outlet and the nearest inlet. It is recommended that, where such systems have to be implemented, they are kept as simple as possible.

19.4.5 Sediment detention

Effective pre-treatment should ideally be implemented via appropriate source control and upstream SUDS management train components (see Chapter 7). Where there are residual sediment risks, or where a sediment forebay is the only suitable management option at the site, then SUDS components can be split to allow heavier sediments to drop out of suspension before the runoff enters the main treatment facility. Sediment detention may either be undertaken in a separate basin or pond, or within a sediment detention area within the main pond. A forebay allows sediment build-up to be monitored easily, and concentrates any required sediment removal activities within a small area, thereby minimising potential damage to the rest of the pond. Sediment waste management is discussed in detail in Chapter 23 and in individual component chapters.

A simple approach to sediment detention is to include a weir or bank across the pond. The design will depend on the depth and configuration of the basin, but the following approaches should normally be considered – either singly or in combination – to separate the sediment basin from the rest of the pond:

- permeable weir, such as gabions, through which low flows would normally pass, but allowing overflow during floods
- earth embankment, designed to overtop and protected accordingly.

In most cases, the water levels on either side of the bank would be virtually identical, although there is the scope for a difference in elevation, particularly in the case of an embankment or weir, provided that it is designed accordingly. Vehicular access should be provided to allow removal of accumulated sediment for all types of sediment trap.

19.5 OUTLET SYSTEMS

Outlet structures control the flow out of the SUDS components, and therefore determine the ability of the system to manage both low and high flows. Water quality flows are normally handled with smaller, more protected outlet structures such as orifices located within screened pipes or risers, perforated plates or risers, small pipes, reverse-slope pipes, and V-notch weirs. Larger flows are typically handled through an overflow, flow over a weir within a manhole, or spillway/weir through an embankment. Overflow weirs can be of different heights and configurations to handle control of multiple design flows.

Outlets are usually built into an embankment with easy access for maintenance. A box or manhole outlet structure can accommodate a variety of outlet control mechanisms, although the depth of such structures should be considered carefully in the context of confined entry requirements. Any pipe bedding and/or surround material can be a conveyance route and where flow controls are included within the design then impervious fill/protection against seepage is required.

Similar techniques to those described for inlets can be employed to integrate outlet structures into the overall landscape. Natural stone and plant material can be used in place of concrete and hard structures to meet aesthetic, amenity, ecology and sustainability objectives. Seepage outlets, which are designed to facilitate the slow release of water can be constructed utilising a porous, planted weir or other natural filter system.

19.5.1 Outlet system design

Once the SUDS component area/volumes and outflow rates have been established, the outlet will need to be designed and sized. The sizing of outlet structures is typically a process where iteration refines the design details. A stage discharge curve is usually established for a given outlet design, then a model is run to determine whether the peak outflow for the water quality volume and the flood frequency curve is at or below the required criteria.

A key step is to identify clearly the duties that the structure must perform, and therefore the components that need to be included. Table 19.1 gives a broad indication of the principal components that may be required. In general, outlet structures should be designed to be as simple as possible to both construct and operate and maintain. The main concern for all outlets should be minimising the risk of blockage.

Table 19.1 *Typical outlet system components*

Component	Description
Flow control device	In most SUDS ponds and detention basins this normally comprises a fixed orifice, or an alternative form of throttle such as a short pipe or culvert with similar hydraulic characteristics. Its principal function is to throttle the discharge passed downstream and thereby retain floodwater in the impoundment. In larger and more complex cases, where detailed flow performance criteria have been laid down, it may comprise multiple outlet devices. There are normally minimum throttle size limits specified by adopting organisations.
Flood overflow weir	This provides the flood discharge route from the pond or detention basin when the available flood attenuation storage capacity is completely utilised. The weir and the flow route downstream are normally designed to pass a flood of a particular exceedance probability. In the case of an off-line pond or detention basin, an overflow weir may not be required if the inlet structure is designed in such a way that flood flows are reliably bypassed whenever the pond or basin is full. In some cases, it may be appropriate to combine the function with the emergency spillway.
Emergency spillway	The emergency spillway provides the ultimate safeguard against uncontrolled overflows and is normally required for both on-line and off-line ponds and detention basins. A shallow grass weir with inclined slopes is often sufficient. Care should be taken with the addition of erosion protection systems as they can cause turbulence and erosion of adjacent sections of embankment.

A range of outlet systems that are generally appropriate for maximum water depths of up to about 2 m are described in the following sections. Designers of large structures should follow the guidance given in the *Design of flood storage reservoirs* (Hall *et al*, 1993) which contains a comprehensive account of the types of control structures which may be deployed for the outlet structures of on-line and off-line flood storage reservoirs. This remains the primary source of information for larger flood storage reservoirs, whether or not they are covered by the Reservoirs Act (DoE, 1975).

19.5.2 Orifices

An orifice is a circular or rectangular opening of a prescribed shape and size. The flow rate depends on the height of the water above the opening (hydraulic head) and the size and edge treatment of the orifice. Multiple orifices may be necessary to meet flow control requirements of different return periods. Orifices act as very efficient throttles (flow constraints) and this efficiency can be disadvantageous in some respects in that it may put water into storage early in the storm, while the downstream channel still has the capacity to accept it.

Orifices may be constructed in a wall or baffle, in perforated risers, or as a "tee" riser section such as that shown in Figures 19.12 and 19.13. With the inlet set below the water surface, tee-risers help to reduce the risks of blockage and, in particular, the chance of oils being transported downstream.

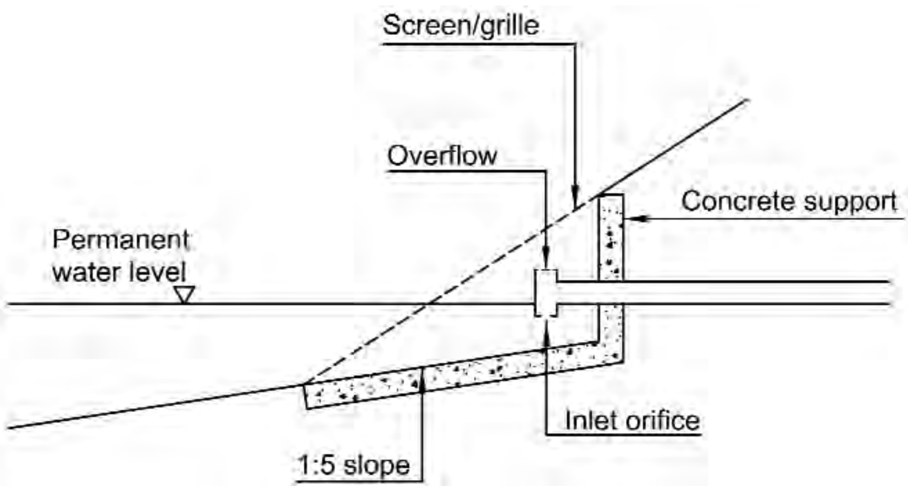


Figure 19.12 *T-piece orifice structure with pipe base providing permanent water level control*

Figure 19.13 *Photograph of screened orifice outfall with T-piece structure (courtesy Robert Bray Associates)*

For a single orifice, the orifice discharge can be determined using the standard orifice equation below:

Box 19.1 *Standard orifice equation*

$$Q = C_d A_o \sqrt{(2gh)}$$

Where:

Q = Orifice discharge rate, m^3/s

C_d = Coefficient of discharge, m (0.6 if material is thinner than orifice diameter; 0.8 if material is thicker than orifice diameter, 0.92 if edges of orifice are rounded)

A_o = area of orifice, m^2

h = hydraulic head, m

If the orifice discharges as a free outfall, then the effective head is measured from the centre of the orifice to the upstream (headwater) surface elevation. If the orifice is submerged, then the effective head is the difference in elevation of the headwater and tailwater surfaces, as shown in Figure 19.14.

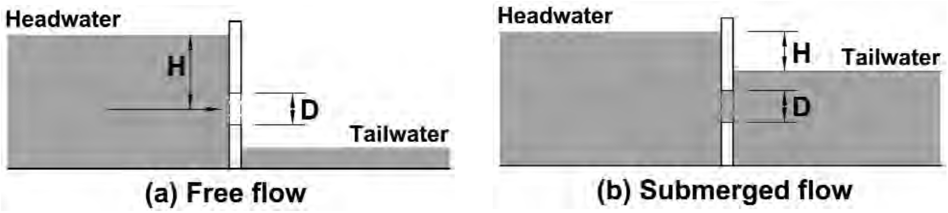


Figure 19.14 *Effective head for orifice discharge calculations*

Exposed orifices with diameters similar to tennis balls and soft drink cans are particularly vulnerable to blockage. Perforated risers with protected orifice plates can be used to minimise blockage rates for very low flow controls (see Section 19.5.3). Other outlet protection systems are described in Section 19.5.7.

Flow through multiple orifices, such as the perforated plate shown in Figure 19.15 below can be computed by summing the flow through individual orifices. For multiple orifices of the same size and under the influence of the same effective head, the total flow can be determined by multiplying the discharge for a single orifice by the number of openings.

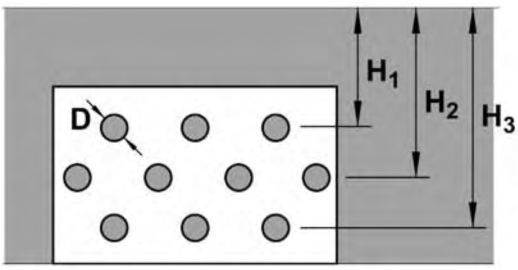


Figure 19.15 *Multiple orifice plate*

19.5.3 Perforated risers

Perforated risers can be used in the following forms:

1. In conjunction with orifice plates as a mechanism to protect against blockage. In this scenario, the perforations in the riser must convey more flow than the orifice plate so as not be become the control.

2. As a more complex flow control structure. In this scenario, each of the orifices on the riser will contribute to the overall head-discharge relationship (see Section 19.5.2).

A shortcut formula has been developed for estimating the total flow capacity of the perforated section (McEnroe *et al*, 1988). The dimensioning is shown in Figure 19.16.

Box 19.2 *Total flow capacity of a perforated riser*

$$Q = C_p \frac{2A_p}{3H_s} (2g)^{1/2} H^{3/2}$$

Where:

Q = discharge, m^3/s

C_p = discharge coefficient (for perforations = 0.61)

A_p = cross sectional area of all holes, m^2

H_s = distance from S/2 below the lowest row of holes to S/2 above the top row, m

S = distance between holes, m

H = effective head, m

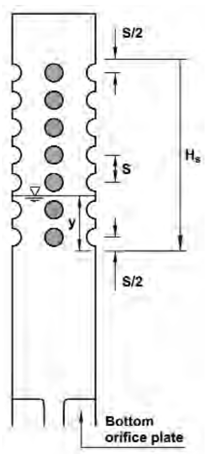


Figure 19.16 *Perforated riser dimensions*

Figure 19.17 is an example of a perforated riser set in a shallow manhole, with the pipe from the SUDS system to the control structure protected from debris by a gabion basket.

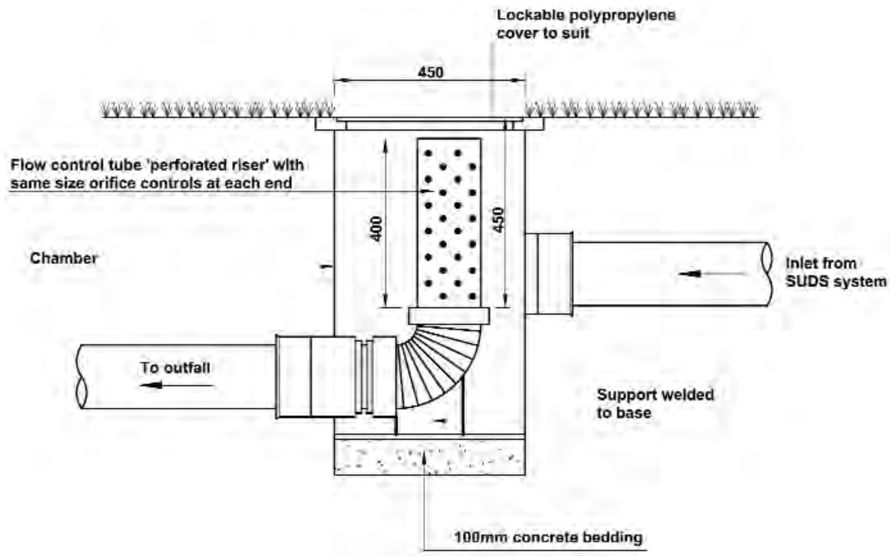


Figure 19.17 *Conceptual layout of protected perforated riser outlet structure for small pond (courtesy Robert Bray Associates)*

Perforations can become affected by silt or fine particles of vegetation and, if maintenance is not regular, the holes in the riser can become blocked. At worst, water can rise to the top of the tube and overflow into the outfall pipe. The bottom orifice controls the flow up to a 300–400 mm head. The use of a perforated riser tube section with orifice controls at each end means the tube will function correctly if it is installed incorrectly during construction or maintenance.

19.5.4 Pipes and culverts

Typical flow control rates required are between 2 and 8 l/s/ha and where the site is split into sub-catchments and effective source control is included then rates should be significantly lower. Pipes are often used as outlet structures for drainage control facilities and, like the orifice, their head-discharge characteristics mean that they are very efficient flow control systems. Pipes smaller than 300 mm can be analysed as a submerged orifice as long as H/D is >1.5 (where H = upstream head, D = pipe diameter). Note: for low flow conditions when the flow reaches and begins to overflow the pipe, weir flow will control. As the flow increases, there will be a transition to orifice flow.

Pipes greater than 300 mm can be analysed as a discharge pipe with headwater (and tailwater if required) effects taken into account. Reference should be made to standard hydraulics text books dealing with pipe flow, CIRIA publication R168, *Culvert design manual* (Ramsbottom *et al*, 1998), and *Tables for the hydraulic design of pipes, sewers and channels* (Barr and HR Wallingford, 2006).

19.5.5 Weirs

Weirs and notches discharge proportionately more water than orifices or pipes, with an equivalent increase in head. An advantage of weirs is that floating debris will pass downstream and they are not vulnerable to blockage. Weirs can be "sharp-crested", "broad-crested", triangular or of various intermediate cross sections, each of which has slightly different head-discharge characteristics. Weirs can be used as level and/or flow control structures and/or emergency spillway devices. The approximate equations for different weir types are given in Figure 19.18.

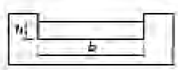
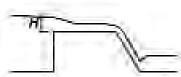
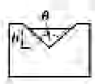
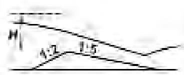
Type of control	*Approx discharge*	*Type of control*	*Approx discharge*
1. Rectangular thin-plate weir full width *b* with no side contractions 	$Q = 0.59b\sqrt{g}\,h^{3/2}$	4. Rectangular profile weir 	$Q = 0.46b\sqrt{g}\,H^{3/2}$
2. Rectangular thin-plate weir with side contractions 	$Q = 0.59\,(b + 0.003)\sqrt{g}\,h^{3/2}$	5. Round nose horizontal-crested weir or flow over a floodbank 	$Q = 0.544b\sqrt{g}\,H^{3/2}$
3. Vee-notch weir 	$Q = 0.58\sqrt{g}\tan\frac{\theta}{2}\,h^{5/2}$	6. Triangular profile crump weir 	$Q = 0.633b\sqrt{g}\,H^{3/2}$

Figure 19.18 *Approximate discharge equations for range of weir types*

Standard hydraulic text books and British Standards should be referred to for further details. Weirs can be set into embankments, forming a point of visual interest, in which case full consideration should be given to the use of natural construction materials. If they have to be housed within sub-surface chambers, special consideration must be given to their long-term operation and maintenance to ensure consistent performance.

19.5.6 Emergency spillways

The term "emergency spillway" is normally taken to refer to the spillway provided for:

- conveying "extreme" floods, that is floods of a greater severity than those handled by the overflow weir incorporated in the outlet structure
- preventing overtopping – and potentially catastrophic erosion – of any perimeter embankments caused by blockage or other failure of the outlet structure.

In the case of ponds and detention basins that come within the ambit of the Reservoirs Act (DoE, 1975), there is recognised guidance on the appropriate exceedance probability for the design flood to be passed via the emergency spillway (ICE, 1996). This guidance is also relevant for ponds and basins which are not covered by the Act, but would nevertheless represent a significant hazard if the embankment were to fail due to flood overtopping.

The emergency spillway for ponds and detention basins normally comprises an open weir and channel, the reasons for this being that:

- the discharge rises non-linearly resulting in significant increases in flow for small increases in head
- there is a low risk of spillway blockage by debris or by incorrect operation.

Other alternatives may be acceptable – for example a labyrinth weir, a siphon, or a bellmouth spillway discharging to a closed conduit – but spillways using gates or other moving parts are unlikely to be appropriate.

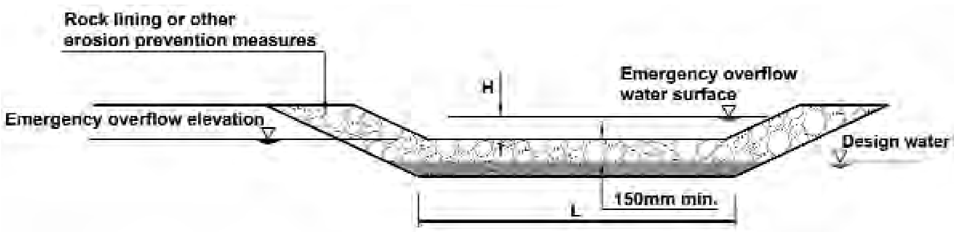


Figure 19.19 *Typical overflow/emergency spillway details*

The emergency overflow spillway weir section must generally be designed to pass at least the 100 year runoff event for developed conditions, assuming a broad-crested weir. Where risks associated with failure of the structure are considered to be high, larger return periods may be chosen. Figure 19.20 shows typical protection to the spillway crest. The downstream face of the overflow may normally be protected by grass. The design of grass-lined spillways has been documented in CIRIA publication R116 (Hewlett *et al*, 1998).

19.5.7 Passive devices

A number of devices are available whose objectives are to vary the hydraulic characteristics of the simple orifice.

When using a simple orifice plate, the flow rate passing through the control is proportional to the upstream head, ie the flow increases steadily until the design point is reached. If a variable greenfield flood frequency curve is specified for the outlet control, then this type of response may be appropriate. If a fixed discharge rate is specified, then a vortex-type device may be useful as this will tend to have an S-shaped head discharge curve, with:

1. Increased forward flows during the early stages of the build-up of upstream head (tending to reduce the required upstream storage volume).
2. A limited flow across a range of upstream heads.
3. A comparable orifice head-discharge relationship once the design limit has been reached.

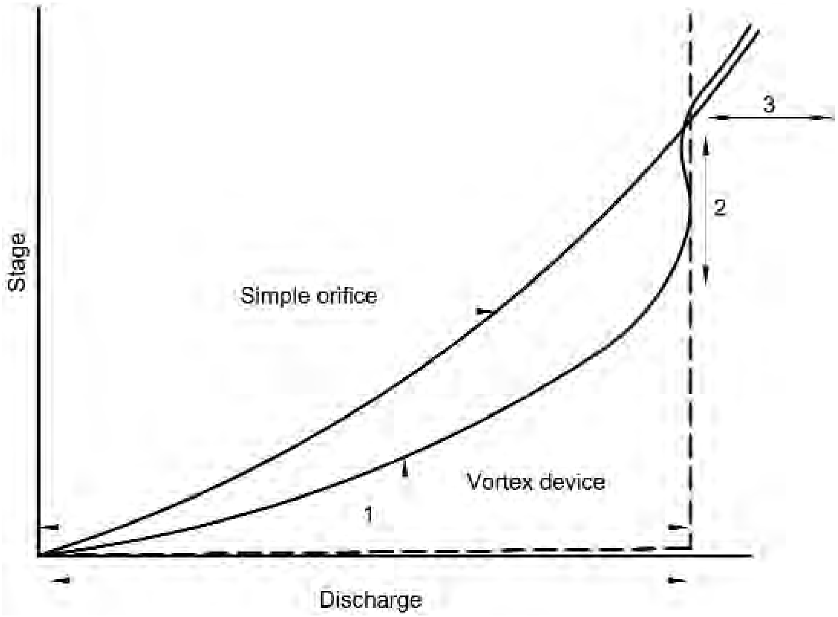


Figure 19.20 *Examples of stage/discharge relationships for outlets*

There are a number of different configurations available for vortex-type devices, all of which rely on generating an air-filled vortex in the outlet tube. The advantages claimed by the manufacturers include:

- the overall cross-sectional area is larger than that of a comparable simple orifice, reducing the risks of blockage
- self-cleansing, with minimal maintenance requirements
- reduces total flood storage requirements by up to 30%
- increases energy dissipation in the vortex, resulting in reduced requirements for downstream energy dissipation.

The design of vortex-type devices is normally undertaken by the manufacturers, to suit a client's particular application, although software packages may include the hydraulic characteristics of typical devices.

19.6 Outlet protection

Small, low-flow orifices, such as those used for extended detention or low-flow applications, can block easily, preventing the structural control from meeting its design purpose and potentially causing flooding and other adverse impacts. Such orifices need to be adequately protected.

There are a number of different anti-clogging designs, including:

- gravel surround
- gabion protection
- reverse slope outlet pipe for a pond or wetland with a permanent pool. The submerged inlet prevents floatables from clogging the pipe and this also avoids discharging warmer water at the surface of the pond. However this design option is not easily visible and therefore its maintenance tends to get overlooked, increasing long-term blockage risks
- orifices protected within perforated risers or T-pieces
- debris guards (stainless steel guard open top and bottom)
- "hooded" outlets.

The following figure shows two styles of perforated pipe outlets for a small detention basin, protected by gabion basket structures.

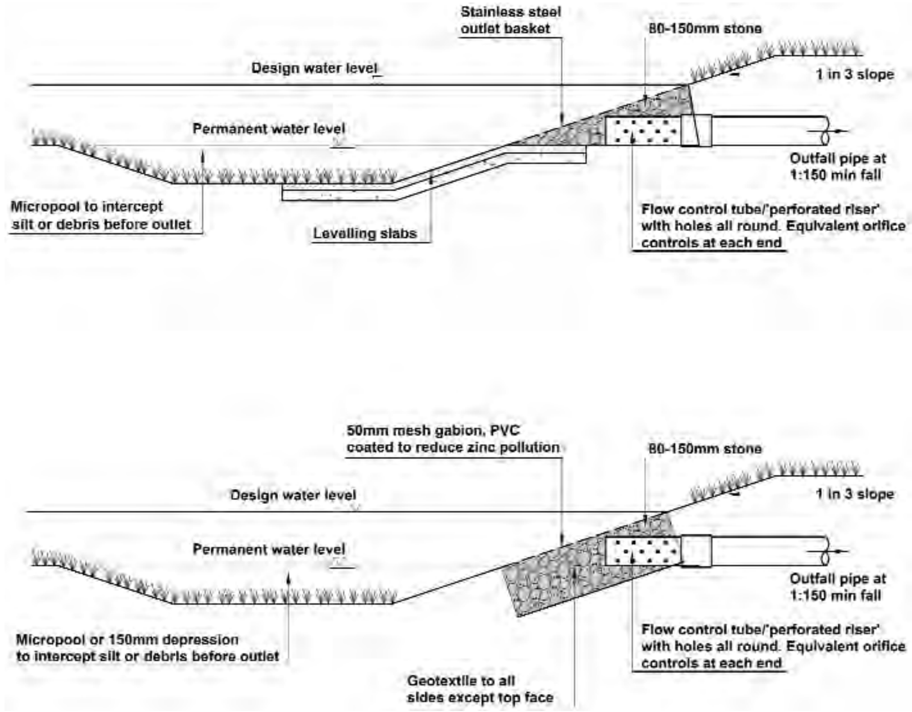


Figure 19.21 *Conceptual layout of "soft" outlet structure for small detention basin (courtesy Robert Bray Associates)*

This figure includes the following components/characteristics:

- micropool to ensure maximum silt/debris drop-out prior to the outlet and to provide habitat enhancement
- concrete slab immediately upstream of the outlet to allow manual silt removal where silt accumulation risks are significant
- gabion basket protects outlet from clogging and vandalism within public open space, including accidental and purposeful blockage of the pipe or control
- orifice plates welded to both inlet and outlet of perforated tube (this reduces the risk of the system being installed the wrong way round and minimises blockage risks)
- filtered passage of water to perforated control tube
- raised outlet reduces silt blockage risk

- 1 in 3 slopes reduce risks of rubbish/vegetation collection against the outlet as such debris will tend to rise with the water level away from the control structure
- low health and safety risks
- low risk of maintenance problems
- aesthetically acceptable.

Photographs of debris guards are given in Figure 19.22.

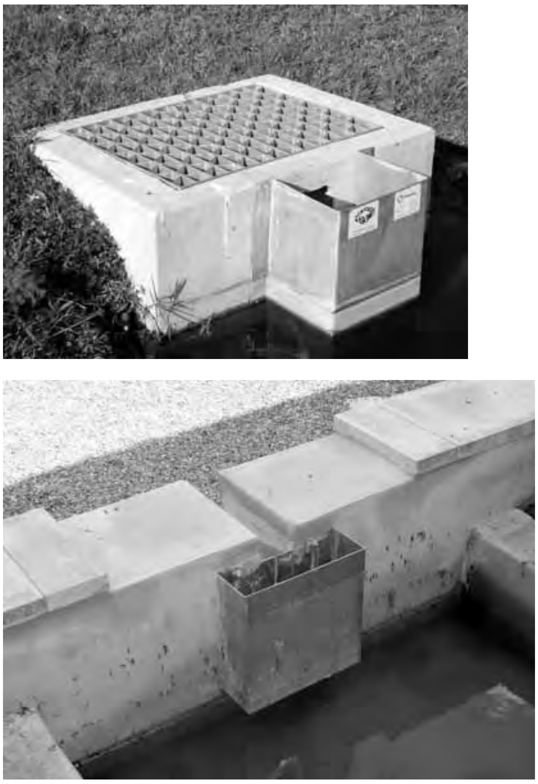


Figure 19.22 *Examples of debris screens over low flow outlet control structures (courtesy Robert Bray Associates)*

19.7 ENERGY DISSIPATION

The primary objective of erosion protection at pipe outlets is the reduction of velocity. Therefore a key consideration in selecting the type of outlet protection is the outlet velocity for the pipes or channels involved. This will be dependent on the flow profile associated with the design storm. Where flows have been effectively managed at source, energy dissipation structures should be required only for overflows and emergency spillway structures.

Examples of energy dissipation options include:

- reducing outlet velocities using upstream SUDS components
- reducing pipe gradient (but not less than the required self-cleansing velocity)
- rip-rap aprons
- loose stone
- gabions
- reinforced grass
- granite setts

- concrete stilling basins
- baffle blocks within a headwall.

For SUDS designs, "hard" systems such as concrete stilling basins and baffle blocks should not be required as velocities should be low. Flow alignment and outfall setback can be considered in conjunction with energy dissipation in sensitive receiving environments.

A few of the options are described in more detail in the sections below.

19.7.1 Rip-rap aprons

A rip-rap lining is a flexible stone layer. It will adjust to settlement, can also serve to trap sediment and reduce flow velocities through a higher Manning's roughness coefficient. The velocities from SUDS schemes should be sufficiently low that protection such as aprons is rarely needed. Where piped flows produce erosive conditions that cannot be avoided appropriate hard engineering designs need to be developed using standard guidelines and manufacturers' design guidance.

19.7.2 Gabions

Gabions can be used as an erosion dissipating surface beneath an outfall. The boxes should either be manufactured of stainless steel or of galvanised steel wire with a PVC coating to prevent zinc from entering the water. The rock or gravel fill should be of a sufficient diameter to prevent wash-out (usually single sized stone), and the dimensions of the blanket should follow a similar design process to that given in Box 19.3.

Gabions in SUDS are usually not load-bearing and therefore thin mattress types (150 mm or so) are usually sufficient. These also allow vegetation to become established, which acts to aid their function in the system.

19.7.3 Flow spreaders

Flow spreaders reduce velocities and distribute point source flows laterally across a horizontal section. For lateral inflows to filter strips, trenches and swales, this is achieved using a level sill (kerb or concrete section) or a gravel strip (gravel diaphragm). For point inflows, flow spreading can be achieved using a concrete/stone/gabion base pad. Sumps are not recommended as they are hazardous to people and wildlife, difficult to maintain, and expensive.

19.7.4 Flow alignment and outfall setback for sensitive receiving environments

Depending on the location and alignment of the pipe outfall and the receiving stream, outfall structures discharging high flows can have a significant effect on receiving channels. Alignment at a right angle to the stream will introduce the discharge at a 90 degree angle to the direction of flow. This can cause scour of the opposite stream bank as well as causing significant turbulence at the point of entry. The preferred approach is to align the pipe flow at no more than a 45 degree angle to the stream. If the pipe outfall has to be directly into the stream channel, then consideration should be given to placing rip-rap on the opposite stream channel boundary. The impact of new pipe outfalls can be reduced significantly by locating them further back from the stream edge and digging a channel from the outfall to the stream. This allows energy dissipation before flows enter the stream. As a minimum, the pipe outfall should be located far enough back from the stream edge to prevent the energy dissipater from intruding into the channel.

19.8 TRASHRACKS AND SECURITY GRILLES

Trashracks and security grilles are applicable only for large inlets and outlets. They will require regular maintenance and in general do not reflect SUDS best practice. It is recommended that such systems are used only in exceptional circumstances.

CIRIA publication R168 (Ramsbottom *et al*, 1997) contains guidance on the use and design of screens (trashracks and security grilles) appropriate to UK conditions. The reasons for providing a screen are:

- to exclude trash which might otherwise block the conduit
- to capture debris in such a way that removal is relatively easy
- to prevent unauthorised access, particularly by children and dogs.

Screens often can be the cause of significant problems and their susceptibility to clogging must always be given full consideration. Firstly, the trapped debris may accumulate and result in severe impairment of the discharge capacity of the conduit. Secondly, the use of security grilles on the outlet from a pipe or culvert can result in debris accumulation which is difficult to remove. CIRIA publication R168 therefore recommends that a thorough assessment be carried out of the need for screens and that, wherever possible, screens should be avoided.

In cases where there is easy public access and an outlet structure discharges to a pipe or culvert that would be hazardous to enter, or where there is a supply of vegetation and other debris which is liable to block a flow control device (such as a small orifice), then the structure should be protected, eg within a gabion or else an entrance screen may be required. The screen aperture should be chosen to exclude debris liable to cause a problem, but allow through smaller debris that is unlikely to cause a blockage. Consideration must also be given as to whether or not a grille could be classed as a foot trap/trip hazard for children. There may be concerns for mesh 50–75 mm mesh sizes where the mesh could be walked over by children.

If it is decided that the exit from a pipe or culvert must be screened for security and/or safety reasons, then it is important that a significantly finer screen be deployed at the corresponding entrance to avoid the passage of debris big enough to block the exit screen.

Trash racks must be large enough that partial plugging will not adversely restrict flows reaching the control outlet. A commonly-used rule thumb is to make the rack area more than 10 times the control outlet orifice. The surface area of the rack should be maximised and the rack should be located a suitable distance from the protected outlet to avoid interference with the hydraulic capacity of the outlet. The spacing of the bars must be proportional to the size of the smallest outlet protected. However, separate racks can be used for different sized outlets. The rack should normally have hinged connections to facilitate the removal of accumulated material except where fears of vandalism require a fixed grille approach.

Minimising health and safety and operational risks should be key concerns. Any grille should be able to be cleared during events from a safe location. Structural design considerations are set out in Box 19.3.

Box 19.3 *Structural trash rack design criteria*

1. **Confirm need**
   Provide screen only where there is a high risk of blockage, and where such a blockage would be significant. Major indicators are a bend or obstruction in culvert; a very long culvert with difficult access and a debris load that potentially contains large items.

2. **Estimate debris amounts**
   Debris is either high (more than 60 m^3 per year), medium (30–60 m^3 per year) or low (less than 30 m^3 per year). Leaves, twigs and small branches will rapidly block a screen, with blockages usually being formed by one or two large items supporting smaller debris.

3. **Design of screen**
   Screen angle should be 60° or less.
   Bar spacing must not exceed 150 mm if designed as security screen, and must not be below 75 mm to avoid trapping small debris.
   Height of the screen must not exceed 2 m.
   Gross area of screen should not be less than:

Debris loading:	*Screen gross area:*
Less than 30 m^3/year	the greater of 6 m^2 or 3 times culvert area
30–60 m^3/year	the greater of 9 m^2 or 7 times culvert area
More than 60 m^3/year	the greater of 12 m^2 or 9 times culvert area

Steel member sizes should generally be not less than 75 mm by 8 mm flats (25 mm for round bars), with lengths over 1.5 m braced.

19.9 FLOW MEASUREMENT

If accurate flow control is required, perhaps also with the facility for monitoring flows during floods, then additional steps need to be taken in the design to ensure that appropriate forms of flow control device are used and that the conditions are suitable for that purpose. This would require the use of upstream level measurements together with components such as:

- a thin-plate orifice
- a thin-plate weir (rectangular and vee-notch)
- a Crump weir
- a critical-depth flume.

These require routine attention to maintain their performance, but this is normally no more than:

- removing any accumulations of sediment that may affect the hydraulic behaviour
- brushing the surfaces to remove slime and algae.

Thin-plate orifices and weirs can sometimes develop leakage problems and also require occasional renewal or refurbishment if their performance is starting to be affected by a loss of true edges compliant with the requisite standards.

Further information on flow measurement structures is given by Ackers *et al* (1978), Bos (1989) and in the relevant British Standards.

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Landscape

20

Contents

Landscape 20

20.1 INTRODUCTION

Landscaping includes the development of appropriate elevations and plans for the surface of the site that allows the environmental impact of the site to be minimised, that retains and enhances existing site drainage features, that facilitates the inclusion of an effective sustainable drainage scheme (including dual use areas where appropriate), and that ensures the safe routing of runoff from rainfall events in excess of those for which the drainage system is designed.

In some cases, effective site landscaping can eliminate the need for structural controls entirely. In addition, landscaping is critical to improving both the function and appearance of SUDS. It has aesthetic, ecological and economic value that is often overlooked during site design and construction.

Planting has specific functions:

- prevents erosion of soil surfaces
- traps silt and prevents re-suspension
- filters and treats pollution
- provides wildlife habitat
- promotes attractive and natural surroundings.

Chapter 6 covers landscaping techniques that aim to minimise and manage runoff at source, and public perception and engagement is discussed in Chapter 24. This chapter addresses the materials and procedures associated with effective landscaping and planting.

20.2 LANDSCAPING OBJECTIVES FOR SUDS PERFORMANCE

A good SUDS landscaping plan should consider the following objectives:

(1) Maximise aesthetic appeal

SUDS should be landscaped so that they are generally accepted as aesthetically pleasing. This can be achieved using sympathetic contouring, planting and through the installation of open water features. Plants and landscape contouring can be used to direct views onto aesthetically-pleasing features and to shield components that may be considered as intrusive or untidy.

(2) Maximise water quality and ecological function

SUDS should be landscaped so that a variety of habitats is provided. Wherever natural habitats exist these should be preserved and should be incorporated into SUDS schemes only where there are no risks and a clear benefit can be demonstrated. Plants should be chosen that grow under local conditions without amendments to soils, are known to provide good erosion protection, optimise silt interception and minimise re-suspension, provide a bioremediation substrate for the treatment of pollution, and give high quality ecological habitat appropriate for the local area.

(3) Maximise the economic value of the site

SUDS landscaping maintains or enhances the economic value of a site when it achieves a system that is aesthetically pleasing and provides amenity values and facilities. Poor landscaping can contribute to the value of the site falling and can have an impact on the quality of life of residents or occupants. To ensure sustainable long-term aesthetic benefits, the landscape must be easy to maintain.

(4) Maximise flow control opportunities

SUDS landscaping is often an integral part of system flow control measures. Landscaping should achieve runoff infiltration wherever possible, provide densely vegetated and shallow gradients to increase hydraulic roughness for flow conveyance facilities, and safe on-site storage for excess runoff.

(5) Provision of a safety function, where required

Planting can be used to delineate the boundary between terrestrial and aquatic features and can create physical barriers to access where required. Planting can also be used to stabilise surfaces where pedestrian or vehicular access is required.

20.3 SITE CHARACTERISTICS

20.3.1 Soil properties

Plant establishment and growth are dependent on a number of different soil characteristics including:

- soil texture
- pH
- nutrient levels
- mineral levels
- salinity
- toxicity
- groundwater level
- frequency of saturated conditions.

Soil samples should be analysed by professionals who can explain the results and provide advice on soil suitability for certain types of plants. Sandy loam, loam, and silt loam are the preferred soils for seeding, and consideration should be given to incorporating these soils into the seedbed. Soil amelioration should normally be required only where toxicity and/or pollution has occurred as a result of previous land use. Ideally, plants should be selected that can establish themselves on the existing soil without requiring amendments.

Areas that have recently been part of a construction site can become compacted so that plant roots cannot penetrate the soil. Such soils should be loosened to a depth of at least 50–100 mm, using tine ripping, although hard soils may require ripping to a greater depth. Loosening soils will improve seed contact with the soil, provide higher germination rates, and allow the roots to penetrate into the soil.

A topsoil layer allows the plants to establish more quickly and roots are able to penetrate deeper and stabilise the soil, making it less likely that the plants will wash out during a heavy storm. Site topsoil should be stripped, rotovated and stored according to recommended guidance (eg BS 3882, BSI, 1994).

It should be re-used as quickly as possible. A minimum of 50 mm subsoil blinding should be added to wildflower grass areas (wildflower seed mixes/plug plants germinate better on subsoil/nutrient poor soil rather than topsoil). A minimum of 100–150 mm topsoil in all areas subject to flow or occasional storage is required.

Topsoil should be stockpiled in mounds up to 2 m high only. If topsoil has been stockpiled in deep mounds for a long time, the microbial activity may be destroyed, and it may therefore be necessary to inoculate the soil after application. Incorporating composted green waste can also rehabilitate micro-organisms and helps lock nutrients into the soil, preventing wash-out. Landscaping within the catchment area of SUDS ponds should avoid the use of nutrient rich topsoil as far as possible and also added nutrients, eg quick-acting or slow-release fertilisers which tend to be used in most landscape specifications.

20.3.2 Soil drainage

Soil moisture and drainage have a direct bearing on the plant species and communities that can be supported. Factors such as soil texture, topography, groundwater levels and climatic patterns all influence soil drainage and the amount of water in the soil. The following categories can be used to describe soil characteristics with respect to drainage:

- **flooded** – standing water is present most of the growing season
- **wet** – standing water is present most of the growing season, except during times of drought. Such conditions often exist on poorly drained soils
- **moist** – soil is damp, and may be poor draining and located in a sheltered position
- **well-drained** – rainwater drains readily. Soils usually have medium textures with a proportion of sand and silt
- **dry** – water drains rapidly or runs off quickly and little water remains in the soil to be available to plants.

20.3.3 Site topography

The degree of slope is not usually critical in plant establishment unless it exceeds 1 in 3 and normal maintenance access is prevented. However, it can limit the site suitability for certain types of plants.

Soils on steep slopes generally drain more rapidly than those on gradual slopes. This means that the soils may remain saturated longer on gradual slopes. If soils on gradual slopes are classified as poorly-drained, care should be taken that plant species are selected that are tolerant of saturation.

Site topography affects maintenance of plant species diversity. Small irregularities in the ground surface (eg depressions, etc) are common in natural systems. More species are found in areas with many micro-topographic features than in areas without such features. In wetland, plant establishment, depth and duration of inundation are principal factors in the zoning of wetland plant species. A particular change in water level will expose a relatively small area on a steep slope in comparison to a much larger area exposed on a gradual or flat slope. Narrow planting zones should, therefore, be delineated on steep slopes for species tolerant of specific hydrologic conditions, whereas gradual slopes enable the use of wider planting zones. Additional detail on the influence of topography on planting is provided in the SEPA publication *Ponds, pools & lochans* (SEPA, 2000).

20.3.4 Site orientation

A southern-facing slope receives more sun and is warmer and drier, while the opposite is true of a northern slope. Eastern- and western-facing slopes are intermediate, receiving morning and afternoon sun, respectively. South-west facing slopes tend to receive more wind.

20.3.5 Site proximity to airfields

Birdstrikes (ie aircraft collisions with large and flocking birds), pose a significant risk, and any site within 13 km radius of an aerodrome is classed as a development that might attract birds, and therefore requires consultation with the airport operator.

The Civil Aviation Authority (CAA) have identified the following significant hazards associated with landscaping features:

1) Dense vegetation cover that may provide roosting or nesting habitats for starlings, rooks, woodpigeon and other aviation-hazard bird species.
2) Fruit or berry bearing plants that provide winter food supplies to starlings, fieldfares, redwings etc.
3) Open water or watercourses that attract gulls and other large waterfowl and cause increased bird movement between existing waters and the new site, over and around the airport.
4) Open grasslands close to water which attract Canada geese and Greylag geese.

SUDS landscapes in these areas should be designed to support non-hazardous species such as passerines (song birds) rather than larger flocking birds.

The severity of the hazard posed by a proposed water feature will vary with the size and nature of the water body, its location relative to the aerodrome, existing water areas and waterfowl feeding sites. The number of water features within a local area has a cumulative effect on the hazard posed.

Large open water areas should be avoided – smaller mosaics of ponds may be more acceptable although even these may have to be netted in some cases. Islands that provide safe nesting locations should not be included within designs and ease of access by birds between the water and land should be constrained.

There should be no berry bearing species included in the planting schemes, and tree species that have maximum growth heights of less than 10 m should be selected. Blocks of planting should be avoided and planting rows should be staggered if a screening function is required. All trees should be planted at least 4 m apart. Grass should be kept long (>200 mm), and managed as a meadow to deter birds.

Additional guidance can be found in the Civil Aviation Authority publication, Safeguarding of aerodromes, Advice Note 3 *Potential bird hazards from amenity landscaping and building design* (CAA, 2003).

20.4 PLANT SELECTION

20.4.1 General plant selection

The list in Box 20.1 gives general guidance on the plant selection process:

Box 20.1 *General plant selection guidance*

1. When selecting plants for SUDS facilities, site characteristics, drainage, slope and orientation should all be taken into account.
2. Consideration should be given to how plant characteristics will affect the landscape aesthetics and the performance of a structural stormwater control or conveyance.
3. The long-term vegetation management requirements should be given full consideration, as these will be a maintenance legacy for the future owners.
4. Existing natural vegetation should be preserved wherever possible.
5. Native plants should be selected that can thrive in on-site soils with no routine or intensive chemical applications.

20.4.2 Use of native species

Generally, native plants should be used, since they are best-suited to thrive under the specific conditions encountered at a site. Relying on local species for planting SUDS is important for both providing habitat and preventing introduced plant species from becoming invasive and taking over adjacent natural communities. SUDS are part of the natural drainage system of a catchment and all planting should be regarded as *de facto* release to the wild. There may be ornamental or ultra-urban situations where species selection may justify non-native plants, but this will require discussion with interested parties and a species risk assessment to ensure there is no likelihood of habitat damage.

It is particularly important that native wetland plants are sourced from a plant nursery that will guarantee that all plants are of UK provenance and that no non-native (exotics) are grown at the nursery. The removal of alien species, should colonisation occur, could be included as a contractual requirement for the plant supplier.

20.4.3 Grass/turf

It is usual to select a grass seed and wildflower mix from a reputable supplier who will guarantee the UK provenance of the seed, and confirm that it is likely to thrive on local soils and environmental conditions without needing additional fertiliser application or use of pesticides. Evidence suggests that most grass swards are colonised within a few years by species adapted to local conditions irrespective of the initial seed mix. Specialist suppliers will provide seed mixes suitable for a wide range of conditions, eg for clay soils, loamy soils, wetland areas, pond edges etc.

A purpose-grown (cultivated) amenity grade turf is generally appropriate, placed over 100–150 mm topsoil. A typical specification would be as follows:

25 per cent perennial rye grass

25 per cent smooth stalked meadow grass

30 per cent slender creeping red fescue

10 per cent chewings fescue

10 per cent browntop bent (including 10% creeping bent *Agrostis stolonifera* if possible).

Where additional erosion protection is required in the early stages, a coir blanket (fully biodegradable) which is either pre-seeded or over-seeded using a specification similar to the above is readily available.

The correct times for seeding are early spring and during autumn depending on site conditions and the condition of the soil preparation.

20.4.4 Use of trees and shrubs

Trees and shrubs are important as they provide visual amenity and shade and offer two stormwater management functions:

1) **Flow control:** Trees hold water on their leaves and branches (interception) and allow it to evaporate, and they can detain flows and dissipate the energy of runoff. Trees and shrubs may also facilitate stormwater infiltration and groundwater recharge because of their more intrusive root systems.
2) **Pollution reduction/stormwater cooling:** Trees and shrubs can provide shade over large areas of impervious surfaces. The hard surface is thus protected from direct solar exposure, which reduces heat gain in the pavement. This, in turn, reduces the heat that is absorbed by stormwater as it flows over the surface.

If carefully chosen, trees and shrubs can be used on most sites. However, the issues listed in Box 20.2 should be taken into account when planting them close to SUDS systems.

Box 20.2 *Use of trees and shrubs for SUDS systems*

1. Trees or large shrubs should not be grown on or very close to water-impounding berms to ensure embankment integrity and allow unobstructed visibility of berm slopes for detecting potential structural problems, such as animal burrows, slumping, or fractures in the berm.
2. Trees and shrubs planted or allowed to grow within 5 m of water-impounding berms should not be taller than 6 m when mature. They should have a fibrous root system, which reduces the likelihood of being blown over, or the possibility of channelling or piping of water through the root system.
3. Trees and shrubs should not be planted within, or close to, pipe inlet or outlets, flow spreaders or man-made drainage structures to avoid root damage and/or clogging.
4. Willows or poplars should not be planted close to stormwater structures, pipes, low permeability liners or water impounding berms.
5. The landscaping should be designed to minimise root penetration of geotextile and linings within stormwater facilities.
6. The shade provided by trees with full canopies causes changes in the nature of the ground flora, particularly reduced vegetative cover.
7. Trees and shrubs around wet pond facilities can discourage their use by waterfowl and reduce the attendant nutrient enrichment problems these birds cause.

20.4.5 Planting for erosion control and bank stability

Where there is a risk of soil surfaces and young plants being washed away or damaged by runoff, care must be taken to ensure appropriate planting and protection. Planting techniques can also help minimise bank stability risks. Good practice guidance is presented in Box 20.3.

Box 20.3 *Planting for erosion control and bank stability*

1. Slopes at risk of erosion should be turfed (eg with a robust amenity turf with Ryegrass) or protected with coir netting or jute mesh. Grass should be maintained at 100 mm height maximum as this strengthens the planting.
2. Where possible, flows should be diverted temporarily from seeded areas until stabilised (typically allowing two cuts before inundation).
3. Stabilise aquatic and safety benches with emergent wetland plants and wet seed mixes.
4. For maintenance access roads, provide a planting surface that can withstand vehicular compaction. Grass mowing and silt management can often be restricted to September and October, and a reinforced grass sward is likely to be appropriate.

20.4.6 Barrier planting

Early SUDS schemes used "hostile" or thorny planting, or very high, dense plants such as the common reed (*Phragmites communis*) or reedmace (*Typha latifolia*) which can grow up to 2 m in height, to try to discourage or physically prevent access to open water features. However, the use of planting as a barrier is currently being reviewed, as it has been shown to have disadvantages which include:

1) This type of planting is unnatural and reduces the biodiversity in the SUDS.
2) Planting barriers can prevent visual access to open water features and may invite people to make an informal route to the water edge and potential hazard.
3) Planting barriers can prevent physical access and therefore obstruct help that might be needed from supervising adults and/or passers by.

An alternative approach is to accept full visual and physical access using lower edge vegetation which occurs in most lowland wetland systems, eg water flag iris (*Iris pseudacous*) which has a height of between 150 and 900 mm depending on season. This type of planting delineates the water (ie the hazard), and is generally more acceptable to local residents and the general public. Maintained access routes down to the water's edge with appropriate width of shallow waters is likely to be the most appropriate risk management strategy.

Figure 20.1 *Low level planting at pond edge*

20.4.7 Plants for ponds and wetlands

The planting requirements for these systems can be split into areas depending on their hydrologic regime, which will dictate the tolerance plants must have to differing degrees of inundation.

(a) Deep water (water depths >450 mm)

Plants in deep water should reduce re-suspension of fine sediment, promote oxygenation and maximise habitats. In general, this area should not be planted as deep water aquatics will colonise naturally if the pond quality is suitable. There is a particular problem with introducing aquatics due to contamination of plant sources in the UK, and any nurseries used must be accredited.

(b) Aquatic bench (water depths: 0–450 mm)

This area is particularly suitable for emergent plants, and is an important habitat for both aquatic and non-aquatic animals. In general, planting should be concentrated in water depths <150 mm. Planting densities of three plants per linear metre or five plants per m^2 are suitable.

The following plant suggestions are based on SEPA, 2000 Appendix 2 and assume base rich – neutral soil conditions.

Erect marginal plants:

Yellow iris (*Iris pseudacorus*).
Gipsywort (*Lyopus europaeus*).
Various species of rush (*Juncus*).
Marsh woundwort (*Stahys palustris*).
Purple loosestrife (*Lythrum salicaria*).
Great water-dock (*Rumex hydrolapathum*).

Low growing marginal plants:

Amphibious bistort (*Persicaria amphibia*).
Creeping bent (*Agrostis stolonifera*).
Marsh-marigold (*Caltha palustris*).
Water mint (*Mentha aquatica*).
Brooklime (*Veronica beccabunga*).
Floating sweet grasses (*Glyceria species*).
Watercress (*Nasturtium officinale*).
Water forget-me-not (*Myosotis scorpioides*).
Fool's watercress (*Apium nodiflorum*).

In housing areas, where it is important that residents find the wetlands attractive, the following plants can be used to maximise initial aesthetic value:

Yellow iris (*Iris pseudacorus*): this provides good foliage, flowers and seed pods and can be used as the dominant plant component in many planting schemes.
Flowering rush (*Butomus umbellatus*).
Lesser reed mace (*Typha angustifolia*).
Meadowsweet (*Filipendula vulgaris*).
Hemp agrimony (*Eupatorium cannabinum*).
Purple loosestrife (*Lythrum salicaria*).
Pendulous sedge (*Carex pendula*).

Plants that should be avoided at all costs are:

Aggressive growers:

Great pond-sedge (*Carex riparia*).
Reed sweet-grass (*Glyceria maxima*).
Bulrush (*Typha latifolia*).
Reed canary grass (*Phalaris arundinacea*).
Branched bur-reed (*Sparganium erectum*).

Alien plants:

Canadian pondweed (*Elodea Canadensis*).
Curly waterweed (*Lagarosiphon major*).
Water fern (*Azolla dilliculoides*).
Floating pennywort (*Hydrocotyle ranunculoides*), often supplied as
Nuttall's pondweed (*Elodea nuttallii*).
Parrot's feather (*Myriophyllum aquaticum*).
New Zealand swamp-stonecrop (*Crassula halmsii*).
Marsh Pennywort (*Hydrocotyle vulgaris*).

(c) **Detention storage zone (regularly inundated, but may be dry in summer months)**

For large basins, plants in this region need to be resistant to wave action/water level change and should help minimise bankside erosion – generally grass (either turfed or seeded), together with scattered shrubs and trees is appropriate.

20.5 PLANTING GUIDANCE

20.5.1 Site preparation

Planting sites should be adequately graded and tree locations and planting areas (for shrubs, vines, and ground covers) should be marked and approved before planting begins. Where possible, concentrated flows should be diverted away from the seeded area at least until the vegetation is established. Some SUDS components may have to be planted in two phases.

A 100–150 mm deep seedbed should be prepared, with the top 75–100 mm consisting of topsoil. The seedbed should be firm but not compact. The top three inches of soil should be loose, moist and free of large clods and stones. For most applications, all stones larger than 50 mm in diameter, roots, litter and any foreign matter should be raked and removed. Site preparation should follow guidance given in the NBS* specifications www.thenbs.com

20.5.2 Seeding

Seed should be applied as soon after seedbed preparation as possible, when the soil is loose and moist. If the seedbed has been idle long enough for the soil to become compact, the topsoil should be harrowed with a disk, or other equipment designed to condition the soil for seeding. Harrowing should be done horizontally across the face of the slope. Seed should be applied using calibrated spreaders, cyclone seeders, mechanical drills, or hydroseeders at specified rates. Seed can also be planted by hand and incorporated into the soil by raking, then lightly compacting to provide good seed-soil contact. All seeding should be undertaken in accordance with NBS specifications (www.thenbs.com). Rates of 25 gm per m^2 are usually appropriate and mulching should not be necessary.

* NBS are the official publishers of the Building Regulations Approved Documents.

20.5.3 Planting

Vegetation can also be established by setting out plants that have been grown to a specified size or age. The plants may be potted in biodegradable tubes or containers of various sizes, or root wrapped, or may be bare root stock. No peat should be present in the compost.

Planting is normally used:

- for shrubs and trees, as these normally take long time to germinate and grow to effective size;
- for all types of landscaping where immediate landscape aesthetics are a particular concern, including urban thoroughfares and interchanges, and residential streets
- for wetlands and wildlife habitat areas where it may be critical to plant the desired species initially, so that the site is not overrun by weeds or undesirable plant species that detract from the intended use of the site
- where rapid soil stabilisation and erosion control is required.

20.5.4 Plant establishment

Plants should be inspected frequently after installation to see if they are thriving, especially after storm events. Dead or damaged plants should be removed and replaced to restore the prescribed number of living plants per square metre. Continued or regular irrigation may be required if planting occurs during dry months or on sandy soils. After 12 months, all planting should be self-sustaining. New planting is usually subject to a 24 month defects liability period.

20.6 REFERENCES

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Construction 21

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Construction 21

The construction of SUDS may require different skills from those employed for traditional drainage infrastructure. This Chapter describes construction best practices that are applicable to all SUDS techniques. The construction requirements specific to each technique are discussed in detail in the individual chapters and the complementary *Site handbook for the construction of SUDS*, CIRIA publication C698..

21.1 CONSTRUCTION PRACTICE

The construction of SUDS usually requires the use of only fairly standard civil engineering construction and landscaping operations, such as excavation, filling, grading, topsoiling, seeding, planting and the like. These operations are specified in various standard construction documents, such as the Civil Engineering Specification for the Water Industry (CESWI). However, there are some specific considerations that are usually applicable to most of the techniques, and these require changes to conventional construction practices and procedures, as described in Box 21.1. Best management practices to address these factors are described in the following sections.

Box 21.1 *Construction considerations for SUDS*

1. **Programming**
Normally, drainage is one of the first facilities to be constructed on a site. For SUDS, although the form of the drainage will be constructed during the earthworks phase, the final construction should not take place until the end of the development programme, unless adequate provision is made to remove any silt that is deposited during construction operations, and refurbish any areas that have been subject to over-compaction. The construction of swales, basins and ponds at an early stage in the construction can assist in managing runoff and help settle out the high volumes of sediments created during construction. However, complete reinstatement of these components will be required once construction is finished. The contract is likely to stipulate establishment of landscaping vegetation, and sediment removal some time after site works have been completed and before the maintenance period begins.

2. **Pollution and sediment control**
Runoff from the construction site must not be allowed to enter SUDS drainage systems unless it has been allowed for in the design and specification. Construction runoff is heavily laden with silt which can clog infiltration systems, build up in storage systems and pollute receiving waters. No traffic should be allowed to run on permeable surface components if it is likely to introduce sediments onto the pavement surface from dusty or muddy areas, or result in over-compaction.

3. **Access and storage areas**
Traditional car parking and other paved areas are usually constructed (or partially constructed) during the initial stages of the development, and then used as access roads and storage areas. If pervious surfaces are proposed, pavement construction should be carried out at the end of the development programme, unless adequate protection is provided to preventing clogging or blinding once it has been constructed.

Box 21.1 *Construction considerations for SUDS (continued)*

4. **Skills**
The contractor and all relevant operatives should have an understanding of the mechanism and purpose of the SUDS components to ensure appropriate construction practice and protection is used.

5. **Infiltration system protection**
If SUDS components are to be lined, the use of hardcore for structural purposes below the level of the liner can be accepted. However the use of hardcore is not advised if infiltration is intended, due to the high proportion of fines generally present. Sensitive ground, such as chalk, may require the use of total exclusion zones for construction traffic to prevent compaction and other damage to the ground that will affect the infiltration performance. This may include protection from runoff during construction if the component is located at a low point on the site.

6. **Landscaping**
The importance of good landscaping is emphasised. As SUDS components are normally surface systems, attention to detail and aesthetics must be given a high priority. The seasonal and physical requirements of planting and establishing vegetation and prevention of soil erosion should be programmed appropriately. Appropriate operative skills with an understanding of all aspects of vegetation are required. In particular, the use of nutrients should be minimised and a particular soil mix will often be needed for the SUDS component. Adjacent ground levels to components must be such as to prevent any overland sediment washoff during high intensity rainfall events, or groundwater seepage during wet periods. There should also be an understanding of the site topography and the levels that need to be achieved to ensure the correct flow of water.

7. **Erosion control**
Before runoff is allowed to flow through SUDS facilities with surface-formed features, such as swales, they must be fully stabilised by planting or temporary erosion protection. This will prevent erosion of the sides and base, and the clogging of other parts of the system by the silt that is entrained.

8. **Handover inspection**
Provision should be made in the construction contract to review the performance of the SUDS when it is completed, and to allow for minor adjustments and refinements to be made to optimise the physical arrangements, based on observed performance.

9. **Specifications and bills of quantities**
Designers should highlight particular matters associated with the above points that are likely to impact the operation and performance of specific SUDS systems. The type of specification and/or bills of quantities will depend upon the form of construction contract being used for the specific project.

21.2 PROGRAMMING

Construction planning needs to take account of the programming and erosion, sediment and pollution control measures described in the following sections, together with the need for inspections by the designer.

Construction programming considerations are summarised in Table 21.1 and discussed in detail in the subsequent text. The generalised construction activities shown in the table do not usually occur in a specified linear sequence, and programmes will vary due to weather and other unpredictable factors.

Table 21.1 *Considerations for construction programming*

Construction activity	Programme consideration
Identify and sign protection areas (*eg* buffer zones, filter strips, trees).	Site delineation should be completed before any construction activity begins.
Construction access, construction entrance, construction routes, equipment parking areas and cutting of vegetation (with any necessary boundary controls).	The first land-disturbing activity. Establish protected areas. Stabilise bare areas and provide temporary protection as construction takes place.
Sediment traps and barriers. Basin traps, sediment fences, and outlet protection (with any necessary boundary controls).	Install principal basins after construction site is accessed. Install additional traps and barriers as needed during grading.
Runoff control. Diversions, silt fence, perimeter ditches and outlet protection.	Install key measures after principal sediment traps have been installed and before grading commences. Install any additional runoff control measures during grading.
Runoff conveyance system. Stabilise stream banks, storm drains, channels, inlet and outlet protection, and slope drains.	Where necessary, stabilise stream banks as early as possible. Install principal runoff conveyance system with runoff control measures. Install remainder of system after grading.
Clearing and grading. Site preparation: cutting, filling and grading, sediment traps, barriers, diversions, drains, surface treatment.	Begin major clearing and grading after principal sediment and key runoff control measures are installed. Clear borrow and disposal areas only as needed. Install additional control measures as grading progresses.
Surface stabilisation: temporary and permanent seeding, mulching, topsoiling and installing rip-rap.	Apply temporary or permanent stabilisation measures immediately on all disturbed areas where work is either delayed or complete.
Building construction: buildings, utilities, paving.	Install necessary erosion and sedimentation control practices as work takes place.
Landscaping and final stabilisation: topsoiling, planting trees and shrubs, permanent seeding, mulching, installing rip-rap.	The last construction phase. Stabilise all open areas, including borrow and spoil areas. Remove and stabilise all temporary control measures.
Commissioning and pre-handover maintenance.	Maintenance inspections should be performed weekly, and maintenance repairs should be made immediately after periods of rainfall.

Construction access is normally the first land-disturbing activity. Care should be exercised not to damage valuable trees or disturb designated buffer zones. Trees should be protected around the drip line of the branches. Activities that could compact the root zone should be avoided.

Sediment basins and traps should be installed before any major site grading takes place. Additional sediment traps and silt fences should be installed as grading takes place to keep sediment contained on site at appropriate locations.

Key runoff-control measures should be located in conjunction with sediment traps to divert water from planned undisturbed areas away from the traps and sediment-laden water into the traps. Diversions should be installed above areas to be disturbed before any grading operations. Any perimeter drains should be installed with stable outlets before opening major areas for development. Any additional facilities needed for runoff control should be installed as grading takes place.

The main runoff-conveyance system with inlet and outlet protection measures should be installed early, and used to convey stormwater runoff through the development site without creating gullies or channels. Install inlet protection for storm drains as soon as the drain is functional to trap sediment on site in shallow pools and to allow flood flows to enter the storm drainage system safely. Install outlet protection at the same time as the conveyance system to prevent damage to the receiving stream.

Normally, stream stabilisation, including necessary stream crossings, should be installed independently and ahead of other construction activities. It is usually best to programme this work as soon as weather conditions permit. Site clearing and project construction increases storm runoff, often making stream-bank stabilisation work more difficult and costly.

Clearing and grading should be started as soon as key erosion and sediment control measures are in place. Once a development area is cleared, grading should follow immediately so that protective ground cover can be re-established quickly. Areas should not be left bare and exposed for extended periods. Adjoining areas planned for development or those that are to be used for borrow and disposal should be left undisturbed as long as possible to serve as natural buffer zones.

Runoff control is essential during the grading operation. Temporary diversions, slope drains, and inlet and outlet protection installed in a timely manner can be very effective in controlling erosion during this critical period of development.

After the land is cleared and graded, surface stabilisation measures should be applied to graded areas, channels, ditches and other disturbed areas. Any disturbed area where active construction will not take place for 60 working days should be stabilised by temporary seeding and/or mulching or by other suitable means. Permanent stabilisation measures should be installed as soon as possible after final grading. Temporary seeding and/or mulching may be necessary during extreme weather conditions with permanent vegetation measures delayed until a more suitable installation time.

Building construction should be coordinated with other development activities so that all work can take place in an orderly manner and on programme. Experience shows that careful project programming improves efficiency, reduces cost and lowers the potential for erosion and sedimentation problems.

Landscaping and final stabilisation is the last major construction phase, but topsoil stockpiling, tree preservation, undisturbed buffer areas, and well-planned road locations established earlier in the project may determine the ease or difficulty of this activity. All disturbed areas should have permanent stabilisation measures applied. Unstable sediment should be removed from sediment basins and traps and if possible incorporated into the topsoil, not just spread on the surface. All temporary structures should be removed after the area above has been properly stabilised. Borrow and disposal areas should be permanently vegetated or otherwise stabilised.

In planning construction work, it may be helpful to outline all land-disturbing activities necessary to complete the proposed project, and then list all practices needed to control erosion and sedimentation on the site. Features requiring particular attention during planning are: site access, storage of materials, interim site drainage during the construction phase and protection of surfaces. These two lists can then be combined in a logical order to provide a practical and effective construction programme. There are likely to be advantages in phasing construction of SUDS components with any land drainage facilities because of the opportunities for cross-linking and enhancing and integrating these facilities – subject to the use of appropriate measures to manage and control erosion and sedimentation during construction activities.

Figure 21.1 *A pond under construction*

21.3 EROSION CONTROL

21.3.1 Factors influencing erosion during construction

Soil erosion is the process by which the land surface is worn away by the action of wind, water, ice, and gravity. The natural rate of erosion is increased greatly by many urban activities – especially construction activities. Any activity that disturbs the natural soil and vegetation has the potential to increase erosion because bare, loose soil is easily moved by wind or water.

Factors affecting the erosion potential of any site include soil type, geology, vegetative cover, topography, climate, and land use. Physical properties of soils such as particle size, cohesiveness, and density affect its erodibility. Loose silt and sand-sized particles are more susceptible to erosion than clay soils. Rocky soils are less susceptible to wind erosion, but are often found on steeper slopes that are subject to water erosion. When surface cover and soil structure are disturbed, the soil's erodibility potential increases. Construction activities disrupt the soil structure and its vegetative cover.

Vegetation plays an important role in controlling erosion. Roots bind soil particles together, and the leaves or blades of grass reduce raindrop impact forces on the soil. Grass litter and other ground cover traps rain which allows infiltration and reduces runoff velocity.

Vegetation reduces wind velocities at the ground surface, and provides a rougher surface which will trap particles moving along the ground. Once vegetation is removed, erosion can proceed unchecked.

The factors that influence land erosion are

- run-off velocity
- run-off volume
- soil type
- vegetation cover
- machinery and plant
- dewatering outlets.

Land erosion is caused by the run-off being of sufficient velocity to strip fine silts and soils. Table 21.2 shows how the different type of soils and the vegetation coverage affects the velocity needed to cause erosion.

Table 21.2 *Maximum allowable velocities based on soil type*

Soil type	Maximum allowable velocity m/s	
	Seeded	Turfed
Sand.	0.6	0.9
Silt loam, sandy loam, loamy sand.	0.6	0.9
Silty clay loam, sandy clay loam.	0.75	1.2
Clay, clay loam, sandy clay, silty clay.	0.9	1.5

21.3.2 Erosion control procedures

The objective of erosion control is to limit the amount and rate of erosion occurring on disturbed areas. Erosion of SUDS techniques will reduce their effectiveness, and add to the silt load that any other technique downstream will have to deal with. Design requirements to help prevent erosion, such as limiting water velocities, are discussed in the appropriate chapters for each technique.

Erosion controls are surface treatments that stabilise soil exposed by excavation or grading.

The objectives for erosion control during construction include the following:

1. Conduct all land-disturbing activities in a manner that effectively reduces accelerated soil erosion and reduces sediment movement and deposition off site.
2. Schedule construction activities to minimise the total amount of soil exposed at any given time to reduce the period of accelerated soil erosion.
3. Establish temporary or permanent cover on areas that have been disturbed as soon as possible after final grading is completed.
4. Design and construct all temporary or permanent facilities for the conveyance of water around, through, or from the disturbed area to limit the flow of water to non-erosive velocities.
5. Remove sediment caused by accelerated soil erosion from surface runoff water before it leaves the site.
6. Stabilise the areas of land disturbance with permanent vegetative cover.

Permanent or temporary soil surface stabilisation should be considered for application to disturbed areas and soil stockpiles as soon as possible after final grade is reached on any portion of the site. Soil surface stabilisation should also be considered for disturbed areas that may not be at final grade but will remain undisturbed for more than 60 days.

A viable vegetative cover should be established within one year on all disturbed areas and soil stockpiles not otherwise permanently stabilised. Vegetation is not considered established until a ground cover is achieved which is sufficiently mature to control soil erosion and can survive moderate runoff events.

Roads and other hard standings should be covered as early as possible with the appropriate aggregate base course where this is specified as part of the pavement.

Soil stockpiles expected to be in place longer than 60 days should be seeded with a temporary grass cover after completion of stockpile construction. If stockpiles are located within 30 metres of a watercourse, additional sediment controls, such as a diversion ditch or silt fence, should be provided.

Properties and roadways adjacent to a construction site should be protected from eroded sediment being transported on to them. Whenever construction vehicles enter onto paved roads, provisions should be made to prevent the transport of sediment (mud and dirt) by those vehicles. Whenever sediment is transported onto a public road, regardless of the size of the site, the roads should be cleaned at least daily.

Temporary diversion ditches should be considered above disturbed areas and may be discharged to a permanent or temporary channel. Diversion ditches located mid-slope on a disturbed area or at the base of a disturbed area should discharge to a sediment trap or basin.

21.3.3 Erosion protection techniques

A number of erosion protection techniques can be used, such as:

1. ***Vegetation,*** which reinforces the soil due to the binding effects of the root structure. It helps protect areas downstream by the friction effect of the vegetation decreasing the runoff velocity.
2. ***Geotextiles and erosion control fabrics,*** which reinforce the soil structure reducing the potential for particle stripping.
3. ***Reinforced grass,*** which consists of plastic moulds which are placed in the soil and allow grass to grow though them. Reinforced grass has the benefit of offering early erosion protection as well as protecting the grass areas from traffic loading.
4. ***Gravel trenches,*** which can be located upstream of exposed land. They intercept runoff flow that then enters a perforated pipe system to an outfall or infiltrates into the ground. However, because they are usually sacrificial in nature, these systems can be relatively expensive to install for short duration periods. If such a system is being installed as part of the final SUDS solution for a site then it should not be used for construction run-off, because heavy sediment loads during construction will reduce its design life.
5. ***Flat sites*** or slack gradients within a site, which will help reduce the velocity of the runoff.
6. ***Impermeable area run-off*** should not be allowed to flow directly over areas of exposed ground. Run-off from these areas should enter a sewer system, flow over a grass/vegetation area, be diverted around, and intercepted by a gravel trench or close-ended ditch.

Further guidance is provided in CIRIA publications R116 (CIRIA, 1996a) and B10 (CIRIA, 1990).

Figure 21.2 *Construction of a swale*

21.4 SEDIMENTATION

21.4.1 Principles of sediment control

During a rainfall event, runoff normally builds up rapidly to a peak and then diminishes. Because the amount of sediment a watercourse can carry is dependent upon the velocity and volume of runoff, sediment is deposited as runoff decreases. The deposited sediments may be re-suspended with subsequent runoff. In this way, sediments are moved progressively downstream.

Wind-blown silt and sand particles are deposited whenever the force of the wind lessens. Much of the wind-eroded material is deposited behind fences, in landscaped areas or downwind of buildings or other obstructions to the wind. Materials transported by bouncing or creeping along the surface are often trapped in surface irregularities near the point of initial movement.

21.4.2 Sediment control procedures

Sediment entrapment facilities are necessary to reduce sediment discharges to downstream properties and receiving waters.

Sediment entrapment facilities include straw bale barriers, geotextile silt fences and sediment basins. The type of sediment entrapment facility to be used depends on the catchment area and site slope. Table 21.3 summarises the recommended maximum catchment areas, slope lengths and slopes for straw bale barriers and geotextile silt fences.

All runoff leaving a disturbed area should pass through a sediment entrapment facility before it exits the site and flows downstream.

Table 21.3 *Sediment entrapment facility limitations*

	Allowable maximum limits		
Sediment control facility	Drainage catchment area (hectares)	Drainage catchment slope length (m)	Drainage catchment slope gradient
Straw bale barrier or silt fence	0.6–1.2 per 100 linear metres	50	1:2 (50%)

Straw bale barriers or silt fences may be used for small sites. When the catchment area is greater than that allowed for straw bale barriers or silt fences, runoff should be collected in diversion ditches and routed through temporary sediment basins.

Straw bales can be placed at the base of a slope to act as a sediment barrier. These are not recommended for use within a swale or channel. Straw bales are temporary in nature and may perform for only a period of weeks or months. Proper installation and maintenance is necessary to ensure their performance.

A silt fence is made of a woven synthetic material, geotextile, and acts to filter runoff. Silt fencing can be placed as a temporary barrier along the contour at the base of a disturbed area, but is not recommended for use in a channel or swale. The material is durable and will last for more than one season if properly installed and maintained. Silt fencing is not intended to be used as a perimeter fence or in areas of concentrated flow. If concentrated flow conditions exist, a more robust filter should be considered.

Silt barriers can also be temporarily installed in any road gullies of partially constructed roads to prevent sediment movement into downstream drainage systems or SUDS components.

Figure 21.3 *A wetland under construction*

21.5 POLLUTION CONTROL

21.5.1 Pollution prevention

The guidance provided in Sections 21.2 and 21.3 should help prevent damage to SUDS techniques during construction. Detailed guidance on prevention of pollution during construction is provided in CIRIA publication C532 (CIRIA, 2002) and also in the pollution prevention guidelines produced by the Environment Agency and SEPA.

The main requirements are to control surface water runoff and pumped water from sites, for example by the use of settling tanks, to ensure that it does not pollute controlled waters. The safe storage of materials and fuels is also important so that if spills occur they are contained (by the use of berms, check ditches or other techniques) and do not cause a pollution incident.

Before mobilisation, the site layout should be planned to consider fully issues such as the location of stockpiles, fuel stores, storage areas, waste disposal, refuelling points, wash down areas, etc. These should be located in areas where they are least likely to affect controlled waters or infiltrate groundwater. Planning should also address subjects such as the diversion of watercourses, prevention of upstream runoff entering the site and the design of haul roads, including the use of road bridges over watercourses to stop vehicles fording streams and rivers.

An environmental plan should also be put in place. The plan should include: the environmental risk assessment with control measures, location of foul drainage disposal routes, location of surface water systems that discharge into watercourses, requirements for discharge and abstraction licences, location of spillage kits and an action plan in the event of an environmental incident (including a list of relevant telephone contact numbers).

21.6 POLLUTION SOURCES AND PREVENTION

21.6.1 Suspended solids

As described in Section 21.2 above, suspended solids are one of the major sources of construction site pollution. The following list indicates a number of sources and the measure that can be taken to help prevent pollution:

1. ***Excavated ground and exposed ground***. The effect of having no vegetation and being recently disturbed allows for relatively low velocity run-off to erode the surface. To help prevent the pollution from entering a watercourse, silt fences, hay bales or stilling ponds should be placed downstream. To limit the volume of run-off reaching the exposed ground, runoff diversion or interception devices should be placed upstream.
2. ***Stockpiles.*** The effects of erosion on a stockpile will depend on the type of material being stored. Fine sand and topsoil stockpiles will be eroded far more readily than heavy granular materials. Stockpiles should be located away from a watercourse or site drainage system. Protective coverings will help prevent runoff stripping the stockpile.
3. ***Plant and wheel washing.*** Plant and wheel washing should take place in designated locations. The area should be tanked and should not be allowed to discharge into a watercourse or infiltrate groundwater, as the wastewater from these devices is highly contaminated with silts, sands, and hydrocarbons. Some proprietary vehicle washing systems offer a recycling facility, which filter and settle solids, with the effluent being pumped back into the system. The solid waste materials from this process need to be treated as contaminated waste due to the high hydrocarbon content.
4. ***Haul roads.*** The runoff from haul roads contains a large amount of suspended solids as well as hydrocarbons. Haul roads should be designed so that the length is kept to a minimum, but still serves it purpose. The gradient should be shallow to prevent increasing runoff velocity and, if possible, bunds and/or discrete ditches constructed to intercept the runoff. Haul roads should be sprayed regularly to keep down dust. If any section of a haul road is hard surfaced, then it should be swept on a regular basis to prevent the accumulation of dust and mud.

5 ***Disturbance of riverbeds or banks.*** Excavation of riverbanks or beds can generate silty water, as the excavated and exposed material is washed downstream. The amount of such excavation needs to be limited and, if undertaken, the water area downstream needs to be protected by booms. For larger projects, consideration should be given to diverting the river during excavations.

6 ***Dewatering operations.*** Groundwater discharge as a result of excavation activity is likely to be heavily polluted with suspended solids, and should not be discharged directly into a watercourse. To help reduce the amount of suspended solids within the runoff a number of techniques can be adopted:

- passing the discharge water over a grass area, the discharge velocity has to be monitored and kept sufficiently low to promote settlement
- passing the discharge water though a temporary gravel strip
- controlled use of skips and/or tanks to act as stilling basins
- controlled use of stilling ponds.

21.6.2 Oils and hydrocarbons

The use of oils and hydrocarbons on construction sites provide an inherent risk of leakages and spillages leading to pollution incidents. Table 21.4 details the potential sources of oil pollution.

Table 21.4 *Sources of oil pollution*

Sources	Potential problem initiators
Storage tanks	Leaking valves. Leaking pipe work. Corrosion. Frost damage. Vandalism. Leaking bund. Removal of waste.
General operation and maintenance	Refuelling. Leaking pumps, browsers, generators, plants, machinery. Disposal of waste oil.
Accidents/incidents	Spillages (greatest risk at refuelling). Over-turning (drums and buckets). Mechanical failure eg rupture of pipes. Inadequate bunded area. Vandalism.

Simple measures can be taken to prevent oil and hydrocarbons becoming pollutants, such as:

- maintenance of machinery and plant
- drip trays
- regular checking of machinery and plant for oil leaks
- correct storage facilities
- check for signs of wear and tear on tanks
- care with specific procedures when refuelling
- designated areas for refuelling
- emergence spill kit located need refuelling area.
- regular emptying of bunds
- tanks located in secure areas to stop vandalism
- booms installed on watercourses.

Figure 21.4 *Permeable pavement: during and post construction*

21.7 Construction planning

Construction planning needs to take account of the programming and erosion, sediment and pollution control measures described in the previous sections, together with the need for inspections.

As noted in Section 21.2 above, the features requiring particular attention during construction planning are: site access, storage of materials, interim site drainage during the construction phase and protection of surfaces (from erosion, sedimentation or over-compaction).

21.7.1 Site assessment

The following guidelines are recommended in developing the erosion and sediment control elements during the planning phase:

1. ***Determine the limits of clearing and grading.*** If the entire site will not undergo excavation and grading, the boundaries of cut and fill operations should be defined. Retaining buffer strips of natural vegetation should be considered.
2. ***Define the layout of buildings and roads.*** This will have been decided previously as a part of the general development plan.
3. ***Determine permanent drainage features.*** The location of permanent channels, surface water sewers, roadside swales and quality controls such as ponds, wetlands, grassed-lined swales, buffer strips, and areas of porous pavement, if known, should be defined.
4. ***Determine the extent of any temporary channel diversions.*** If permanent channel improvements are a part of the plan, the route, sizing, and lining needed for temporary channel diversions should be determined. Location and type of temporary channel crossings can be assessed.
5. ***Determine the boundaries of drainage catchments.*** The size will determine the types of sediment controls to be used. Areas located off the site that contribute to overland flow runoff should be assessed. Measures to limit the size of upland overland flow areas, such as diversion ditches, will need to be considered.
6. ***Select sediment controls.*** Division of large drainage catchments into sub-areas each served by a sediment basin can also be considered.
7. ***Determine the staging of construction.*** The construction programme will determine what areas should be disturbed at various stages throughout the development plan. The opportunity for staging cut-and-fill operations to minimise the period of exposure of soils can be assessed. The sequence for installing sediment controls and erosion controls should also be determined.

8 ***Identify locations of topsoil stockpiles.*** Areas for storing topsoil should be determined.

9 ***Identify location of temporary construction roads, vehicle tracking controls, and material storage areas.***

10 ***Select erosion controls.*** All areas of exposed soil will require a control measure be defined dependent on the duration of exposure. These can be selected based on the construction programme.

21.7.2 Inspections

Inspection of the construction of a SUDS scheme should be carried out to ensure that the system is being constructed correctly, and that design assumptions and criteria are not invalidated – for example, by the construction methods used, by changes made on site or by variations in ground conditions. The form of the inspection will depend upon the type of construction contract used, however either self-certification by the contractor or supervisory inspection by the designer is a typical approach.

These inspections should be undertaken as necessary, but as a minimum would generally be expected to include the following:

1. Pre-excavation inspection to ensure that construction runoff is being adequately dealt with on site and will not cause clogging of the SUDS system(s).
2. Inspections of excavations for ponds, infiltration devices, swales, etc.
3. Inspections during laying of any pipework.
4. Inspections and testing during the placing of earthworks materials or filter materials.
5. Inspection of the prepared SUDS technique before planting begins.
6. Inspection of completed planting.
7. Final inspection before handover to client.

The contractor installing the SUDS scheme should be made fully aware of the requirement for inspections, to avoid work being undertaken that cannot be validated.

21.8 CONTRACTOR'S METHOD STATEMENTS

The implementation of a comprehensive QA regime is fundamental to the achievement of a minimum standard of workmanship. It is generally accepted that a high proportion of the perceived failures of SUDS techniques are as a direct result of either poor quality workmanship at the installation stage or damage during construction.

Guidance on construction standards for each individual technique is provided in the appropriate chapters.

Correct construction of SUDS is of equal importance to design if the systems are to be implemented successfully, and the key to this is conveying information to site staff (management and operatives). They should be made aware of how the SUDS scheme operates, the design requirements and how their actions on site can affect the final performance of the scheme. It is important to talk to people on site, especially operatives, and to ensure that all sub-contractors and their staff are also involved in this process.

Site staff and operatives should also be taught how to install critical items, if necessary, for example where geotextiles and geomembranes are to be placed in the construction. In one case, an impermeable geomembrane was placed in a pervious surface in place of the geotextile – with obvious consequences. This can be viewed as an extreme example, but clogging, blinding or over-compaction of permeable surfaces due to unconsidered construction activities are likely to be more common.

The preparation and dissemination of appropriately detailed method statements emphasising the differences from traditional construction activities is seen as an important communication channel, to be used in conjunction with tool-box talks, and direct briefings to operatives. To assist in these processes CIRIA has produced the *Site handbook for the construction of SUDS* (C698) to accompany this manual, and which can be purchased separately (visit www.ciriabooks.com).

Figure 21.5 *A swale under construction*

21.9 POST CONSTRUCTION REHABILITATION AND HAND-OVER

When construction is complete, there is likely to be a commissioning period in which the permanent SUDS facilities are made "live", this is likely to include diversion of drainage flows into the new facilities. If permanent facilities have been used wholly (or in part) to drain the site or as other forms of temporary works such as roads or storage areas, then rehabilitation works may be required to reconstitute or restore them to their design condition. Once the permanent facilities have been demonstrated to work as envisaged, then temporary drainage and sediment and erosion control measures can be carefully dismantled so that sediment loading on downstream systems is not generated.

After construction, a validation report should be prepared that discusses the inspections described in Section 21.7 above, the reasons for any variations made to the design, any non-compliances that have been identified and how they were rectified.

During the first year of operation there may be a need for ongoing monitoring to identify any modifications that may be required to optimise performance. The scope of the monitoring will be site-specific and depends on the sensitivity of the design and the consequences if the SUDS does not perform as designed.

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22 Operation and maintenance

Contents

Operation and maintenance 22

22.1 INTRODUCTION

Unlike conventional drainage systems, SUDS features should be visible and their function should be easily understood by those responsible for maintenance. When problems occur, they are generally obvious and can be remedied simply, using standard landscaping practice. If systems are properly monitored and maintained, any deterioration in performance can often be managed out.

Like any drainage system maintenance is a necessary and important consideration of SUDS design and sufficient thought should be given to long-term maintenance and its funding during feasibility and planning stages. In particular, the following requirements should be given full consideration:

1 **Maintenance access** – ensuring appropriate and long-term access to all points in the system where future maintenance may be required.
2 **Forebays** and/or appropriate pre-treatment structures to facilitate the sediment management process.
3 **Bypass systems** or appropriate temporary drainage infrastructure for use if required during sediment management or other maintenance activities.
4 **The availability** of disposal areas for organic arisings (green waste) and sediments.

Appropriate legal agreements between SUDS stakeholders that define maintenance responsibilities are presented in the SUDS Interim Code of Practice (NSWG, 2004) and *Model agreements for SUDS* (CIRIA, 2004). This chapter discusses the principles of good practice operation and maintenance activities and the types of documents that can be developed to define the requirements at a particular site. Specific maintenance requirements for each SUDS component are listed in detail towards the end of each of the component chapters.

22.2 OWNER'S MANUAL

SUDS are different from conventional drainage and require different maintenance régimes. Owners of developments with SUDS should be provided with an owner's manual.

This should include the following:

- location of all SUDS techniques in a site
- brief summary of how the techniques work, their purpose and how they can be damaged
- maintenance requirements (a maintenance plan) and a maintenance record
- explanation of the consequences of not carrying out the maintenance that is specified
- identification of areas where certain activities are prohibited (for example stockpiling materials on pervious surfaces)

- an action plan for dealing with accidental spillages
- advice on what to do if alterations are to be made to a development, if service companies undertake excavations or other similar works carried out that could affect the SUDS.

The owner's manual should also include brief details of the design concepts and criteria for the SUDS scheme and how the owner or operator must ensure that any works undertaken on a development do not compromise this. For example, householders should be made aware that surface water drainage is connected to soakaways.

22.3 LEVEL OF OPERATION AND MAINTENANCE

There are many factors which will influence the type and intensity of maintenance required for SUDS at any particular site, including:

- type of SUDS scheme
- land-use associated with contributing catchment
- level of construction ongoing within the contributing catchment
- planting types
- habitat types that have been created
- amenity requirements of the area.

The demands on the SUDS scheme to perform a particular aesthetic function will be a key driver, with high frequencies of grass cutting and vegetation management often being required for appearance and amenity value rather than for functional reasons.

It is recommended that SUDS are not handed over to maintenance authorities until upstream construction has ceased, the contributing catchment has stabilised, and any rehabilitation of downstream components has been undertaken by the developer/contractor. However, if maintenance agreements have to be put in place before this, and the level of construction activity in the contributing catchment is high, maintenance specifications should be prepared that take account of high sediment accumulation rates and the increased risks of potential spillages.

22.4 OPERATION AND MAINTENANCE ACTIVITY CATEGORIES

There are likely to be three categories of maintenance activities:

1. **Regular maintenance** (including inspections and monitoring).
2. **Occasional maintenance.**
3. **Remedial maintenance.**

Regular maintenance consists of basic tasks done on a frequent and predictable schedule, including vegetation management, litter and debris removal, and inspections.

Occasional maintenance comprises tasks that are likely to be required periodically, but on a much less frequent and predictable basis than the routine tasks (sediment removal is an example). Table 22.1 summarises the likely maintenance activities required for each SUDS component and guidance on specific maintenance activities is given in the following sections.

Remedial maintenance comprises intermittent tasks that may be required to rectify faults associated with the system, although the likelihood of faults can be minimised by good design. Where remedial work is found to be necessary, it is likely to be due to site-specific characteristics or unforeseen events, and as such timings are difficult to predict. Remedial maintenance items can comprise items such as:

- inlet/outlet repairs
- erosion repairs
- reinstatement or realignment of edgings, barriers, rip-rap or other erosion control
- infiltration surface rehabilitation
- replacement of blocked filter fabrics
- construction stage sediment removal (although this activity should have been undertaken before the maintenance contract)
- system rehabilitation immediately following a pollution event.

Table 22.1 *Typical key SUDS components operation and maintenance activities*
For full specifications, see individual chapters.

O&M activity	SUDS component												
	Pond	Wetland	Detention basin	Infiltration basin	Soakaway	Infiltration trench	Filter trench	Modular storage	Pervious pavement	Swale/bioretention/green roofs	Filter strip	Sand filter	Pre-treatment systems
Regular maintenance													
Inspection	■	■	■	■	■	■	■	■	■	■	■	■	■
Litter/debris removal	■	■	■	■	□	■	■	□	■	■	■	■	■
Grass cutting	■	■	■	■	□	■	■	□	□	■	■	□	□
Weed/invasive plant control	□	□	□	□		□	□		□	□	□	□	□
Shrub management	□	□	□	□					□	□	□		□
Shoreline vegetation management	■	■	□										□
Aquatic vegetation management	■	■	□										□
Occasional maintenance													
Sediment management (*)	■	■	■	■	■	■	■	■	■	■	■	■	■
Vegetation/plant replacement	□	□	□	□						□	□		□
Vacuum sweeping and brushing									■				
Remedial maintenance													
Structure rehabilitation/repair	□	□	□	□	□	□	□	□	□	□	□	□	□
Infiltration surface reconditioning				□	□	□	□		□	□	□	□	

■ Will be required
□ May be required

* Sediment should be collected and managed in pre-treatment systems, upstream of the main device.

The maintenance regime of a site also needs to consider the response to extreme pollution events. A response action plan should be developed and communicated to all those involved in the operation of a site, so that if a spillage occurs it can be prevented from causing pollution to receiving waters.

22.5 HEALTH AND SAFETY

To comply with the Construction (Design and Management) Regulations (DETR, 1994) (see Section 2.5.10), designers must assess all foreseeable risks during construction and maintenance and the design must minimise them by the following (in order of preference):

1. **Avoid.**
2. **Reduce.**
3. **Identify and mitigate residual risks.**

Designers must also make contractors and others aware of risks in the Health and Safety file, which is a record of the key health and safety risks that will need to be managed during future maintenance work. For example, the file for a SUDS pond should contain information on the collection of hazardous compounds in the sediment so that maintenance contractors are aware of them and can take appropriate precautions. During construction the residual risks must be identified and an action plan developed to deal with them safely (the Health and Safety Plan).

All those responsible for maintenance should take appropriate health and safety precautions for all activities (including lone working, if relevant) and risk assessments should always be undertaken. Guidance on generic health and safety principles is given in Section 3.4.2 and component-specific issues are addressed in individual chapters. Relevant health and safety legislation (see Section 2.5.10) should be followed at all times.

22.6 REGULAR MAINTENANCE ACTIVITIES

22.6.1 Inspections and reporting

Regular SUDS scheme inspections will:

- help determine optimum future maintenance activities
- confirm hydraulic, water quality, amenity and ecological performance
- allow identification of potential system failures, eg blockage, poor infiltration, poor water quality etc.

Inspections can generally be required at monthly site visits (eg for grass cutting) for little additional cost, and should, therefore, be subsumed into regular maintenance requirements. During the first year of operation, inspections should ideally be carried out after every significant storm event to ensure proper functioning, but in practice this may be difficult or impractical to arrange.

Typical routine inspection questions that will indicate when occasional or remedial maintenance activities are required, and/or when water quality requires investigation include:

- are inlets or outlets blocked?
- does any part of the system appear to be leaking (especially ponds and wetlands)?
- is the vegetation healthy?
- is there evidence of poor water quality (eg algae, oils, milky froth, odour, unusual colourings)?
- is there evidence of sediment build-up?
- is there evidence of ponding above an infiltration surface?
- is there any evidence of structural damage that requires repair?
- are there areas of erosion or channelling over vegetated surfaces?

Inspections of the construction of a SUDS scheme by the design consultant pre-handover is vital to ensure that the system has been constructed correctly and that design assumptions and criteria are not invalidated, for example, by construction methods, by changes made on site or by variations in ground conditions. Inspections should be undertaken through the construction as necessary but as a minimum would generally be expected to include the following:

1. Pre-excavation inspection to ensure that construction runoff is being adequately dealt with on site and will not cause clogging of the SUDS scheme.
2. Inspections of excavations for ponds, infiltration devices, swales, etc.
3. Inspections during laying of any pipework.
4. Inspections and testing during the placing of earthworks materials or filter materials.
5. Inspection of prepared SUDS technique before planting begins.
6. Inspection of completed planting.
7. Final inspection before handover to client.

When construction is completed the consultant should provide a validation report that discusses the inspections, the reasons for any variations made to the design, any identified non-compliances and how they were rectified. During the first year of operation there may be a need for monitoring to identify any modifications required to optimise performance. The scope of the monitoring will be site-specific and depends on the sensitivity of the design and the consequences of the SUDS not performing as expected.

For large sites, it is recommended that an annual maintenance report and record should be prepared by the maintenance contractor which should be retained with the owner's manual (see Section 22.2). The report should provide the following information:

- observations resulting from inspections
- measured sediment depths (where appropriate)
- monitoring results, if flow or water quality monitoring was undertaken
- maintenance and operation activities undertaken during the year
- recommendations for inspection and maintenance programme for the following year.

22.6.2 Litter/debris removal

This is an integral part of SUDS maintenance and reduces the risks of inlet and outlet blockages, retains amenity value and minimises pollution risks. High litter removal frequencies may be required at high profile commercial/retail parks where aesthetics are a major driver.

22.6.3 Grass cutting

It is recommended that grass cutting be minimised around SUDS facilities, apart from swales and filter strips and structural embankments where a height of 100–150 mm is recommended to prevent the plants falling over, or "lodging", when water flows across the surface. In general, allowing grass to grow tends to enhance water quality performance. Short grass around a wet system such as pond or wetland provides an ideal habitat for nuisance species such as geese; allowing the grass to grow is an effective means of discouraging them. Grass around wet pond or wetland systems should not be cut to the edge of the permanent water.

Grass cutting is an activity undertaken primarily to enhance the perceived aesthetics of the facility. The frequency of cutting will tend to depend on surrounding land uses, and public requirements. Therefore, grass cutting should be done as infrequently as possible, recognising the aesthetic concerns of local residents. However, grass around inlet and outlet infrastructure should be strimmed closely to reduce risks to system performance. If a manicured, parkland effect is required, then cutting will need to be undertaken more regularly than for meadow type grass areas, which aim to maximise habitat and biodiversity potential.

22.6.4 Weed/invasive plant control

Weeds are generally defined as vegetation types that are unwanted in a particular area. For SUDS, weeds are often alien or invasive species, which do not enhance the technical performance or aesthetic value of the system, or non-native species and the spread of which is undesirable.

In some places, weeding has to be done by hand to prevent the destruction of surrounding vegetation (hand weeding should generally be required only during the first year, ie during plant establishment). However, over grassed surfaces, mowing can be an effective management measure. The use of herbicides and pesticides should be prohibited since they cause water quality deterioration. The use of fertilisers should also be limited or prohibited to minimise nutrient loadings which are damaging to water bodies.

22.6.5 Shrub management

Shrubs tend to be densely planted and are likely to require weeding at the base, especially during the first year to ensure that they get enough water. Shrubs should be selected so they can grow to their maximum natural height without pruning.

22.6.6 Aquatic/shoreline vegetation management

Aquatic plant aftercare in the first 1–3 years may be required to ensure establishment of planted vegetation and control nuisance weeds/invasive plants. Once established, the build-up of dead vegetation from previous seasons should be removed at convenient intervals to reduce organic silt accumulation (eg every three years and at the end of landscape contract periods).

Emergent vegetation may need to be harvested every 5–10 years to maintain flood attenuation volumes, optimise water quality treatment potential and ensure fresh growth, although this is often not required. Care should be taken to avoid nesting birds during the breeding season and to avoid great crested newt and water vole habitats. The typical window for this activity is towards the end of the growing season (September and October). As vegetation matures, plant height may also become a safety issue in residential areas.

Where emergent vegetation is managed, up to 25 per cent can be removed by cutting at 100 mm above soil level using shearing action machinery. Up to 25 per cent of submerged vegetation can be cut and raked out at any one time, using approved rakes, grabs or other techniques, depending on whether clay or waterproof membranes are present. Aquatic vegetation arisings should be stacked close to the water's edge for 48 hours to de-water and allow wildlife to return to the SUDS feature. They should then be removed to wildlife piles, compost heaps or off site before decomposition, rotting or damage to existing vegetation can occur.

Algae removal may be undertaken for aesthetic purposes during the first 3–5 years of a pond/wetland's life. The growth of algae, which is considered by some to be visually intrusive, is encouraged by nutrients introduced into the water body. This situation should settle down once upstream construction activities are complete.

22.6.7 Management of green waste

Appropriate methods should be implemented to dispose of green waste, including:

1 The development of wildlife piles

These provide refuges, hibernation shelter, food and egg laying sites for a large number of animals. When rotted down at the end of 3–5 years they provide compost that can be used as fertiliser for planting areas outside of the SUDS system.

In general:

- wildlife piles should be located in sunny or semi-shaded areas away from direct access by people
- their bases should be constructed using substantial prunings or other branch material laid in a criss-cross pattern
- seasonal shrub and other woody prunings should be added through the winter
- non-woody and grass cuttings should be added through the summer
- wildlife piles should comprise tidy piles up to 1.2 m high
- new wildlife piles should be constructed each year and old wildlife piles should be used as compost to plant beds after 3–5 years
- wildlife piles should be located above normal flood level of watercourses and be protected by hedges or similar features.

A schematic of a typical wildlife pile structure is shown in Figure 22.1.

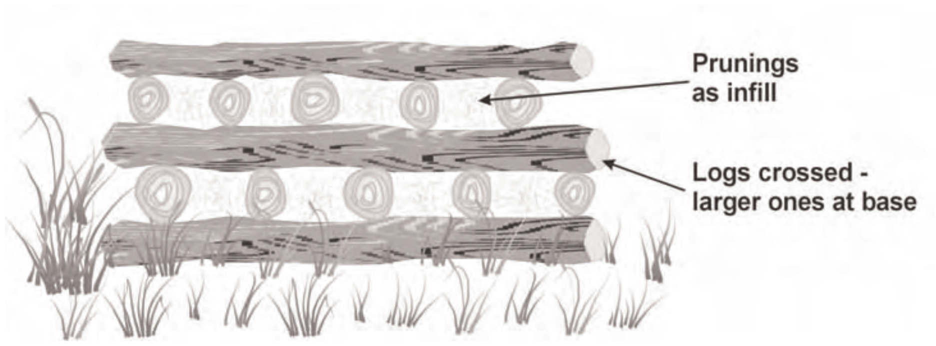

Figure 22.1 *Schematic of a wildlife pile (courtesy of Steve Wilson and Robert Bray of Sustainable Drainage Associates)*

2 On- or off-site composting

A compost facility allows all green waste, particularly grass cuttings and prunings to be recycled and provide compost for mulching ornamental plant beds. The following process should be followed for composting:

- shred all arisings from site
- combine all arisings in active compost bin with grass cuttings not exceeding 70%
- turn and mix active compost when bin is >50% full, at weekly intervals for at least four weeks
- turn and mix full bin every 28 days until used
- combine adjacent compost bins/bays when contents are settled to 50% volume reduction
- Use compost after 3–4 months.

A schematic/photo of a typical composting structure is given in Figure 22.2.

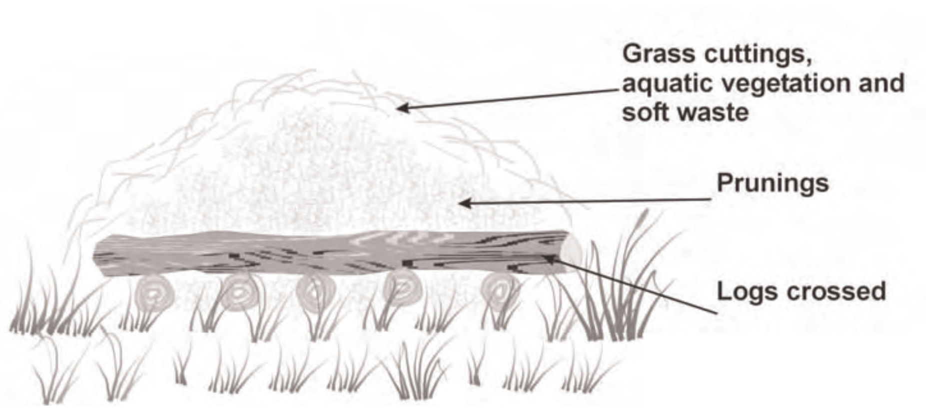

Figure 22.2 *Schematic of a composting structure (courtesy Steve Wilson and Robert Bray of Sustainable Drainage Associates)*

3 Disposal to landfill

As a last resort, green waste can be disposed of to some approved tips or landfill sites, although it is only accepted at certain locations.

The legal and regulatory issues of waste management (including green waste) are discussed in Chapter 23.

22.6.8 Vacuum sweeping and brushing

Pervious surfaces need to be regularly cleaned of silt and other sediments to preserve their infiltration capacity. Advice issued with permeable pre-cast concrete paving suggests a minimum of three sweepings per year. Chapter 12 should be referred to for details of this process.

22.7 IRREGULAR MAINTENANCE ACTIVITIES

22.7.1 Sediment removal

To ensure long-term effectiveness, the sediment that accumulates in SUDS should be removed periodically. The required frequency of sediment removal is dependent on many factors including:

- design of upstream drainage system
- type of system
- design storage volume
- characteristics of upstream catchment area (eg land use, level of imperviousness, upstream construction activities, erosion control management and effectiveness of upstream pre-treatment).

Sediment accumulation will typically be rapid for the entire construction period (including time required for the building, turfing and landscaping of all upstream development plots). Once a catchment is completely developed and all vegetation is well-established, sediment mobility and accumulation is likely to drop significantly.

Detailed information on waste management (in particular sediment removal) is provided in Chapter 23.

22.7.2 Vegetation/plant replacement

Some replacement of plants may be required in the first 12 months after installation, especially after storm events. Dead or damaged plants should be removed and replaced to restore the prescribed number of living plants per hectare.

Inspection programmes should identify areas of filtration, or infiltration surfaces where vegetation growth is poor and likely to cause a reduced level of system performance. Such areas can then be rehabilitated and plant growth repaired.

22.8 REMEDIAL MAINTENANCE

22.8.1 Structure rehabilitation/repair

There will come a time with most SUDS techniques when a major overhaul of the system is required to remove clogged filters, geotextiles, gravel etc. This will typically be between 10 and 25 years, depending on the technique and factors such as the type of catchment and sediment load. The SUDS design should allow for vehicle access to undertake this work and consider the need for the overhaul without causing major disruption. For example the use of geotextiles close to the surface in pervious surfaces traps the majority of sediment in a relatively easily accessible location. Reconstruction of the surface layer and bedding layer is all that is required, rather than reconstruction of the whole pavement depth.

Major overhaul is most likely to be required on techniques that rely on filtration through soils or aggregates, such as sand filters and infiltration devices. Other SUDS techniques are unlikely to need major overhaul if routine maintenance is undertaken as required (for example ponds and wetlands).

Rehabilitation activities for each SUDS component are described in the individual component chapters. The requirements should be identified in the owner's manual.

22.8.2 Infiltration surface rehabilitation

In the event that grassed surface permeability has reduced, there are a number of landscape techniques that can be used to open the surface to encourage infiltration. Such activities are not commonplace and are likely to be required only in circumstances where silt has not been effectively managed upstream.

1. Scarifying to remove "thatch". Thatch is a tightly intermingled organic layer of dead and living shoots, stems and roots, developing between the zone of green vegetation and the soil surface. Scarifying with tractor-drawn or self-propelled equipment to a depth of at least 50 mm breaks up silt deposits, removes dead grass and other organic matter and relieves compaction of the soil surface.
2. Spiking or tining the soil, using aerating equipment to encourage water percolation. This is particularly effective if followed by top dressing with a medium to fine sand, and is best undertaken when the soil is moist. Spiking or tining with tractor drawn or self-propelled equipment penetrates and perforates soil layers to a depth of at least 100 mm (at 100 mm centres) and allows the entry of air, water, nutrients and top dressing materials.
3. As a last resort, it may be necessary to remove and replace the grass and topsoil by:
   - removing accumulated silt and (subject to a toxicity test) applying to land or dispose of to landfill
   - removing damaged turf which should be composted
   - cultivating remaining topsoil to required levels
   - re turfing (using turf of a quality and appearance to match existing) or reseeding (to BS 7370: Part 3, Clause 12.6 (BSI, 1991) using seed to match existing turf) area to required levels. It may be necessary to supply and fix fully biodegradable coir blanket to protect seeded soil. Turf and seeded areas should be top dressed with fine sieved topsoil to BS 3882 (BSI, 1994) to achieve final design levels. Watering will be required to promote successful germination and/or establishment.

22.9 APPLICATIONS OF THE PRINCIPLES OF LANDSCAPE MAINTENANCE

In contrast to conventional drainage, which comprises mainly sub-surface pipework and associated infrastructure, SUDS are predominantly surface systems. A key feature of SUDS is their integration within the local landscape and their amenity contribution, and it is appropriate therefore that landscape maintenance practice is applied to their management.

22.9.1 Landscape maintenance documentation

Typical landscape maintenance documentation and its potential relevance to SUDS systems is summarised below:

(A) Management plan – describing the management objectives for a site over time, and the management strategies that should be employed to realise these objectives and reconcile any potential conflicts that may arise.

Management plans are most appropriate for application in major parks and open spaces, wherever there are alternative choices for future action, and potential conflicts of purpose and priorities that need to be resolved. The following extract from *A guide to management plans for parks and open spaces* (Barber, 1991) sets out the types of management plans that can be prepared:

(i) Management plan
This predicts a degree of physical change, and therefore should present design proposals in its recommendations. It puts the emphasis on the presentation of anticipated physical change with much of the documentation being in support.

(ii) Outline plan
This is generally accepted as a more appropriate title for a management plan that wishes to establish the guiding principles, without providing detailed proposals which might constrain future options for achieving the outline objectives.

(iii) Maintenance plan
This is appropriate if the principal interest is in establishing the best way of maintaining an area, or where there is a need to match maintenance aspirations to a secure financial base. Planned maintenance programmes over longer timescales can be made more secure by the more public exposure of the need and the commitment that the Maintenance Plan should be able to guarantee. A Maintenance Plan can also establish changes in maintenance regimes that may be required to match a change in objectives e.g. the need to adapt operation and maintenance practices to accommodate specific wildlife habitats that may develop.

For a SUDS scheme, the maintenance plan will generally be the most appropriate type of management plan to use. The document should include an explanation of the function of the SUDS scheme and why it is being used on the site.

Where the drainage system has an impact on the wildlife value or public use of a site, it would be prudent to develop this simple explanation further to explain habitat enhancement goals, health and safety issues and long-term management implications. Sites with special wildlife or amenity interest may require detailed management plans, which monitor habitat development, infrastructure changes or damage to sites and ensure rapid responses to such changes, should they occur.

It is common for smaller commercial, industrial and housing sites to have a simple maintenance statement. In this case, a single page explaining the site management (including the sustainable drainage system) would be useful for all parties involved in the care of the development.

(B) Conditions of contract – appropriate conditions will be required. Advice can be sought from the Landscape Institute. Guidance is also provided in CIRIA publication C625 (Shaffer *et al*, 2004).

(C) Specification – detailing the materials to be used and the standard of work required.

A specification, usually preceded by preliminaries, details how work shall be carried out and contains clauses that give general instructions to the contractor. Specific SUDS maintenance clauses may be included in a general specification or as a separate "Sustainable drainage maintenance specification" section.

(D) Schedule of work – itemising the tasks to be undertaken and the frequency at which they will be performed.

The tasks required to maintain the site and the frequency necessary to achieve an acceptable standard should be set out in the schedule of work.

Smaller sites will usually have simple specification notes given to a contractor as a basis for maintenance on a performance basis. Examples of performance criteria are items such as:

- length of grass
- tidiness
- extent of weed growth, etc.

This document will often form the basis of a pricing mechanism, and can also act as a checklist to ensure the work has been carried out satisfactorily.

For additional information on the development of appropriate schedules, reference should be made to *The operation and maintenance of sustainable drainage systems* (HR Wallingford, 2004).

22.9.2 Frequency of maintenance tasks

Landscape maintenance contract periods are usually of one or three years' duration. The three-year period is increasingly common to ensure continuity and commitment to long-term landscape care. The frequency of regular landscape maintenance tasks in a contract period can range from daily to once in the contract period. In practice most site tasks are based on monthly or fortnightly site visits, except where grass or weed growth requires a higher frequency of work. In many cases a performance specification is used with terms such as "beds shall be maintained weed-free" or "grass shall be cut to a height of 50 mm with a minimum height of 25 mm and a maximum height of 100 mm" to obtain the required standards.

Frequency can be specified within the schedule to include irregular items such as "'meadow grass' - cut two times annually in July and September to a height of 50 mm, all arisings raked off and removed to wildlife features, compost facility or to tip", which provides flexibility for work that is not critical to the management of the site.

Maintenance tasks which suit a performance approach commonly include plant growth, grass cutting, pruning and tree maintenance. However work tasks such as sweeping paths, regular litter collection and cleaning road surfaces will require work at an agreed frequency with more specific timings such as weekly, monthly or annually.

Where the frequency and timing of tasks is critical, a mixture of performance and frequency specification is necessary to provide effective maintenance.

SUDS maintenance generally tends towards a frequency requirement to ensure a predicable standard of care which can be recorded on site and which provides a reasonable basis for pricing work. A convenient frequency for many tasks is at a monthly inspection as this is the usual minimum site attendance required in a landscape specification. The monthly frequency should provide for an inspection of all SUDS features and checking all inlets and outlets.

Certain SUDS maintenance tasks however fall outside this monthly cycle and need to be accommodated in the contract. The two most obvious are:

- wetland vegetation maintenance
- silt management.

There are other tasks associated with ensuring the long-term performance of the systems that may be more difficult to predict, and may even fall outside any contract period. It may therefore be more appropriate to review requirements for system rehabilitation at interim periods, when contracts are falling due for renewal.

22.10 REFERENCES

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A Guide to Management Plans for Parks and Open Spaces (plus supplement)
Institute of Leisure and Amenity Management

BSI (British Standards Institution) (1991)
BS 7370 Part 3: *Grounds maintenance. Recommendations for maintenance of amenity and functional turf (other than sports turf).*
BSI

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BSI

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Waste management

23

Contents

Waste management 23

23.1 INTRODUCTION

SUDS remove pollutants from runoff, minimising the water quality impacts to receiving water bodies. A key part of this process is sediment control. Sediment accumulates in SUDS scheme for two main reasons:

1. Stormwater runoff brings debris and silt from hard surfaces.
2. Green areas and vegetated systems generate organic waste due to plant growth and die-off.

If sediment is not removed from the drainage system (either via effective pre-treatment, or through mechanical sediment extraction), the following problems can develop:

1. SUDS facilities can become sources of stormwater pollutants as the inorganic and organic sediments that accumulate on their base become re-suspended during storm events.
2. Storage capacity may be reduced.
3. Inlets and outlet blockages may increase.
4. Problems associated with reduced amenity/aesthetic value, odours and vectors (eg flies, mosquitoes) may arise.

To prevent this, SUDS (and their pre-treatment structures), should be inspected periodically, the level of sediment (and other waste) accumulation should be monitored, and the systems cleaned when appropriate. Sediments and other debris may contain a variety of pollutants and proper handling and disposal of these materials is essential.

The extraction and disposal of waste such as sediments, vegetation, contaminated geotextiles and other structural material arising from the maintenance of SUDS must always be guided by the latest regulations and legislation. This chapter refers to legislation that is current at the time of writing (2006) but which, over time, may be amended. It is therefore the responsibility of the SUDS scheme operator to keep abreast of the latest information and requirements. The environmental regulator should be contacted to confirm the required protocols for the proper handling of sediment or waste at a particular site.

23.2 PROPERTIES OF SEDIMENTS

Stormwater sediments have properties that are site- and catchment-specific, and it is extremely difficult to give "typical" sediment properties. The surface layer (approximately the top 5 cm) is likely to be high in organic matter, have a high water content, and a low density.

Testing for the presence, concentration and toxicity of metals in both the UK and the US has indicated that the extracted sediments tend to be non-hazardous as defined by current standards. Nutrient concentrations in pond sediments are generally lower than nutrient concentrations found in combined sewer overflows. Currently, there are few data available on the presence of total petrohydrocarbon (TPH) and polyaromatic hydrocarbon (PAH) concentrations in sediments. Urban stormwater solids may contain bacteria and viruses, including faecal streptococcus and faecal coliform from animal and human wastes.

Stormwater may also contain traces of fertilisers, herbicides, and household substances such as paints and cleaning materials which may contain substances that are potentially hazardous.

23.3 SEDIMENT CATEGORISATION

Sediment management and disposal options will depend largely on the concentrations of component pollutants. The decision-making process is summarised in Figure 23.1 and the reuse or disposal options are described in more detail through the chapter.

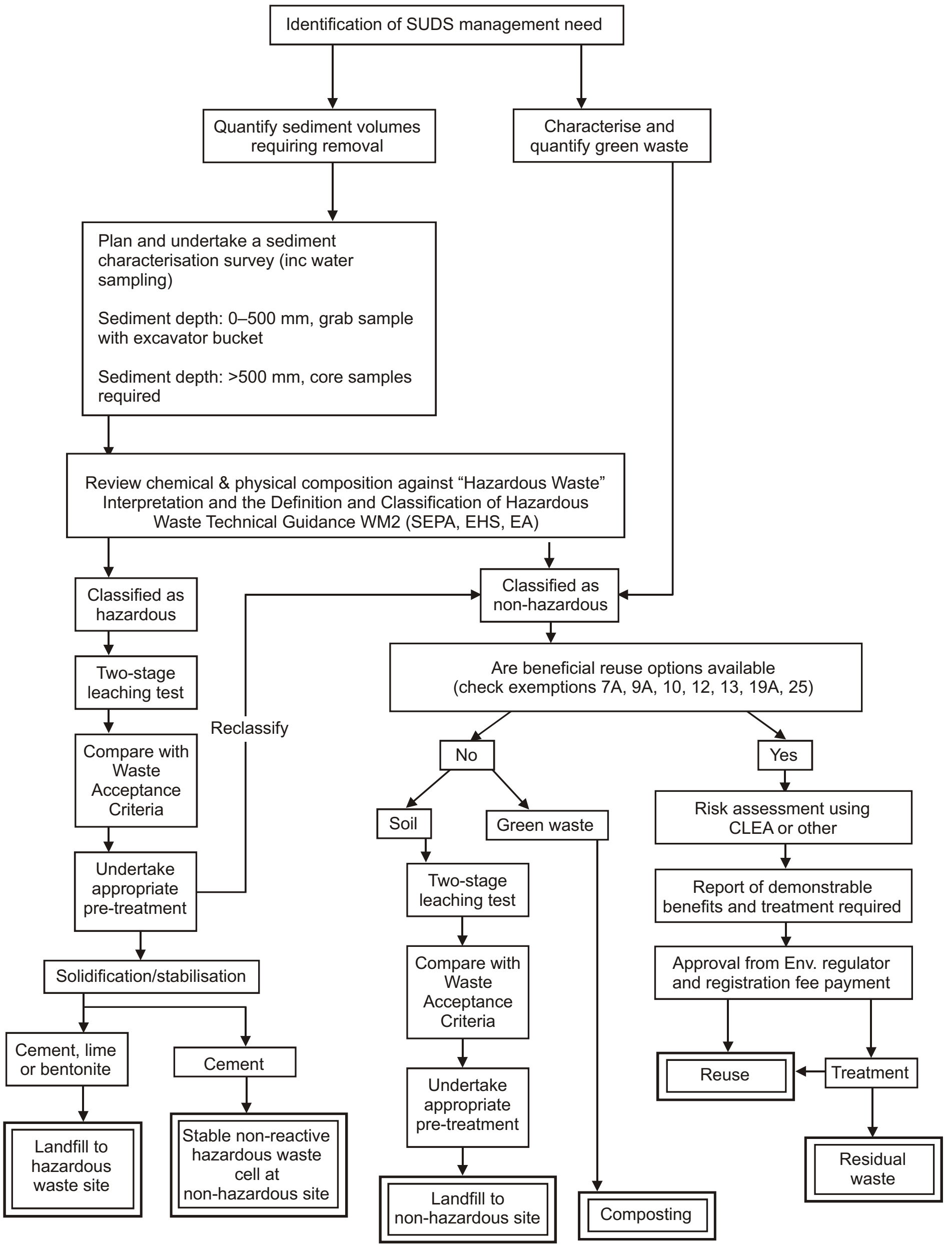


Figure 23.1 *Sediment categorisation and associated disposal options (Kellagher* et al*, 2006)*

* The CLEA model (Contaminated Land Exposure Assessment (EA, 2002)) is a probabilistic computer tool, produced by the Environment Agency, that is used to derive an assessment of the human health risk from contaminated soils. The model has a database of nine contaminants, which are toxic metals and metalloids with the exception of benzo(a)pyrene and phenol. Users can modify existing contaminants and add new organic contaminants to the database. In undertaking the risk assessment the model considers only on-site human receptors in the following land use scenarios:

- residential (with plant uptake)
- residential (without plant uptake)
- allotments
- commercial and industrial.

Where sediments derived from SUDS are proposed to be beneficially reused in one of the above land use scenarios, the CLEA model may have some application but, to ensure all risks including environmental risks are assessed, other proprietary tools available from waste management consultants should be used together with the CLEA model or on their own.

Where viruses or other pathogens/micro-organisms are present, they have the potential to be spread from land application of residuals or landfill sites unless proper precautions are taken. Measures that reduce their concentration and minimise any residuals-vector contact include stabilisation of the solids, immediate covering of landfill trenches, treatment by pasteurisation, heat treatment and irradiation.

23.4 SEDIMENT REMOVAL REQUIREMENTS

23.4.1 General considerations

Sediment removal from SUDS components should always be carried out in a way that causes no damage to the SUDS facility, and impacts on ecological systems and aesthetic appearance are minimised. The appropriate method of silt removal at a particular site will depend on design characteristics, visual requirements, wildlife concerns and sediment depths. It can be carried out with hand tools or appropriate mechanical equipment. In particular, it is recommended to:

1. Establish how the structure is lined and avoid damage to clay puddle layers or waterproof membranes.
2. Where machinery is used to excavate sediment, undertake the operation in dry weather when surrounding ground is firm and ideally operate from a hard surface.
3. Use machinery with an extending arm to avoid contact with edges, banks and other features to a minimum distance of 1 m from the edge. Use a bucket without teeth to avoid puncturing clay layers or waterproof membranes.
4. Undertake work between September and March to minimise impacts on receiving waterbodies (high suspended solids can cause reduced dissolved oxygen levels which causes particular problems during elevated summer temperatures). Where required, works may be restricted to September and October inclusive, so that breeding or hibernating wildlife is protected.

The decision-making process for different management options for sediment removal is summarised in Figure 23.2. Specific requirements of different SUDS components are presented in the following sections.

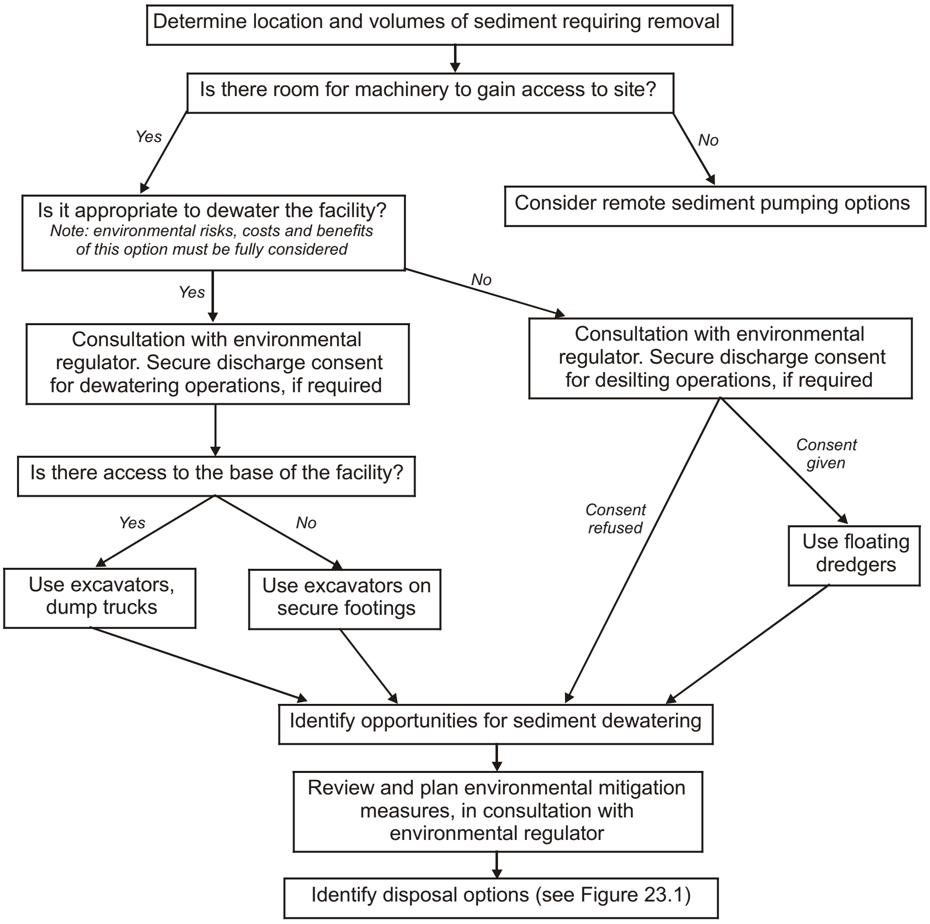


Figure 23.2 *Sediment removal decision making*

23.4.2 Retention ponds

Depending on allowances made during storage capacity design, wet ponds may eventually accumulate sufficient sediment to impact on the storage capacity of the permanent pool. This loss of capacity can affect both the appearance and the pollution removal efficiency of the pond. The loss in storage will occur more rapidly if the pond receives additional sediment input during the construction phase. A sediment clean-out cycle of 15–25 years is recommended, although this may be extended to 30–50 years if an effective and well-maintained pre-treatment system or forebay is present.

The following issues should also be considered:

1. Regular partial sediment removal is most effective, but may not be economic. However, where possible, sediment should not be removed from more than 50 per cent of the pond or wetland area at any one time.
2. Appropriate bankside working areas should be selected, and wetland and bankside habitats protected.
3. Sufficient vegetation should be retained to ensure rapid re-colonisation of damaged areas.
4. Ideally, sediment removal should remove accumulated inorganic and organic sediment only but not wetland subsoil or topsoil layers. In practice, this can be difficult to achieve.

23.4.3 Detention basins

With time, dry basins accumulate sediment that will gradually reduce both the storage capacity available and the sediment trapping efficiency. In addition, sediment may tend to accumulate around the control device, which increases the risk that either the orifice may become clogged or sediment may become re-entrained into the outflow. It is therefore recommended that sediment clean-out cycles of 5–10 years be considered (unless effective and well-maintained pre-treatment renders this unnecessary). Sediment excavation – using front-end loaders or backhoes – is simple if appropriate access is available for the equipment. A dump truck with a watertight tailgate is likely to be required to remove the sediment from the site.

23.4.4 Infiltration and filtration devices

Infiltration basins are usually located in residential catchments that do not generate large sediment loads, and should always have a pre-treatment or other sediment trapping system upstream. Even with low sediment loads, the system performance can still become significantly impaired. The sediment deposits reduce the storage capacity and may also clog the surface soils.

Methods to remove sediment from infiltration devices are different from retention/detention basins. Removal should not start until the basin has dried out, preferably to the point where the surface material begins to crack. The top layer should then be removed using lightweight equipment, with care being taken not to unduly compact the basin surface. The remaining soil can then be scarified or tilled to restore the surface infiltration capacity (see Chapter 20 for detail of these methods). Vegetated areas disturbed during sediment removal should be replanted immediately to reduce the risk of erosion.

The inlets to subsurface trenches (filter trenches and infiltration trenches) must be checked periodically and cleaned out when sediment has caused significant depletion of capacity (eg 10 per cent). This can be done either manually or by using a vacuum pump. Where inspection chambers indicate that sediment is causing poor flow through the trench, then the gravels should be removed, washed and replaced. Care will be needed with appropriate discharge of the wash water.

Sand filter systems are likely to require replacement of the filter medium every 3–5 years, depending on the pollutant load. However, accumulated trash and debris should be removed from the surface every six months (or as necessary) and the filter surface rehabilitated. Sand filter systems should generally be cleaned manually. Accumulated sediments on the surface of filter strips and swales will periodically need to be removed manually to retain the original surface grade, prevent ponding and channelling, and retain the system capacity.

Maintenance of porous pavement systems involves removing sediment from the pavement surface using vacuum sweeping. It is recommended that the pavement be vacuum swept and hosed down by a high pressure jet 2–3 times a year.

Individual component chapters should be referenced for additional detail.

23.4.5 Oil and grit separators

Oil and grit separators should ideally be cleaned out regularly to prevent re-entry of any residuals or pollutants into the downstream SUDS system. The frequency will depend on the site-specific pollutant load but, as a minimum, cleaning operations should take place every six months. They can be cleaned by vacuum pumping which transfers a slurry of water and sediment to a tanker, or by adding chemicals to help solidify the residuals which can then be removed manually.

23.4.6 Sediment removal operations

Specialist contractors should generally undertake silt removal. The types of machines capable of de-silting a pond will vary. It may be possible to drain the pond and employ a bulldozer or excavator with swamp tracks to excavate sediments from within the basin, or else an excavator may have to be employed from the bank. Standard hydraulic excavators have limited reach and so, most commonly, long-reach excavators are used that can reach in excess of 12 m.

For larger pools, specialist long-reach excavators with a reach up to 16 to 25 m will be required. A further option is to accommodate machinery on floating pontoons and/or barges. Figures 23.3 and 23.4 show floating excavators working in water, Figure 23.5 shows a large long-reach excavator.

Figure 23.3 *Floating excavator working in small pond*

Figure 23.4 *Dredger on floating barge*

Figure 23.5 *Long reach excavator on floating pontoon*

Long-reach excavators cannot operate close to overhead power lines for safety reasons and require a clear area to swing their bucket and dump spoil. They are therefore generally inappropriate for use on a pool surrounded by trees. They are usually delivered to site by a low-loader and require good access as they have a large track width. Because of their weight (the largest can measure up to 80 tonnes), small bridges may not be able to accommodate them. (Note: Fig 23.5 shows a pontoon with "jack-up" legs – such legs should not be used in pools with liners).

Tracked loading shovels can lift and dump as well as push spoil, but it can be used only where access to the pond bottom is possible and there is a solid base to the pond beneath the silt. This type of machine can move spoil quickly and can be fitted with swamp tracks to prevent sinking into the silt.

A mud cat works by sucking silt off the bottom through flexible pipes to specially constructed reservoirs on land. It is extremely costly to bring to site and because of its size, requires good access. It pumps a substantial amount of water as well as silt, and a suitable space around the pool must be available for the construction of settlement lagoons which can take more than a year to dry out thoroughly and consolidate.

23.5 DE-WATERING OF SUDS

If de-watering of ponds in advance of sediment extraction is feasible at a site, and assuming that the water body can be left drained for a reasonable period (ie a few weeks), then this can considerably reduce the volume of material to be extracted and disposed of and will often allow some biodegradation of organic material.

De-watering can be undertaken by:

1. Draining down the pond using the penstock or outlet valve (if included within the design).
2. Pumping out the pond.

Both options require consideration of the environmental impact of the de-watering, especially with respect to downstream receiving waters. The process is likely to require discharge consent from the environmental regulator (or sewerage undertaker if discharge to a receiving sewer is proposed) and large-scale de-watering may also require planning permission. Testing of the system water quality (for COD, BOD, suspended solids and metals – in consultation with the environmental regulator) may be required to demonstrate the likely risks to the local environment and can be undertaken together with the sediment sampling.

The water may contain high concentrations of suspended solids that are either already in suspension or become entrained as a result of the pumping process. Adequate sediment control must therefore be provided before the pumped water is discharged. Once the pumped water is running clear then the sediment control devices may be bypassed as long as sediment is not re-introduced into the system. Appropriate sediment control systems include:

- temporary traps formed by constructing an earth embankment with a gravel filled outlet across a swale
- sediment basins (this can include the use of floodable fields)
- sumps (either constructed or mobile proprietary units)
- geotextile filters.

23.6 SEDIMENT DISPOSAL OPTIONS

The options for sediment disposal at a particular site will generally be dependent on its characteristics in terms of contaminants. Sediments excavated from SUDS facilities are classified as waste and should be sampled and subjected to laboratory chemical testing to determine the extent and nature of any contamination and whether it is biodegradable, ie can be effectively treated and applied to land. Waste from SUDS facilities that receive runoff from residential or standard road/roof areas is generally considered to be non-hazardous.

The level of contamination will inform the disposal or recovery options and associated costs/charges. The potential risk to the disposal site also needs to be assessed in terms of the contaminant's mobility from the dredged material to the surrounding environment. Leachate testing will provide information on a contaminant's mobility. If the waste has a high level of organic matter, then it may be viable to treat (eg compost) the waste or apply it to land, providing the application can be shown to be beneficial and there are no potentially detrimental effects associated with the use of the treated material.

The excavation and disposal of sediments from SUDS is a waste management treatment activity that will require a licence (under the Waste Management Licensing Regulations, 1994 as amended), unless the operations meet the requirements of a particular exemption, in which case a licence may not be required. A waste management licence is a legal document, issued by the environmental regulator, and works to ensure that the authorised activities do not cause pollution of the environment, harm to human health or serious detriment to local amenities. There are two types of waste management licence:

1. **Site Licence:** authorising the deposit, recovery or disposal of controlled waste in or on land;
2. **Mobile Plant Licence:** authorising the recovery or disposal of controlled waste using certain types of mobile plant.

To qualify for a licence exemption, the proposed activity should meet the limitations of each exemption as laid out in the Waste Management Licensing Regulations (DoE, 1994), and should also meet the relevant objectives of Article 4 of the Waste Framework Directive (EC, 1991) and the overriding requirement that:

- the waste must be recovered or disposed of without endangering human health and without using processes or methods which could harm the environment and in particular without:

  (i) risk to water, air, soil, plants or animals or

  (ii) causing nuisance through noise or odours or

  (iii) adversely affecting the countryside or places of special interest.

If this overriding requirement or any one of the specific limitations is unlikely to be met, then a waste management licence will be required. The legislation, including the exemption requirements, is summarised in Section 23.8.

A range of waste disposal options are discussed in the following sections.

23.6.1 Centralised treatment

This involves the treatment of sediment at a waste water treatment works, or soil treatment facility. The treated waste may be disposed of at a suitably-licensed or permitted landfill site. It may also be possible to apply the treated sediment to land if the application can be shown to be beneficial and there are no potentially detrimental effects associated with the activity.

23.6.2 On-site handling

This option may be used after the sediments have been analysed and confirmed as being non-hazardous. Sediments and their associated pollutants must be prevented from flowing back into the SUDS scheme or receiving watercourse during rainfall events. Preliminary de-watering of the material will generally be required. It may be possible to utilise the sediments under a waste management licensing exemption but, where the activity does not or cannot comply with the criteria stipulated in an exemption and its associated "relevant objectives", then a waste management licence or permit may be required.

23.6.3 Off-site land application

The treatment of land with dredged waste has to be undertaken using quantities and frequencies that convey positive benefits to both land and the ecology, ensuring that the activity does not endanger human health and without using processes or methods which could harm the environment. As with on-site handling, it may be possible to apply the waste to land under a waste management licensing exemption.

23.6.4 Landfill

Landfill is the least sustainable option and should be selected only when all other options have been given full consideration. Waste may be disposed of at suitably-licenced or permitted landfill sites. However, not all sites will be authorised to accept dredgings and sites should be contacted directly to ascertain whether they are able and willing to accept the waste.

Disposal to a landfill site may be the preferred option when:

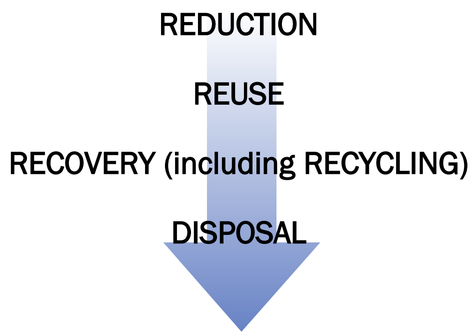
- the quantity of material is small
- no cost-effective alternative is available
- no land application option is available.

A list of landfill sites that can accept hazardous wastes and stable non-reactive hazardous wastes may be obtained from the environmental regulator and specific sites should always be contacted for confirmation of licence/permit conditions and material acceptability.

23.7 WASTE TREATMENT

23.7.1 Introduction

The treatment and disposal options of contaminated soil and sediments should take account of government policy which is that, subject to the best practicable environmental option (BPEO) in each case, waste management should be based on a hierarchy in which the order of preference is as follows:



The objectives for the treatment of waste before disposal are likely to include:

- meeting pre-treatment requirements for land application or landfill (generally to improve characteristics or remove certain contaminants)
- minimising waste volumes before land application or landfill.

Treatment options include:

- de-watering (by gravity or mechanical methods)
- chemical stabilisation of organic and inorganic pollutants
- physical stabilisation of waste for ease of transport and to comply with any landfill pre-treatment requirements
- screening and separating sediments to minimise landfill requirements
- blending, composting and bioremediation before land application.

Treatment of sediments to remove the contaminated fraction can be achieved by physical, chemical or biological means, but whichever method is used, this generates waste products that need to be dealt with.

23.7.2 De-watering

The de-watering of sediments is difficult and the process deployed and its cost is largely influenced by the physical characteristics of the material. Sediments containing large quantities (in excess of 60 per cent) of sands and gravels can be treated by separating the sand and gravel fractions and passing them over a de-watering deck with the fines (silts and clays) de-watered in a centrifuge or belt or filter press. Where there is a predominance of fines, centrifuges or presses can be used, as can lagoons where the sediments can drain naturally over time, aided by an excavator turning the material periodically. All de-watering methods will require a discharge consent for the disposal of the effluent to sewer or to surface or groundwater.

23.7.3 Chemical stabilisation

Chemical stabilisation involves the addition and mixing of an additive, most often in powdered form, to the contaminated sediment. The additive is designed to chemically react with, or use surface adsorption and electronic charges, to stabilise the contaminants and prevent them being released by either precipitation or leaching. This method is most commonly, although not exclusively, used for the treatment of inorganic contaminants.

23.7.4 Physical stabilisation

Physical stabilisation is used to improve the characteristics of wet sediments and or weak soils to enable them to be used beneficially or to improve handling for transport and disposal. There are many examples of wet sediments being treated with ordinary Portland cement or lime, sometimes in combination with pulverised fuel ash to create a soil-like material with strengths in excess of 100 kN/m^2.

The use of cement and lime increases the pH of the silt, promoting alkaline conditions (which can themselves be toxic) and adding to the biological breakdown of the leaf litter or other organic remains.

23.7.5 Screening and separation

As a primary method of treatment, screening and separation is a useful method of removing oversize materials and debris such as bricks, shopping trolleys, bikes etc from the sediments. This reduces the quantity of potentially hazardous sediments, as such debris would generally be classified as inert and be disposed of at lower cost. Screening of sediments can generally remove materials down to 20 mm. Separation would most commonly involve the removal of sands and gravels from the silt and the clay fraction, thereby creating a clean material that could potentially be reused, leaving the finer materials for further treatment. Where organic contaminants are present, separation would normally be part of a soil washing process.

Soil washing is a technique used for the cleaning of contaminated soils and sediments, removing both inorganic and organic contaminants. As contaminants predominantly adhere to the finer fractions of sediments, such as organic matter and silts/clays, soil washing makes use of the differences in grain sizes and density of the components, and washes and separates the different fractions using screens, scrubber barrels, hydro cyclones and presses. Contaminants are separated from the sand and gravel and concentrated in the fines that are pressed to form a filter cake that can be further treated or disposed of at landfill as a greatly reduced volume.

23.7.6 Blending

Blending of sediments with other waste materials is generally undertaken to create a dry, physically improved material. It is not permitted to blend wastes for the purpose of diluting the contaminants or for disposal to landfill.

23.7.7 Composting

Composting is a recognised technique for the treatment of wastes containing large quantities of organic matter that, when combined with soil minerals, can be used to create a nutrient rich soil that can be beneficially used. Organic sediment can either be composted as dug, by forming into windrows and allowing naturally occurring bacteria and organisms to break down the organic matter, or it can be mixed with green wastes such as leaf mould or wood chippings to increase the organic matter content. Whereas dug sediments are composted, the high moisture content will retard the process and the addition of green waste can be beneficial in aiding the composting process.

23.7.8 Bioremediation

Bioremediation is a form of composting where the organisms and bacteria used to break down organic matter are similarly used to break down organic contaminants, such as hydrocarbons in soils, and sediments. In this instance the level of contamination may require the introduction of additives to aid the process of decomposition of the organic contaminants. The advantage of such treatment is that contaminants are converted to safe elements leaving a relatively clean soil that could be reused. The disadvantages are that potentially large areas of impermeable surface are required for the windrowing of the material and that the process can take months to complete.

Discussions should be held with specialist contractors who can advise on the cost and feasibility of alternatives to landfill.

23.8 Regulatory implications

The legal definition of waste is set out in the Environmental Protection Act (DoE, 1990) and is due to be amended in England and Wales under the Environment Act (DoE, 1995) which will give waste the same meaning as in the EC Framework Directive on Waste (EC, 1991). This has already occurred in Scotland. Under Article 1(a) of the Waste Framework Directive, waste is defined as "any substance or object in the categories set out in Annex 1 which the holder discards or intends, or is required to discard". Under this definition, any vegetation, sediment or debris arising from a SUDS maintenance operation would be classified as waste, and the SUDS owner would be classed as the "Waste Holder" and will therefore be bound by the various pieces of legislation relating to the management, treatment, transfer and disposal of wastes.

Table 23.1 summarises the current regulatory constraints and obligations for waste management and disposal.

Table 23.1 *Legal/regulatory documentation and implications for SUDS*

Legal/regulatory documents			
England & Wales	**Scotland**	**Northern Ireland**	**Implications for SUDS**
Duty of Care for Waste, as set out in Section 34 of the Environmental Protection Act (DoE, 1990), and as implemented by the Environmental Protection (Duty of Care) Regulations.	The Environmental Protection Act (DoE, 1990) applies to England, Scotland and Wales and sections 3, 62, 140, 141, 142, 146, 147, 148, 153, 156 and 158 apply in Northern Ireland.		Under the Duty of Care: All waste must be stored and disposed of responsibly. Waste must be handled or dealt with only by individuals or businesses authorised to deal with it. A record must be kept of all waste received. Any wastes produced through the construction and operation of SUDS has to be categorised according to the European Waste Catalogue, and its movement must be accompanied by a Waste Transfer note.
Waste Management Licensing Regulations (DoE, 1994, as amended) made in accordance with the waste management licensing system set out under Part 2 of the Environmental Protection Act (DoE, 1990). These Regulations came into force on 10 August 1994 and apply to England, Scotland and Wales.		Waste & Contaminated Land Order (DoENI, 1997) and the Waste Management Licensing Regulations (Northern Ireland) (DoENI, 2003) - Came into force on 19th December 2003.	The treatment of wastes from SUDS will need to be under the management of a person appropriately qualified and registered with the Waste Management Industry Training and Advisory Board (WAMITAB). If on-site treatment of the wastes before landfilling or beneficial reuse under exemption takes place, the activity will be covered by the Waste Management Licensing Regulations in that the activity will require either a site licence or a mobile plant licence for the dewatering of muds, sludges, soils and dredgings or for the treatment by lime. Such licences are issued by the EA in England and Wales, SEPA in Scotland and the Environment and Heritage Service (EHS) in Northern Ireland. If the wastes are to be beneficially reused without the need for a Waste Management Licence then the wastes themselves and the end use are required to be covered by an Exemption.
The Waste Management Licensing (England and Wales)(Amendment and Related Provisions) Regulations (Defra, 2005) (came into force 1 July 2005).	Waste Management Licensing Amendment (Scotland) Regulations (SE, 2004).	Waste & Contaminated Land Order (DoENI, 1997) and the Waste Management Licensing Regulations (Northern Ireland) (DoENI, 2003).	If wastes arising from the maintenance of SUDS are to be disposed of through beneficial reuse, the proposed activity will need to meet the requirements of one of the exemptions and having done so, be registered. The exemption registration process requires a burden of proof in demonstrating that the conditions of the particular exemption are met and that the activity is unlikely to cause pollution of the environment or harm to human health.
Waste Management Licensing Exemptions (Defra, 2005): 7A: Land Treatment.		Exemption 9.	Non-contaminated sediments arising from SUDS can be placed on the land surrounding the SUDS (without planning permission), provided: it is within the operational land of the SUDS owner; that the land is not used for agriculture; and can be demonstrated that the deposit results in an ecological improvement to the land.
Waste Management Licensing Exemptions: 9A: Use of waste for land reclamation.		Exemption 11.	This allows for the beneficial reuse of dredged sediments, as long as they are not classified as hazardous, on land that is being restored or reclaimed from a previously industrial or otherwise developed site. This activity does require planning permission.
Waste Management Licensing Exemptions: 12A: Composting of biodegradable waste.		Exemption 13.	This includes a schedule of wastes, including dredgings, that can be composted and the means by which this can be done. Biodegradable wastes such as grass cuttings and aquatic vegetation may potentially be classed as garden wastes and as such composted adjacent to the SUDS without the need for containment or impermeable surfaces.
Waste Management Licensing Exemptions: 19A: Storage and use of building waste.		Exemption 19.	If SUDS could be excavated in the dry, then recovered sediments could be beneficially reused as "building material", eg to raise banks or for other landscaping. However, if wet excavation occurs then the material can be used only in land drainage works.
Waste Management Licensing Exemptions: 25: Deposit of waste.		Exemption 25.	This exemption would allow the direct dredging of the sediments to the surrounding banks provided there is demonstrable benefit to agriculture or ecology.
Landfill Regulations (Defra, 2002) (implemented in 2003 and 2004).	The Landfill (Scotland) Regulations (SE, 2003).	Landfill Regulations (Northern Ireland) (DoENI, 2003).	These ban the landfilling of liquid hazardous wastes and sludges unless pre-treated to form a solid. Landfills and wastes are reclassified as either hazardous, non-hazardous or inert and co-disposal between categories is banned. There is an additional requirement to pre-treat hazardous waste for volume reduction, to make it non-reactive, and to improve physical stability. A landfill can accept waste only if the appropriate waste acceptance criteria are met.
Landfill (England and Wales) Amendment Regulations (Defra, 2005) .	As above.	As above.	The producer of the waste will be required to undertake analysis of the waste including the CEN leaching test so as to properly characterise the waste as hazardous, non-hazardous or inert, to assign a Waste Catalogue Code and to provide a full description for the receiving landfill.
Hazardous Waste (England and Wales) Regulations (Defra, 2005).	Special Waste Amendment (Scotland) Regulations (SE, 2004).	The Hazardous Waste Regulations (Northern Ireland) (DoENI, 2005).	These replace the Special Waste Regulations that applied in England and Wales, Scotland and Northern Ireland and require the waste producer to register a hazardous waste site, to charaterise the waste as hazardous, non-hazardous or inert and to code the waste appropriately using the Waste Catalogue Codes.

23.9 REFERENCES

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Landfill (England and Wales) Regulations
Department for the Environment, Food and Rural Affairs, HMSO, London

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Waste Management Licensing (England and Wales) (Amendment and Related Provisions) Regulations
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DoE (1990)
Environmental Protection Act
Department of the Environment, HMSO, London

DoE (1994)
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Department of the Environment, HMSO, London

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Environment Act
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DoE (1995b)
Environmental Protection (Duty of Care) Regulations
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DoENI (1997)
Waste and Contaminated Land (Northern Ireland) Order
Department of the Environment Northern Ireland, Belfast

DoENI (2003a)
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Community engagement 24

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Community engagement 24

24.1 PUBLIC PERCEPTION

Unlike conventional drainage, SUDS often form part of public open space, with the potential to promote interaction between communities and their local environment, resulting in additional amenity benefits. With SUDS being championed within the UK, public understanding of the philosophy driving their implementation becomes increasingly important for the contribution to sustainable development and acceptance by local residents.

Positive attitudes towards SUDS attract property purchasers who view well-designed and aesthetically pleasing systems as an added benefit. Public awareness of the multiple benefits of SUDS to the wider community is fundamental in promoting a positive response not only from the existing population, but also from potential new residents. Increasingly, schools are implementing SUDS and using them to promote local support and as an educational tool. Implementation case studies of SUDS in schools are presented in CIRIA document W12 (Duggin & Reed, 2006) *Sustainable water management in schools*.

Table 24.1 *Key factors for SUDS evaluation*

System performance	Do the public have an understanding of their function and purpose? Do the SUDS meet acceptable design criteria in terms of management of flood risk and pollution control?
Landscaping and aesthetics	Are the SUDS sympathetic and enhance the local environment? Are they maintained to an appropriate standard?
Amenity and recreational value	Is there an added benefit to local residents for leisure activities, eg walking, jogging, picnicing, cycling, bird watching?
Contribution to biodiversity	Do the SUDS contribute to positive and diverse flora and fauna at the site?
Education strategy	Are members of the public adequately informed regarding the multiple purpose benefits of the SUDS to the local environment and how they can contribute to their performance and value?
Health and safety risks	Have site-specific safety issues been adequately addressed through sensible design and the provision of warning signs, fencing, etc.
Socio-economic status	Have appropriate educational campaigns been launched taking into account the socio economic background of the local community? Research has identified that people in a high socio-economic group more positively accept environmentally sound practices.

24.2 PUBLIC ENGAGEMENT

Public engagement is a powerful tool that can bring about environmental and behavioural changes. Raising understanding of the functions of SUDS and engaging the community in the decision making processes related to environmental enhancement is likely to result in a sense of empowerment and a responsible approach to the components.

24.2.1 Public communication

All interested and affected parties in the community (eg local residents, community councils, educational establishments, local authorities, environmental groups, business operators and other stakeholders), should be actively engaged in consultation regarding the drainage system. A key aspiration should be for overall community enhancement.

A public education programme may initiate a three-way communication link between maintenance organisations (local authority or private sector), residents in the local community, and potential funders of future environmental or amenity-based enhancement schemes. Educating younger members of the community through school or youth interaction projects should develop environmental awareness from an early age, and will help engender long-term commitment. Involving children also helps to reach members of the community who would not normally become voluntarily involved in community engagement strategies.

24.2.2 Public awareness

Research has shown that homeowners willingly embrace SUDS when they are informed of the integrated benefits that the systems can offer (HR Wallingford, 2003). Many individuals are happy to be a part of an environmentally sustainable solution if they are in a position to be so, rather than putting their environment at risk.

In the past there has been some reluctance to inform local residents of the purpose of a SUDS scheme, largely due to what has proven to be misplaced concerns by developers and eventual owners of the systems, who believed that householders were likely to prefer conventional, subsurface drainage solutions. This resulted in many homeowners purchasing properties in the vicinity of SUDS without prior knowledge of their true function. In some cases this led to disapproval of the SUDS scheme, especially in circumstances where the facility was not suitably designed or maintained, and where a deterioration in performance had led to the site becoming a target for vandalism and dumping of waste (HR Wallingford, 2004).

24.2.3 Public engagement principles

Three key principles underpin successful community engagement:

1. Have a clear agenda defining the purpose and goals of the engagement initiative. Success is dependent on the outcomes desired.
2. Seek out and facilitate the inclusion of all relevant stakeholders throughout the process, with specific attention being paid to socio-economic background and community-specific needs and rules of engagement.
3. Remove barriers, establish relationships and set targets. This will promote community mobilisation and give participants a genuine sense of ownership and responsibility.

The route towards effective community engagement is summarised in Figure 24.1.

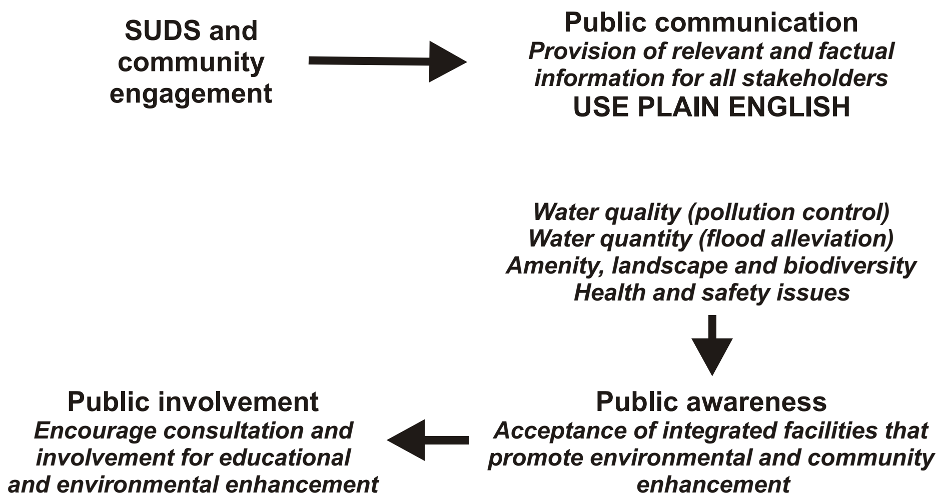

Figure 24.1 *Engaging the community*

Figure 24.2 illustrates the role of public participation as implied by the Water Framework Directive (EC, 2000). The levels of public participation build on one another – once background information is available, consultation can take place and the active involvement of the public can then be encouraged.

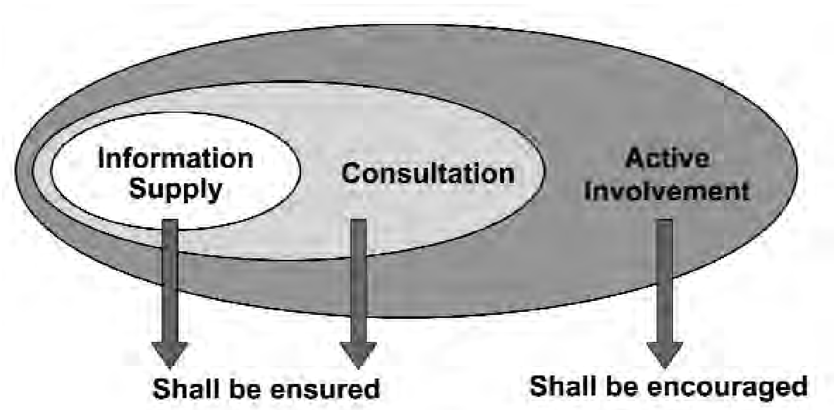

Figure 24.2 *The role of public participation*

For residents in new developments the developer or local authority should supply information about SUDS before a purchase is made. In retrofit situations, the public should be consulted before implementation of SUDS with the intention of including them in the decision-making process at the inception of the schemes.

24.3 PUBLIC ENGAGEMENT METHODS

24.3.1 Information leaflets

Information leaflets should provide clear and factual information explaining why SUDS are being implemented or have been proposed, what the safety issues are and the many additional benefits that they offer to the new or existing community over a traditional drainage scheme.

The leaflet shown in Figure 24.3 had a major role in engaging the public with the SUDS ponds at the DEX (Dunfermline Eastern Expansion) site in Scotland.

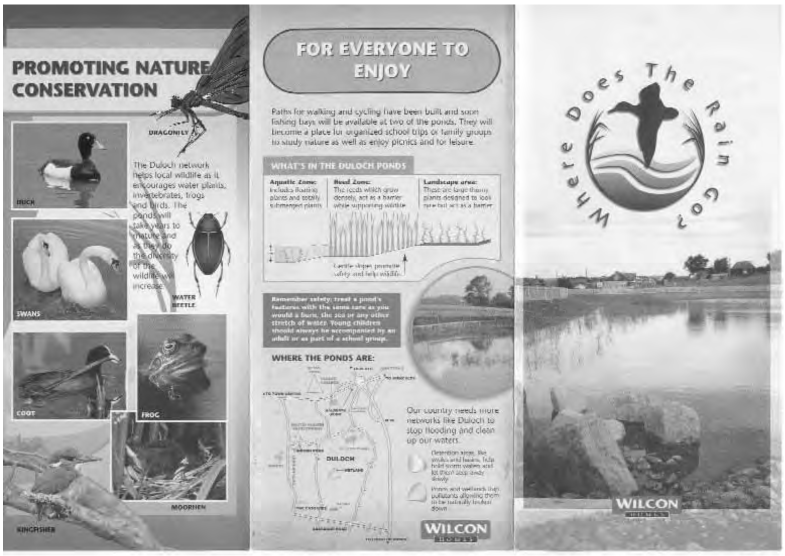

Figure 24.3 *Wilcon Homes information leaflet for the DEX development in 1998*

24.3.2 Media coverage

Local and national press articles should be encouraged as an effective way of raising the profile of SUDS and generating community interest. Examples of the content of press coverage include;

- promotion of the benefits
- SUDS education campaigns
- environmental enhancement initiatives and campaigns
- wildlife surveys within schools

24.3.3 Interpretive/educational signage

Clear signage and/or information boards at strategic locations reinforce local knowledge and inform visitors of benefits such as amenity value and creation of wildlife habitats. The information provided may also caution or advise visitors as to potential health and safety issues associated with the system. Figure 24.4 shows an example of an informative sign.

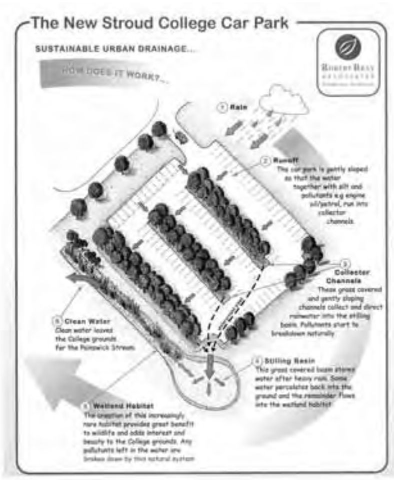

Figure 24.4 *Stroud College educational sign*

24.3.4 Dedicated websites

Websites can provide important routes for reaching the public and can address a plethora of issues relating to both the SUDS and related community activities. There might, for example, be links to other communities within the UK having SUDS, to other information sources relating to issues surrounding the systems, and there could be information regarding community events and activities that may relate to the SUDS ie fundraising events, organised nature trails, picnics etc.

24.3.5 Focus groups

Focus groups and talks can be set up where local representatives are invited to discuss scheme development and scheme operation, including amenity and ecological issues. These provide an important forum for stakeholders to give feedback and express concerns or requests. This approach provided much of the baseline information for the DEX Community Engagement Project. As well as focus groups, talks can be given to local council and local community council groups about the scheme and how best to facilitate and promote the community engagement process.

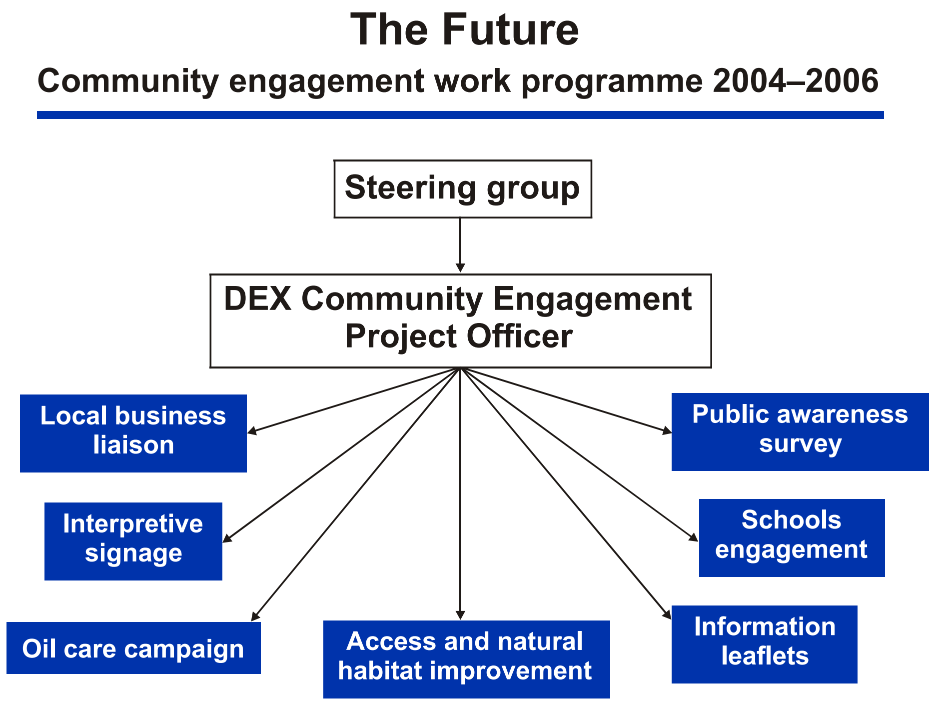

Figure 24.5 *DEX community education project*

24.3.6 Industry collaboration

Corporate social responsibility is becoming increasingly important to industry and contact with local companies and/or larger multi-nationals in the area can sometimes provide resources to help promote community engagement. In addition to financial support, companies can organise internal/external events to promote SUDS facilities or facilitate communication.

24.4 FACILITATING THE INTEGRATION OF SUDS WITHIN THE COMMUNITY

24.4.1 Community friendly design and detailing

Design and detailing can have a major impact on the way that SUDS are perceived. Recommendations from previous SUDS public perception studies include:

- make the pond appear to be as natural as possible
- include marginal vegetation and barrier planting
- introduce wildlife and protect existing species
- make side slopes shallow
- install an explanatory board close to the pond
- install signs warning of deep water
- create walkways around the pond
- create picnic areas and/or benches around the pond
- introduce variations in planting heights around the pond
- install dog fouling bins around the pond
- introduce fish in the pond (where appropriate).

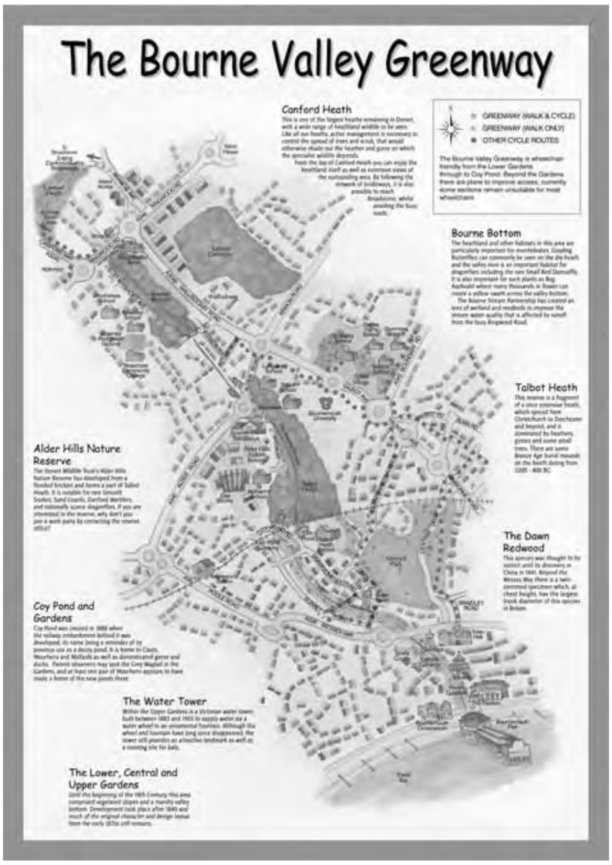

Figure 24.7 *Map showing Bourne Valley improvements – this can be viewed at* www.bournestreampartnership.org.uk/greenway_map.htm

24.4.2 Maintaining SUDS for the community

Once the SUDS components are installed, the maintenance must serve both functional and community needs. Key community recommendations from previous SUDS public perception surveys include:

- removing litter frequently
- removing silt which might be perceived as noxious
- cleaning inlets and outlets to avoid blockages
- maintaining marginal vegetation.

24.5 MANAGING PUBLIC HEALTH AND SAFETY CONCERNS

There are a number of health and safety benefits related to the implementation of SUDS including:

- fewer manhole covers and road drains – reducing the risk of accidents to cyclists, motorcyclists and pedestrians
- pervious surfaces – reducing the risk of standing water during intense storm events, and decreasing the possibility of personal distress and/or the risk of accidents
- wildlife and associated recreational opportunities contributing to the enhanced physical, social, psychological and economic welfare of the local residents.

The owner or responsible person for a SUDS pond or basin has a duty of care to visitors under the Occupiers' Liability Acts (DoE, 1957 and 1984), to ensure that they are reasonably safe.

The perceived risk of litigation, following a drowning or injury at a SUDS pond may be seen as a barrier to the adoption of these structures by local authorities and water companies, although with careful design these risks can be reduced.

The principal dangers that could be encountered at a SUDS pond, wetland or basin after heavy rainfall are:

- drowning risks resulting from open water and thin ice
- health risks associated with the presence of blue green algae and pathogens in the SUDS system.

There are fact sheets produced by the Royal Society for the Prevention of Accidents (RoSPA) which are available on their website on the following issues:

- water safety
- ice safety
- taking children swimming
- government garden pond safety campaign
- water safety for children and young people
- be water wise.

24.5.1 Possible drowning risks

There is a perception that it is children who are most at risk from drowning, but the statistics from RoSPA for 2002, summarised in Box 24.1, show this is not the case.

Box 24.1 *Risk of drowning by age (RoSPA, 2002)*

> The drowning rate per 100 000 of population in 2002 was 0.72. The majority of drowning victims were men aged between 15 and 45 years for whom the combined total was 151, which comprises 35 per cent of all deaths. For the third year running, deaths amongst the under-15s remained static at 40 and of this figure a total of 17 under-fives was again the same as the previous year.

Figures 24.7 and 24.8 show the RoSPA 2002 statistics for drowning locations and causes.

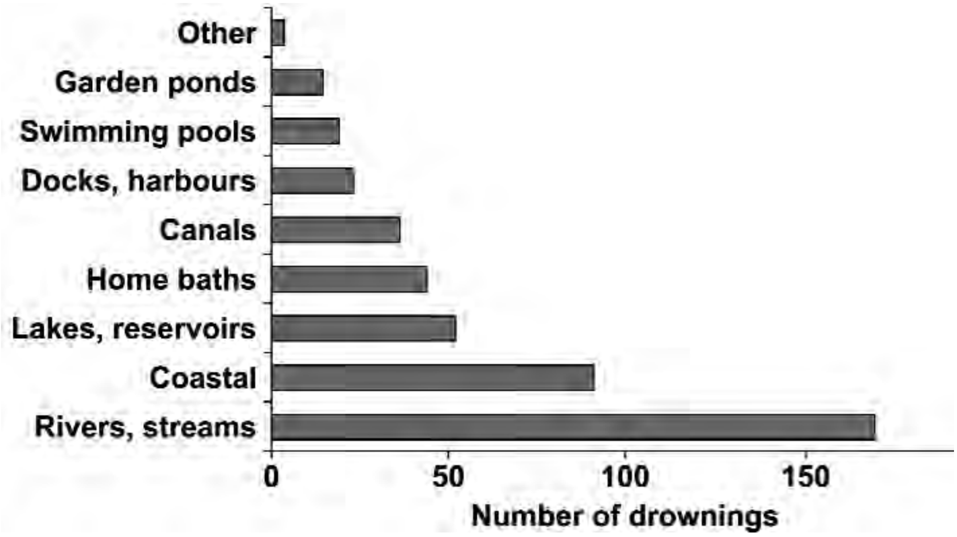

Figure 24.7 *Drowning locations (RoSPA data for 2002)*

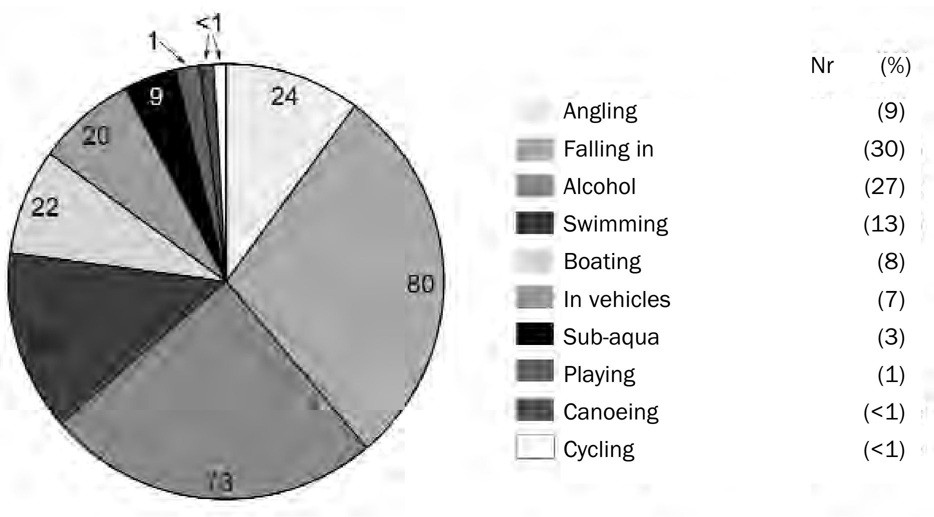

Figure 24.8 *Activities causing drowning (RoSPA data, 2002)*

This shows that the risk associated with lakes and reservoirs is similar to the risk associated with baths at home. It also highlights that the greatest hazard occurs where there are risks of people falling in to deep water, where the person is under the influence of alcohol, and where people are swimming.

Therefore by minimising water depths and ensuring shallow slopes around open water, risks should be minimised.

The publication *Safety at inland water sites – operational guidelines,* (RoSPA 1999), highlights that strategic water safety management via risk assessment and hazard identification is crucial for owners of SUDS. RoSPA guidance on preventing accidents at open water bodies identifies that the most positive way of countering drowning is to prevent entry into the water in the first place. It is essential to counter each of the factors which contribute to drowning as early as possible, and certainly before the stage of possible rescue is reached. These factors form links in what is referred to as the "Drowning Chain", ie the possible combination of events which can lead to drowning.

Box 24.2 *The Drowning Chain links*

The "Drowning Chain" links

1. **Ignorance, disregard or misjudgement of danger.** An intervention is most successful if it breaks this first link in the drowning chain. Recognition and avoidance of danger comes through education. The danger is recognised, respected and avoided.
2. **Unrestricted access to hazards.** The second link in the drowning chain is to deny access to the hazard. This may be done by warning of danger or by otherwise preventing potential casualties from entering into danger, eg fencing, barrier planting.
3. **Absence of adequate supervision.** Absence of adequate supervision can be countered only by more competent training and education.
4. **Inability to save yourself, or be rescued.** If the drowning chain is still intact, and the victim has not been "saved", only the fourth and final link remains! Now only self-rescue, or rescue by another person, can avoid the worst consequences.

Public education through publicity and signage is therefore essential to highlight the risks, especially if there is unrestricted access to a water body. Local media, leaflets and fliers can also be used to support any risk awareness-raising initiative.

24.5.2 Possible health risks

There is no data available regarding actual health risks from small waterbodies that may be considered representative of SUDS components. Therefore, the text that follows is a theoretical evaluation of possible health risks that could potentially be associated with SUDS as a result of their physical characteristics.

Freshwater algae are generally microscopic, but under certain environmental conditions very rapid growth may occur leading to the formation of "algal blooms" or "scums" which can be toxic to humans and other organisms. The most common and visible are the cyanobacteria or blue-green algae which usually appear as a scum in summer or autumn after a long period of warm weather, followed by heavy rain and then more warm, still conditions. People, especially children, and domestic animals should avoid contact with the concentrated scum, which may be toxic. The scum usually, but not always, disappears in winter.

Strategies to control exposure to cyanobacteria include:

- reducing or preventing sewage effluent or nutrients entering SUDS systems
- biological control of the algae (generally by adding barley straw bales into open water systems)
- restricting access to waters by people and animals when the blooms are evident
- control by creating deeper waters (not usually an option for SUDS), enhancing aquatic vegetative growth and regular pond clearing.

The most serious pathogen that may be encountered in SUDS is the *Leptospirosis* bacterium or Weil's disease, which affects both humans and animals and is carried by rodents. The bacteria enter the body via the mouth and nose and skin abrasions. Discouraging rodents is essential to control what is potentially a serious hazard.

Appropriate mitigating measures include:

- providing litter bins close to the SUDS
- picking up and disposing of litter regularly
- raising awareness of the importance of litter disposal
- rodent control if there is a particular problem
- discouraging human contact with the water.

24.6 EXAMPLES OF COMMUNITY ENGAGEMENT STRATEGIES FOR SUDS SCHEMES

There have already been a number of very successful community engagement projects implemented for both SUDS schemes and other relevant environmental enhancement projects. Some of these are presented in the following sections.

24.6.1 Resolving safety issues at DEX

Figure 24.9 *Examples of warning signs from DEX, Scotland*

In 2000, the SUDS at DEX near Dunfermline in Scotland received a commendation from the Scottish Executive in the Scottish Awards for Quality in Planning section for development on the ground. The SUDS at DEX now provide significant amenity and ecological benefits to the surrounding community. Initially there was a great deal of controversy about the safety aspects of having such large bodies of water close to housing. To overcome these perceived problems, the planning services devised a four-point plan that is based on the "drowning chain factors" to optimise the safety of the ponds. These were:

1. The ponds were designed with shallow side slopes (1 in 3) above the permanent pool and 1 in 4 below the water level for around five metres into the permanent water body.
2. Barrier planting was used to deter public access to the ponds in the form of aquatic vegetation (reeds) that extend from the water's edge into the pond for a width of 4–6 metres, and marginal planting on the side slopes around the pond in the form of hostile (thorny) shrubs.
3. Metal fencing one metre high was used to prevent young children from reaching open water, but allowing access to adults should this be required in the case of an emergency.
4. The designs afforded a level of natural surveillance by those in the surrounding area. There are roads and footpaths close by, or housing directly overlooking the ponds.
5. Signage provided further warning information.

Fife Council has recently adopted the open area of the DEX ponds and is actively engaged in developing amenity and habitat enhancement strategies which also incorporate further safety measures. These plans include formalised paths around the structures that lead the public away from hazardous areas such as steep side slopes and areas where there is access to the water body. At one pond, where there is a very steep banking to the side of the pond, the council will sow a mix of wild flower and grass, and the vegetation will not be maintained. This measure should further discourage the public from accessing the area.

24.6.2 The River Quaggy at Chinbrook Meadows

Chinbrook Meadows is a large municipal park within Grove Park, Lewisham. The park has been transformed into a more valuable community resource centred on the naturalisation of the River Quaggy. Expanded facilities were structured around the river, community safety in the park was addressed, and the visual attractiveness of the area was enhanced by community art. A survey conducted by Lewisham Council found that people now regard the park as the most popular leisure facility in the borough.

The core of the project was to restore the river, unlocking it from its concrete engineered channel and allowing it to meander as a naturally flowing river. The local landscape was fully integrated with the engineering works. This ensured that the final landscape was a balance between managing flood risk and establishing a sustainable river flow.

Figure 24.10 *Before and after at the Quaggy River*

From the outset, the refurbishment of Chinbrook Meadows was closely entwined with community needs and public engagement was of critical importance and the following was carried out:

- residents' steering group established
- leaflet drops and publicity in local papers
- outdoor classroom created at the eastern corner of the river to encourage understanding of the river ecology
- space adjacent to the river includes a boardwalk over the river, wide enough to accommodate wheelchairs
- community art projects developed in the park, based on ideas contributed by local children and associated with an environmental theme
- carved benches provided creating a formal space for teaching.

Environmentally, the project is an example of successful flood plain management. The potential cost of flooding to neighbouring houses has been alleviated as a result of increasing the flood attenuation capacity of the whole park. The risk of accidents and injuries has decreased by removing the concrete and reducing the velocity of water in the channel.

24.6.3 Community engagement as part of the NOLIMP project on the River Dee

The general focus of the NOLIMP project is the River Dee, the largest river in north east Scotland, with a total catchment area of approximately 2100 km^2. The focus of the project is to catalyse and deliver improvements in the physio-chemical, biological and hydromorphological quality in a number of pilot tributaries of the River Dee. It is the first initiative of its kind in the UK and is part of a wider European drive to bring together communities and land-owners, with agencies and researchers, to improve the quality of the water environment.

The NOLIMP project has been working together with the local primary school in one of three sub-catchments of the River Dee. The school was presented with their "Dee Riverbank", an environmental education resource box commissioned by the project. A local professional artist was then commissioned to hold workshops with the children, encouraging them to think about what the river means to them and to decide which elements they wanted to focus on within their wall mural. The whole school contributed, either through research of the river environment or the actual painting.

Figure 24.11 *Schoolchildren painting a mural of the river*

Other project targets include:

- community participation – helping communities generate ideas of environmental improvement
- involvement of local businesses in pollution prevention
- development of a resource pack for schools and a website
- creation of wetlands in the Tarland Burn to improve water quality and provide new wildlife habitats
- planting of trees to encourage more species to live in and around the river
- management of flood risk by using natural features and new wetlands
- helping farmers and foresters reduce pollution
- creation of habitats to improve biodiversity,
- creation of a wetland to reduce the impact of run-off from residential and industrial areas
- re-establishment of habitats and restoring the burn to its natural state.

24.7 REFERENCES

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SR 626
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RoSPA (1999)
Safety at Inland Water Sites – Operational Guidelines

Costs and benefits

25

Contents

Costs and benefits 25

25.1 INTRODUCTION

The cost of implementing a SUDS scheme will generally fall to the developer. These costs are typically similar to the equivalent conventional drainage system. SUDS costs can be weighed against the various benefits that they provide – although many of these benefits are likely to accrue to society rather than the developer or implementing body. In addition to capital costs, SUDS may require routine monitoring and maintenance, and a long-term operating finance stream will therefore be required.
A conceptual schematic of a potential cost profile is shown in Figure 25.1.

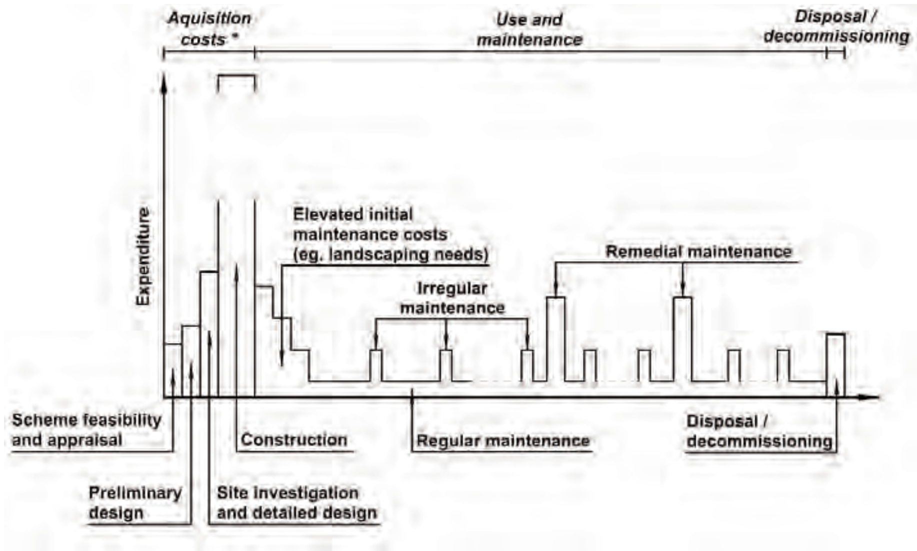

Figure 25.1 *Conceptual SUDS expenditure profile*

In order that ongoing costs are taken into account at planning and feasibility stages, it is recommended that a whole life cost (WLC) approach is taken to scheme costing. Whole life costing involves estimating the present day value of total costs of the structure throughout its likely operating life. The benefits of taking such an approach include:

- improved understanding of long-term investment requirements, in addition to capital costs
- more robust decision-making at project appraisal stage
- improved assessment of long-term risks to drainage system performance and inclusion of monitoring and management plans to minimise these risks
- reduced uncertainties associated with the development of adoption agreements and commuted sum contributions.

Benefits will also accrue throughout the lifetime of a SUDS scheme and may not be realised immediately following construction, so any economic appraisal that quantifies both costs and benefits needs to adopt a long-term approach.

This chapter discusses both capital and long-term costs and benefits and sets out an appropriate whole life costing approach for scheme appraisal.

25.2 CONSTRUCTION COSTS

Construction costs should include:

1 The cost of erosion and sediment control during construction.
2 Material costs.
3 Construction (labour and equipment costs).
3 Planting and landscaping costs.

The cost of constructing a SUDS scheme is inherently variable and will depend heavily on the size of the contributing catchment area. Additional influencing factors include:

- soil type (eg excavation costs are likely to be significantly higher in rocky soils; infiltration opportunities will vary)
- groundwater vulnerability (eg sensitive groundwater zones may require costly impermeable geomembrane liners to be included within the design)
- design criteria (these will determine component sizes and extent of management train needed)
- design features (eg heavily planted ponds can be much more expensive than ponds left to colonise naturally)
- access and space requirements
- location (eg material and labour costs vary regionally, local rainfall characteristics will affect sizing)
- inlet/outlet hydraulic control characteristics.

The following table indicates possible capital cost ranges, based on a review of literature and some UK costs, undertaken in 2004 as part of HR Wallingford's work for the DTI on whole life costing for SUDS. Costs should always be verified for appropriateness, and fully updated using a site-specific cost review. The influencing factors presented above could shift costs up or down from the given ranges. If these ranges are being used, the full report should be referred to for detail as extrapolations outside the range of systems for which the data was collected may not be appropriate.

Table 25.1 *SUDS components capital cost ranges (HR Wallingford, 2004)*

Component	Cost	Unit
Filter drain	£100– £140	/m^3 stored volume
Infiltration trench	£55–£65	/m^3 stored volume
Soakaway	> £100	/m^3 stored volume
Permeable pavement	£30–£40	/m^2 permeable surface
Infiltration basin	£10–£15	/m^3 detention volume
Detention basin	£15–£20	/m^3 detention volume
Wetland	£25–£30	/m^3 treatment volume
Retention pond	£15–£25	/m^3 treatment volume
Swale	£10–£15	/m^2 swale area
Filter strip	£2–£4	/m^2 filter strip area

In general, the total volume or area of a component is likely to be a strong predictor of cost. However, there are economies of scale associated with construction due to costs of inlet and outlet structures, and mobilisation of equipment that are relatively similar regardless of component size.

25.3 DESIGN, CONTINGENCY AND PLANNING COSTS

In general, these costs are expressed as a percentage of the total construction costs and 30 per cent is indicative of typical fee costs. If initial site investigation costs are likely to be significant, then these should be included.

25.4 LAND COSTS

Land costs are likely to be the most significant factor influencing the cost of implementing a SUDS scheme and can vary widely between sites. In some cases, the effective cost of the land for a scheme can be zero, eg where the site has dual use, such as a car park or recreational area, or where the scheme forms part of a required public open space area. However, in high density settings the value of land can far outweigh construction costs and the land-take associated with specific SUDS components may determine the selection of drainage options at a particular site. Whether or not the cost of land should be included within a whole life cost assessment will depend on the use of the land, the stakeholders involved, and the purpose of the assessment.

25.5 OPERATION AND MAINTENANCE COSTS

Sustainable drainage schemes require ongoing maintenance in order to ensure short-term operation, and minimise risks to long term performance.

Operation and maintenance activities can be classified as follows:

- inspection and monitoring
- regular maintenance
  (eg clearing inlets and outlets, collecting trash and debris, grass-cutting, vegetation management, brushing of permeable surfaces, and emptying of silt traps)
- irregular maintenance
  (eg responding to problems e.g. blocked culverts/trash-racks, pollution incidents, vegetation death, structural damage etc)
- remedial maintenance
  (eg for major mid-life refurbishment such as geotextile replacement, vegetation replacement, soakaway replacement, major sediment removal activities etc).

Operation and maintenance costs will comprise:

- labour and equipment costs
- material costs
- replacement and/or additional planting costs
- disposal costs of, for example, contaminated sediments, vegetation.

Routine maintenance can be sub-divided into aesthetic maintenance and functional maintenance. Functional maintenance is required to ensure performance and public safety, while aesthetic maintenance is important for public acceptance and environmental benefits. Aesthetic maintenance is more important for highly visible SUDS schemes, especially where they are located close to residential areas or public open space. In addition to variation in aesthetic maintenance requirements (and therefore costs), management activities required for a SUDS scheme can vary substantially depending on:

- location (this will influence material, labour and equipment charges)
- ease of access (confined sites can be much more expensive to maintain due to requirements for specialist equipment)
- upstream activities (in particular, any ongoing level of development)
- sediment management system design.

The following table indicates possible annual operation and maintenance cost ranges, based on a review of very limited literature and UK costs where available, undertaken in 2004 on whole life costing for SUDS. Costs should be verified for appropriateness, and fully updated using a site-specific cost review. The influencing factors discussed above could shift costs up or down from the suggested ranges. The full report should also be referred to for detail, if these ranges are being used, as extrapolations outside the range for which the data was collected may not be appropriate.

Table 25.2 *SUDS components operation and maintenance cost ranges (HR Wallingford, 2004)*

Component	Annual cost (for regular maintenance only)	Unit
Filter drain/infiltration trench	£0.2–£1	/m^2 of filter surface area
Swale	£0.10	/m^2 of swale surface area
Filter strip	£0.10	/m^2 of filter surface area
Soakaway	£0.10	/m^2 of treated area
Permeable pavement	£0.5–£1	/m^3 of storage volume
Detention/infiltration basin	£0.1–£0.3	/m^2 of detention basin area
Wetland	£0.10	/m^2 of wetland surface area
Retention pond	£0.5–£1.5	/m^2 of retention pond surface area

Where non-structural stormwater management measures such as street sweeping and public education programmes are included as part of a drainage scheme, these ongoing costs should be included as an ongoing maintenance cost. It is very difficult, however, to give generic estimates of such activities, and costs should be developed on a site-by-site basis. Such costs are not normally included as part of stormwater management.

25.6 MONITORING COSTS

For large schemes, the environmental regulator may press for the inclusion of a long-term monitoring regime as a condition of planning. At such sites, these capital and ongoing costs would need to be included in any economic scheme evaluation.

25.7 RESIDUAL COSTS

In a full economic evaluation, the residual value of the drainage system should be included in the analysis. The land occupied by the system could theoretically have residual or "reclaim" value if the function of the drainage system is no longer required at the end of the design life. However, in reality, the following factors mean that it is more appropriate to assume this value to be low or zero:

- the land areas are too small and distributed to be of value for alternative use or development
- the land is part of public open space required by planning conditions

- high likelihood that the space will be required to fulfil a drainage function after the allocated design life.

25.8 DISPOSAL/DECOMMISSIONING

It is likely that any drainage scheme would either be fully rehabilitated at the end of its design life or, if the site was being re-developed, disposal/decommissioning costs required for the drainage system would be accepted by the developer. Such costs are likely to be small due to the landscaped nature of SUDS, and the lack of significant hard (concrete) infrastructure. Disposal costs are likely to be influenced by increasing landfill charges.

25.9 ENVIRONMENTAL COSTS AND BENEFITS

25.9.1 Environmental costs

Environmental risks that may lead to environmental damage can, to a certain extent, often be managed through design, regular monitoring and appropriate maintenance. However, if the costs associated with flood damage as a result of the system being surcharged (due to design exceedance and/or poor performance), are likely to fall to the scheme owner/operator, an estimate of the risk and cost associated with such an incident may be considered appropriate to include, as follows:

Annual risk cost (£) = ***Annual probability of event occurrence (%)*** × ***Consequence (£)***

Similarly, an estimate could also be made of the likelihood of a severe pollution event occurring (probability – percentage), that may require complete system rehabilitation and/or incur regulatory fines (consequence – £).

25.9.2 Environmental benefits

It is difficult to quantify the benefits associated with individual SUDS schemes. Theoretically, a benefit assessment would account for:

1. The hydraulic benefits, including peak flow rate reductions, storm runoff volume reductions, and enhancements to river baseflow and aquifer recharge.
2. The pollutant loading reductions achieved by the system, and associated benefits to in-stream ecology, human health, and human value perceptions.
3. The amenity and recreational benefit enjoyed by those who live close to the SUDS scheme.
4. The additional value of properties adjacent or within view of the SUDS scheme.
5. The ecological value of the SUDS schemes themselves.

The Government recognises (in "Environmental Valuation Source List for the UK" (DETR, 2000)) that although there are techniques available to value the environment, environmental benefits have to be considered within a situation-specific context. The Green Book (HM Treasury, 2003) stated that "wider social and environmental costs and benefits for which there is no market price need to be brought into any assessment. They will often be more difficult to assess but are important and should not be ignored simply because they cannot be easily costed."

Although it is possible to identify how and where environmental benefits (or "externalities") may occur, it is less easy to estimate the economic values. Probably the most popular method of trying to estimate values for environmental characteristics is based on simulating a hypothetical market for environmental goods, and is known as Contingent Valuation Method (CVM). This estimates the willingness to pay for a change in the quality or quantity of an environmental good or service, using sample evidence drawn from questionnaires and surveys.

To carry out a CVM study requires a significant investment in time and resources. However a growing number of CVM studies have now been carried out in the UK (eg to value water quality improvements, the benefits of reduced air pollution and the value of ecologically important species), and an alternative approach is to make use of the results of other CVM studies using a benefit transfer approach. This adjusts the values found from other studies by taking into account the characteristics of the study area, and could be a good indication of the range of possible values that might be expected from a full CVM study. The Environment Agency has produced a set of guidelines entitled *Assessment of benefits for water quality and water resource Schemes in the PR04 environment programme* (Environment Agency, 2003), and this presents some relevant datasets. HR Wallingford's report *Whole life costing for sustainable drainage* (HR Wallingford, 2004) provides some additional guidance and data in this respect.

25.10 WHOLE LIFE COSTING

25.10.1 Approach

Whole life costing is about identifying future costs and benefits and referring them back to present day costs using standard accounting techniques such as "Present Value". This can be thought of as the sum of money that would be needed today to meet all future costs as they arise throughout the life cycle of a scheme or structure. The formula for calculating the present value is given in the following equation:

$$\mathbf{PV} = \sum_{t=0}^{t=N} \frac{C_t}{(1+\frac{r}{100})^t}$$

where N = Time horizon in years

C_t = Total monetary costs in year t

r = Discount rate

The whole life costing approach is described by Figure 25.2.

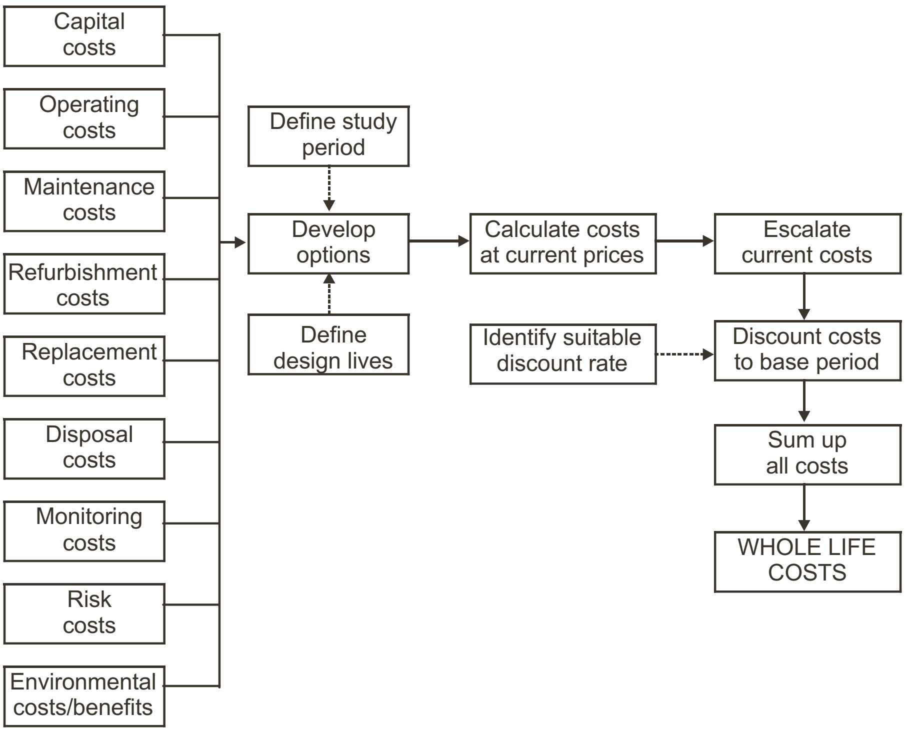

Figure 25.2 *Present value whole life costing approach*

25.10.2 Discount rate and discount period

The discount rate is the rate used to convert all future costs and benefits to "present values" so that they can be compared. It is the difference between the rate of return on the open market and inflation. The recommended discount rate has historically been set by financial institutions at between 5 and 10 per cent. In the public sector, the discount rate is set by the Treasury and it is currently recommending a rate of 3.5 per cent, a recent shift from a long-term value set at 6 per cent. This reduction in the discount rate effectively puts a higher weight on future costs, to encourage longer-term, more sustainable development. The Treasury also recommends that for projects with long-term impacts (over 30 years), a declining schedule of discount rates should be used rather than the standard discount rate (see Table 25.3). The rationale for declining long-term discount rates results from uncertainty about the future, which has been shown to cause declining discount rates over time.

Table 25.3 *The Treasury recommended declining long-term discount rate*

Period of years	0–30	31–75	76–125	126–200	201–300	300+
Discount rate	3.50%	3.00%	2.50%	2.00%	1.50%	1.00%

Selection of the most appropriate discount rate is one of the most contentious issues in WLC analyses, as it can have a significant effect on the outcome of the analysis. Calculations using a high discount rate will make future costs less important, while a lower discount rate will reduce the impact of capital costs on the WLC.

Discount periods of 25–30 years are commonly used for analysis in the water industry. Commuted sums that can be paid by developers to local authorities for the adoption of SUDS are currently limited to 25 year periods. However, it is likely that the costlier rehabilitation works may be required from about this time post-construction and longer discount periods should therefore be considered. The primary purpose of expenditure on sustainable drainage systems is to maintain the system's performance, an implication of this being that there is an indefinite "useful life" for the system. The "useful life" is being constantly altered by the maintenance activities that are or are not undertaken. A period of analysis should be selected that ensures all significant future maintenance activities are accounted for.

The following graph shows the impact of time on the relative contribution of yearly costs to the total in a 100-year analysis, using both 3.5 (declining with time) per cent and 6 per cent discount rates.

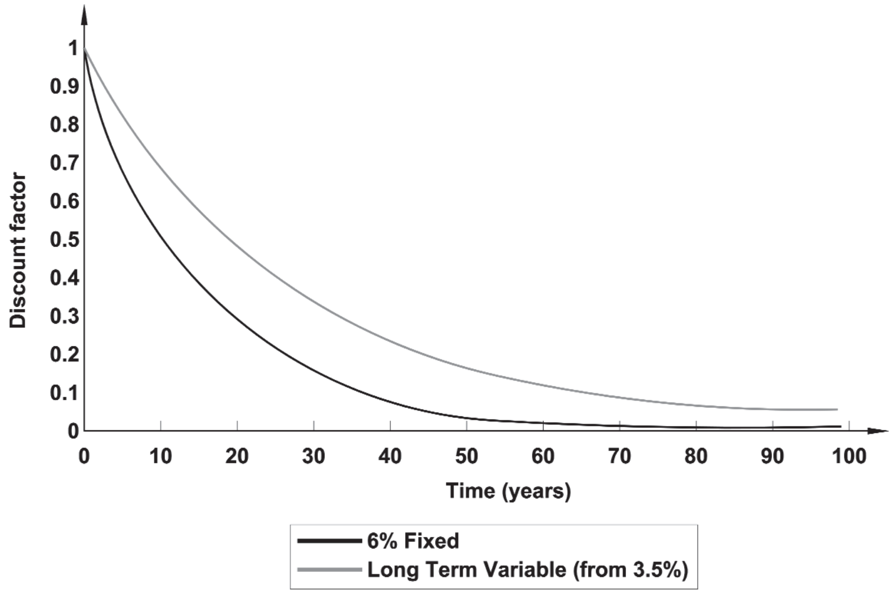

Figure 25.3 *Contribution of annual costs using different discount rates*

This shows that, at a 6 per cent discount rate, the relative contribution of annual expenditures becomes insignificant when compared to the WLC of the system for discount periods of greater than 50 years. Using a 3.5 per cent (declining with time) discount rate, greater weight is given to operation and maintenance costs, and thus expenditure between years 50 and 100 is more significant.

25.11 WHOLE LIFE COSTING CASE STUDY: HOPWOOD SERVICES

25.11.1 Introduction

The case study presented here is taken from the HR Wallingford Report SR 627 (*Whole life costing for SUDS* (HR Wallingford, 2004)) where a whole life costing approach was applied to the SUDS scheme at Hopwood Park motorway service area (Junction 2, M42), near Bromsgrove in Worcestershire. This site comprises 34 hectares, of which nine hectares was developed as motorway service area and 25 hectares as wildlife reserve. The site slopes down to the Hopwood Stream, which is a tributary of the River Arrow.

The system was designed to manage runoff from the 1 in 25 year return period design event, and the "greenfield runoff rate" discharge limit from the site was set to 5 l/s/ha. The 10 mm "first flush" volume is treated by stone trench filtering or wetland treatment before slow release to the stream or wildlife area. Storm events in excess of the 10 mm "first flush" can by-pass "primary treatment" but must pass through a balancing pond which is designed to have a wetland treatment zone to "polish" water passing through the system. Separate spillage containment is provided to areas at risk from severe pollution.

The site can be split into three main areas (excluding the runoff from the amenity building itself), and the characteristics of each drainage system are summarised below:

The HGV lorry park

- water runs across a grass filter strip to trap silt
- 10 mm "first flush" runoff enters a stone collector trench which treats oils and other pollutants naturally
- a spillage basin with wetland "treatment zone" and outlet valve isolates any spillage event
- heavy rain passes across the trench into a grass swale
- a balancing pond with marginal wetland "treatment zone" receives all water before release to the wildlife reserve wetland.

Main access road, fuel filling area and coach park

- a proprietary silt and oil interceptor begins treatment of runoff which has been collected by conventional gully and pipe drainage
- two spillage basins with wetland "treatment zones" and outlet valves isolate any spillage event
- a "constructed wetland" cleans 10 mm "first flush" runoff with an additional outlet valve to isolate any spillage event
- a wetland ditch, receiving water at a controlled rate to prevent erosion, conveys treated "first flush" runoff to the balancing pond with marginal wetland "treatment zone"
- a bypass swale collects storm overflow and conveys it parallel to the ditch over the rip-rap cascade into the pond
- a final balancing pond and treatment wetland receive all water as the last link in the management train before release to the "stilling area" and Hopwood Stream.

Car park

- a sub-surface collector trench treats 10 mm "first flush" runoff
- a bypass channel conveys stormwater directly to the pond
- a pipe outlet delivers all runoff to a balancing pond and marginal wetland "treatment zone" before release to the "stilling area" and Hopwood Stream.

A plan of the development is shown in Figure 25.4.

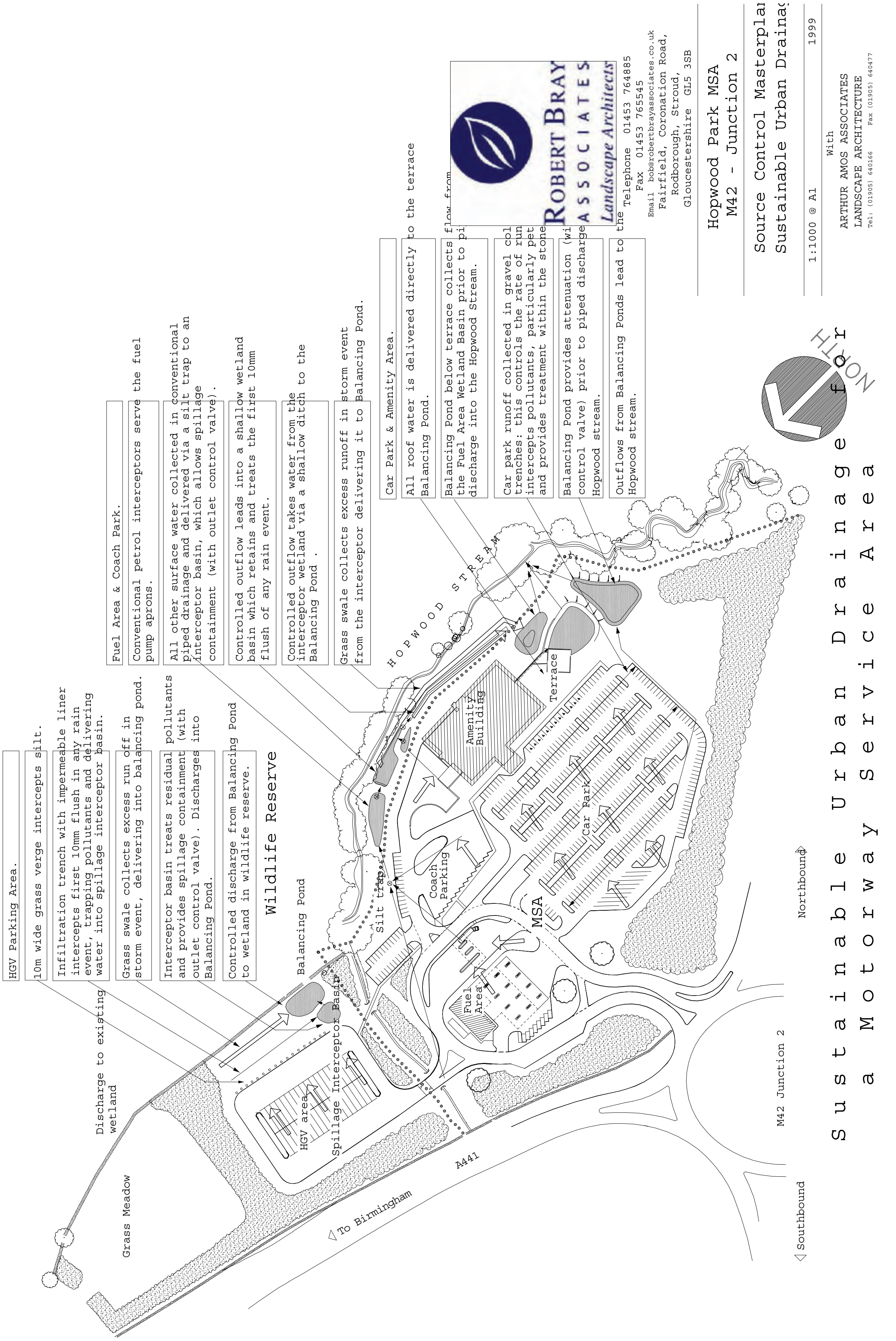

Figure 25.4 *Hopwood Park sustainable drainage scheme*

25.11.2 Capital costs

Actual capital costs for this scheme are not known, so a pricing exercise was undertaken based on activities associated with SUDS construction and using unit costs taken from standard UK pricing schedules. Because of the wide variability in unit costs and the influence of site-specific characteristics, these figures may not be accurate for this particular site. However, the exercise does demonstrate the process of building up capital costs for a typical sustainable drainage scheme.

The costs do not include any of the conventional pipework, proprietary silt traps/oil interceptors, penstocks or valves. The costs also exclude the sub-surface treatment trenches, deep manholes and pipework associated with the main car park drainage as this system is very site-specific.

Table 25.4 *Estimated capital costs for case study site*

Cost components	Cost (£)
Swales 1 Ground works, clearance, excavation, disposal of excavated material, geotextiles, topsoil, turfing, outlet infrastructure, erosion control.	15 000
Filter drain 2 Ground works, clearance, excavation, disposal of excavated material, upstream filter strip, geomembrane, bedding, perforated pipe, granular fill, outlet infrastructure, erosion control.	10 500
Ponds and wetlands 3 Inlet infrastructure, groundworks, clearance, excavation, disposal of excavated material, geomembrane liners, replacement and preparation of topsoil, grassing, barrier planting, bankside planting, aquatic planting, outlet infrastructure, erosion control.	17 500
Supporting costs 4 Planning, design, legal, permitting fees, construction supervision etc. Assume 30% of base construction cost.	13 000
Land take 5 Assume value of land taken by SUDS at Hopwood has no opportunity cost value, ie the areas taken by the SUDS components would have been open space/wildlife reserve irrespective of drainage design.	0
TOTAL	**£56 000**

25.11.3 Operation and maintenance costs

Regular operation and maintenance activities

The following costed maintenance schedules have been based on material in HR Wallingford, 2004 (*Operation and maintenance of sustainable drainage systems (and associated costs)*).

Table 25.5 *Annual, regular operation and maintenance activities*

Peripheral planting	Annual frequency	Unit rate (£)	Total cost (£)
All grass verges 1.2 m–3 m wide or as drawings. All grass around source control areas. All cuttings collected and removed from site, at first and last cut annually. Cuts at 35–50 mm with 75 mm max.	12 cuts	150	1800
Meadow grass to all mounds and native planting areas will require 2 no cuts at 75 mm at an agreed frequency, probably July and October. All raisings to be raked off and stacked in wildlife piles on site.	2 cuts	400	800
Woodland grass to woodland edge and along the stream corridor on the MSA side of the Hopwood Stream 1 cut at 75 mm, all arisings to be raked off and stacked in wildlife piles on site.	1 cut	250	250
All native planting to be checked at grass maintenance visits and stakes and guards kept in good order at all times. All losses to be made good Oct–Dec each year.	3 visits	60	180
Allowance to pick up all litter in planting at monthly site visits.	10 visits	30	300
Sustainable drainage features			
Litter: pick up all litter in planting at monthly site visits.	12 visits	20	240
Grass generally as required. 35–50 mm not to exceed 75 mm. Fortnightly or as required April 1 to Oct 30 plus 2 additional visits Nov and March as specification.	16 visits	25	400
Swale grass as required. 100 mm minimum – 150 mm maximum as required.	8 visits	25	200
Wetland ditch vegetation management. Autumn and spring if necessary.	2 visits	40	80
Aquatic plant management (Sept to Nov). Remove nuisance plants, end of season clearance of up to 25% of growth.	5 visits	100	500
Inlets and outlets			
1 Inlets and outlets 22 no. Remove debris, strim and remove arisings, remove accumulated silt from aprons.	12 visits	50	600
2 Valves. Ensure fully operational.	2 visits	10	20
Rip-rap inspection.	12 visits	10	120
Grass weir inspection.	12 visits	10	120
Stilling area inspection.	12 visits	10	120
Undertake monthly visual monitoring of the site			
Inspect surfaces and ponds for sediment accumulation and damage, monitor aquatic vegetation. Monitor system effectiveness and identify requirements for rehabilitation works.	12 visits	15	180
		TOTAL	£5910

25.11.4 Irregular maintenance

The frequency at which irregular maintenance is required is dependent to a large extent on site characteristics and system design and is, therefore, difficult to predict. If regular monitoring of the system is undertaken over, for example, a three-year period, then these frequencies can be defined with more confidence and long-term maintenance costs re-evaluated.

Table 25.6 indicates the types of activities that should be considered, with estimated frequencies. For more information, see HR Wallingford, 2004.

Table 25.6 *Occasional/infrequent maintenance*

	Estimated frequency (years)	Unit rate(£)
Swale		
Removal of excess silt due to slow accumulation and dispose of to land (subject to toxicity test).	3	250
Surface treatment to encourage infiltration in the case of reduced permeability.	3	250
Replace topsoil and dispose of accumulated silts and topsoil to land (subject to toxicity test).	25	2000
Filter drain and filter strip		
Removal of excess silt due to slow accumulation and dispose of to land (subject to toxicity test).	3	250
Limited weed control (using non-toxic/biodegradable substances).	3	50
Removal and cleaning of stone, removal and safe disposal of geotextile, replacement of geotextile and clean stone.	25	1000
Ponds and wetlands		
Partial silt removal and disposal to land (subject to toxicity test).	3	500

25.11.5 Remedial operation and maintenance/rehabilitation

Remedial maintenance can often be managed out through good design. Where such activities are found to be necessary, this is likely to be due to site-specific characteristics or unforeseen events. Frequencies are presented here in order to allow rehabilitation costs to feature in this example whole life cost appraisal. A lump sum contingency is entered into the "unit rate" column, as it is not likely that all the identified activities would be required.

Table 25.7 *Irregular operation and maintenance/rehabilitation*

	Estimated frequency (years)	Unit rate
Swale Reinstatement and repair of edgings. Reinstatement of levels and turf due to erosion by rills and gullies. Repair/rehabilitation of outlets. **System rehabilitation as a result of high silt loads discharged during a single event.**	10	3000
Filter drain and filter strip Reinstatement and repair of edgings. Reinstatement of levels and turf due to erosion by rills and gullies. System rehabilitation as a result of high silt loads discharged during a single event. Repair/rehabilitation of inlets, outlets, overflows, rip rap and erosion control.	10	3000
Ponds and wetlands Removal of silt. Repair of erosion or other damage. Replacement of aquatic or barrier planting. Repair/rehabilitation of inlets, outlets, overflows, rip-rap and erosion control.	10	5000

25.11.6 Risk costs

In this example, the costs associated with hydraulic system performance failure have been managed out through good design and established monitoring and maintenance regimes. The impact of water quality failure will be borne by the local environment, and there should be no cost to the SUDS owner. Therefore risk costs can be ignored.

25.11.7 Environmental benefits

There are a range of environmental benefits ("negative" costs) that will accrue from implementing SUDS at this site, compared to conventional drainage. These include amenity and recreation opportunities, biodiversity and ecological enhancement, base flow augmentation for the receiving watercourse, water quality improvements, and net flood risk reduction. Very few of these benefits will be seen as tangible value to the SUDS owner, but it is beneficial to highlight potential values as part of this case study and the assumption is made that the benefits will be felt in terms of increased revenue in the amenity building.

There is good access to the SUDS, the site is available at all times of year, public facilities have been provided (eg footpaths), and the characteristics of the site are relatively rare for a motorway service area. Although a large proportion of the visitors will be interested only in purchasing fuel, food and drink, and will pay little attention to their environment, there is undoubtedly an improved environmental quality associated with the site. In the summer, there will be a much greater appreciation of the features when many people will eat outside. In such cases, the SUDS owner may experience increased revenue as a result of the SUDS. The per annum value of recreation benefits arising from the scheme could be estimated using the following relationship:

$$\textit{Benefits} = \textit{Number of visits} \times \textit{Transfer value (per visit per year)}$$

There are no guidelines on estimating transfer (see Section 25.8.2) values of this type, but from material collated in Section 4.6.1 of HR Wallingford, 2004, a preliminary conservative value could be taken to be £0.10 per car per visit.

The number of car parking spaces is approximately 500 – it is assumed that number of visitors per day is 1000, and that 2 per cent of these visitors appreciate the SUDS features. This gives an environmental benefit (related to recreation and amenity) value of $0.02 \times 0.1 \times 1000 =$ £2/ day (or £730/year).

It is very difficult to estimate the economic value of changes in water quality or improvement in biodiversity and no attempt is made to do so here.

25.11.8 Disposal costs

Costs associated with the disposal of vegetation, granular fill, geotextile and sediments have been accounted for within the operation and maintenance estimates. No allowance is made for decommissioning the system as it is assumed that if there was a change in site use, such costs would be covered by the future developer.

25.11.9 Residual costs

The land taken by the SUDS components is not land that would otherwise be available for development. The site is located away from residential areas and is now an established wildlife park, therefore the residual land cost at the end of the study period can be ignored/assumed to be zero.

25.11.10 Discount rate

The discount rate currently recommended by the Treasury is 3.5 per cent, and this is used for the WLC example.

25.11.11 Whole life cost analysis

Table 25.8 and Figures 25.5 and 25.6 demonstrate an assessment of SUDS investment costs through time using a WLC approach. It should be noted that the environmental benefits are subtracted from the costs, as they will act as an offset.

Table 25.8 *Derivation of net present values of SUDS expenditure*

Hopwood Services									
Discount rate			3.5%						
		Capital	Environmental benefits	Risks	Regular maintenance	Irregular maintenance	Irregular refurbishment	Cash	PV
Year	Cash sum (£)	56,000	35,770	0	289,590	22,200	44,000	376,020	206,786
	Discount factor								
0	1.000	56,000	0	0	0	0	0	56,000	56,000
1	0.966	0	730	0	5910	0	0	5,180	5,005
2	0.934	0	730	0	5910	0	0	5,180	4,836
3	0.902	0	730	0	5910	1,200	0	6,380	5,754
4	0.871	0	730	0	5910	0	0	5,180	4,514
5	0.842	0	730	0	5910	0	0	5,180	4,361
6	0.814	0	730	0	5910	1,200	0	6,380	5,190
7	0.786	0	730	0	5910	0	0	5,180	4,071
8	0.759	0	730	0	5910	0	0	5,180	3,934
9	0.734	0	730	0	5910	1,200	0	6,380	4,681
10	0.709	0	730	0	5910	0	11,000	16,180	11,470
11	0.685	0	730	0	5910	0	0	5,180	3,548
12	0.662	0	730	0	5910	1,200	0	6,380	4,222
13	0.639	0	730	0	5910	0	0	5,180	3,312
14	0.618	0	730	0	5910	0	0	5,180	3,200
15	0.597	0	730	0	5910	1,200	0	6,380	3,808
16	0.577	0	730	0	5910	0	0	5,180	2,987
17	0.557	0	730	0	5910	0	0	5,180	2,886
18	0.538	0	730	0	5910	1,200	0	6,380	3,435
19	0.520	0	730	0	5910	0	0	5,180	2,694
20	0.503	0	730	0	5910	0	11,000	16,180	8,132
21	0.486	0	730	0	5910	1,200	0	6,380	3,098
22	0.469	0	730	0	5910	0	0	5,180	2,430
23	0.453	0	730	0	5910	0	0	5,180	2,348
24	0.438	0	730	0	5910	1,200	0	6,380	2,794
25	0.423	0	730	0	5910	3,000	0	8,180	3,461
26	0.409	0	730	0	5910	0	0	5,180	2,118
27	0.395	0	730	0	5910	1,200	0	6,380	2,520
28	0.382	0	730	0	5910	0	0	5,180	1,977
29	0.369	0	730	0	5910	0	0	5,180	1,910
30	0.356	0	730	0	5910	1,200	11,000	17,380	6,192
31	0.344	0	730	0	5910	0	0	5,180	1,783
32	0.333	0	730	0	5910	0	0	5,180	1,723
33	0.321	0	730	0	5910	1,200	0	6,380	2,050
34	0.310	0	730	0	5910	0	0	5,180	1,608
35	0.300	0	730	0	5910	0	0	5,180	1,554
36	0.290	0	730	0	5910	1,200	0	6,380	1,849
37	0.280	0	730	0	5910	0	0	5,180	1,451
38	0.271	0	730	0	5910	0	0	5,180	1,402
39	0.261	0	730	0	5910	1,200	0	6,380	1,668
40	0.253	0	730	0	5910	0	11,000	16,180	4,087
41	0.244	0	730	0	5910	0	0	5,180	1,264
42	0.236	0	730	0	5910	1,200	0	6,380	1,504
43	0.228	0	730	0	5910	0	0	5,180	1,180
44	0.220	0	730	0	5910	0	0	5,180	1,140
45	0.213	0	730	0	5910	1,200	0	6,380	1,357
46	0.205	0	730	0	5910	0	0	5,180	1,064
47	0.199	0	730	0	5910	0	0	5,180	1,028
48	0.192	0	730	0	5910	1,200	0	6,380	1,224
49	0.185	0	730	0	5910	0	0	5,180	960

The expenditure profiles are shown in Figures 25.5 and 25.6.

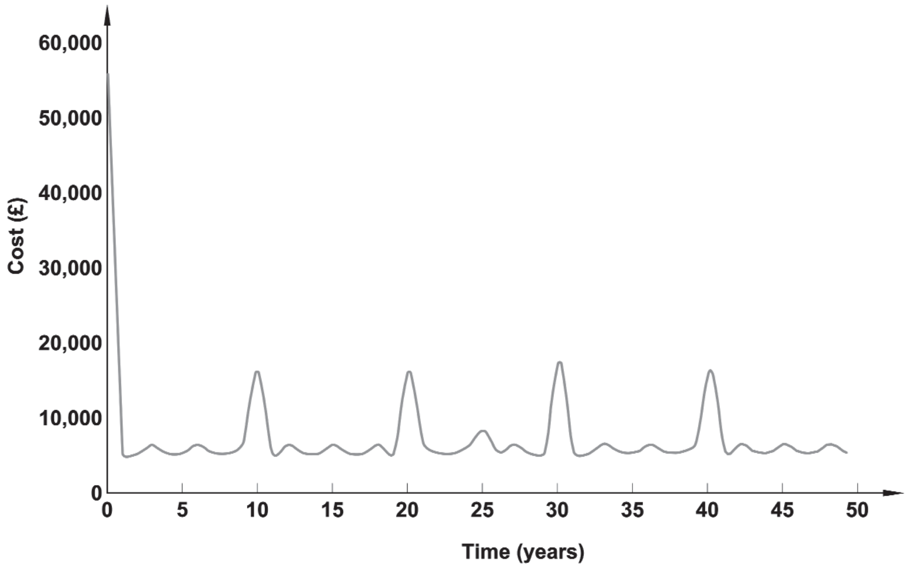

Figure 25.5 *SUDS expenditure with time (net present costs): case study example*

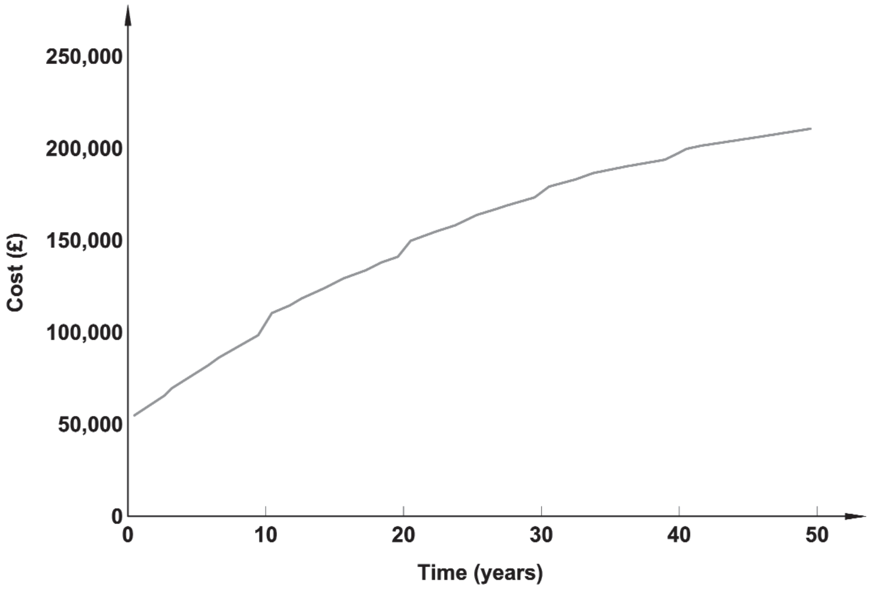

Figure 25.6 *Cumulative SUDS expenditure (net present costs): case study example*

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Glossary and abbreviations

Glossary

Adsorption	The adherence of gas, vapour, or dissolved matter to the surface of solids.
Algae	Simple plants ranging from single cells to large plants.
Amenity	The quality of being pleasant or attractive; agreeableness. A feature that increases attractiveness or value, especially of a piece of real estate or a geographic location
Ammonia	A water soluble chemical compound, produced by the decomposition of organic material. Ammonia affects the quality of fisheries and the suitability of abstractions for potable water supply. Used as a water quality indicator. Ammonia is a List II substance (see below).
Aquatic bench	A horizontal strip lying just beneath the water surface on which aquatic planting is established.
Aquifer	A sub-surface zone or formation of rock or soil containing a body of groundwater.
Asphalt	European standard description of all mixtures of mineral aggregates bound with bituminous materials used in the construction and maintenance of paved surfaces.
Atmospheric	From the atmosphere.
Attenuation	Reduction of peak flow and increased duration of a flow event.
Attenuation storage	Volume used to store runoff during extreme rainfall events. Comes into use once the inflow is greater than the controlled outflow.
Baffle	A device designed to prevent flows short-circuiting through a pond.
Balancing pond	A pond designed to attenuate flows by storing runoff during the storm and releasing it at a controlled rate during and after the storm. The pond always contains water.
Base flow	The sustained flow in a channel or drainage system.
Basin	A ground depression acting as a flow control or water treatment structure that is normally dry and has a proper outfall, but is designed to detain stormwater temporarily.
Bentonite	A colloidal clay, largely made up of the mineral sodium montmorillonite, a hydrated aluminium silicate.
Berm	A mound of earth formed to control the flow of surface water.
Binder course	European standard description of the second layer of an asphalt pavement currently known in UK as basecourse.

Biochemical oxygen demand (BOD)	The measure of the concentration of biodegradable organic carbon compounds in solution. Used as a water quality indicator.
Biodegradable	Capable of being decomposed by bacteria or other living organisms.
Biodegradation	Decomposition of organic matter by micro-organisms and other living things.
Biodiversity	The diversity of plant and animal life in a particular habitat
Bioretention area	A depressed landscaping area that is allowed to collect runoff so it percolates through the soil below the area into an underdrain, thereby promoting pollutant removal.
Bitumen	A hydrocarbon binder. A virtually no volatile adhesive material derived from crude petroleum that is used to coat mineral aggregate for use in construction and maintenance of paved surfaces.
Block paving	Pre-cast concrete or clay brick sized flexible modular paving system.
Breakthrough head	The water pressure required to cause flow of water through the material (eg geotextile)
Brownfield site	A site that has been previously developed.
Brown roof	A roof that incorporates a substrate (laid over a waterproof membrane) that is allowed to colonise naturally. Sometimes referred to as an alternative roof.
Buffer	Something that helps reduce the scale of an impact.
Bund	A barrier, dam, or mound usually formed from earthworks material and used to contain or exclude water (or other liquids) from an area of the site.
California bearing ratio (CBR) value	An empirical measure of the stiffness and strength of soils, used in road pavement design.
Capping layer	A layer of unbound aggregate of lower quality than sub-base that is used to improve the performance of the foundation soils before laying the sub-base and to protect the sub-grade from damage by construction traffic.
Carriageway	That part of the road used to carry vehicular traffic.
Casing	An impervious, durable pipe placed in a borehole to prevent the walls of the borehole from collapsing, and to seal off surface drainage or undesirable water, gas or other fluids, and prevent their entrance into such an excavation.
Catchment	The area contributing surface water flow to a point on a drainage or river system. Can be divided into sub-catchments.
Catchpit	A small chamber incorporating a sediment collection sump which the runoff flows through.
Chemical oxygen demand (COD)	The measure of the amount of oxygen taken up by chemical oxidation of a substance in solution. Used as a water quality indicator.
Cistern	A fixed container for holding water to be used as toilet flush water.
Coliform	Bacteria found in the intestines, faeces, nutrient rich waters, soil, and decaying plant matter.

Combined sewer	A sewer designed to carry foul sewage and surface runoff in the same pipe.
Construction cycle	The sequence of events or activities carried out in the development of a construction project.
Construction (Design and Management) Regulations 1994 (CDM)	Construction (Design and Management) Regulations 1994, which emphasise the importance of addressing construction health and safety issues at the design phase of a construction project.
Construction Quality Assurance (CQA)	A documented management system designed to provide adequate confidence that items or services meet contractual requirements and will perform adequately in service. CQA usually includes inspection and testing of installed components and recording the results.
Contaminated ground	Ground that has the presence of such substances which, when present in sufficient quantities or concentrations, are likely to have detrimental effects on potential targets.
Continuously graded	A soil or aggregate with a balanced range of particle sizes with significant proportions of all fractions from the maximum nominal size down.
Control structure	Structure to control the volume or rate of flow of water through or over it.
Controlled waters	Waters defined and protected under the Water Resources Act 1991. Any relevant territorial waters that extend seaward for three miles from the baselines, any coastal waters which extend inland from those baselines to the limit of the highest tide or the freshwater limit of any river or watercourse, any enclosed dock which adjoins coastal waters, inland freshwaters, including rivers, watercourses, and ponds and lakes with discharges and ground waters (waters contained in underground strata). For the full definition refer to the Water Resources Act 1991.
Conventional drainage	The traditional method of draining surface water using subsurface pipes and storage tanks.
Conveyance	Movement of water from one location to another.
Creep	A load placed on a polymer material will result in an initial deformation, but with the load remaining over time, further deformation will continue to occur. The rate of creep becomes greater as the applied load increases.
Critical duration event	The duration of rainfall event likely to cause the highest peak flows at a particular location, for a specified return period event.
Cross-contamination	Pipes carrying mains water connected to pipes carrying non-potable water.
Curtilage	Land area within property boundaries.
Degradation	Being broken down to a less complex/lower state.
De-nitrification	A microbial process that reduces nitrate to nitrite and nitrite to nitrogen gas.
Deposition	Laying down of matter via a natural process.

Design criteria	A set of standards agreed by the developer, planners, and regulators that the proposed system should satisfy.
Detention basin	A vegetated depression that is normally dry except following storm events. Constructed to store water temporarily to attenuate flows. May allow infiltration of water to the ground.
Detention pond/tank	A pond or tank that has a lower outflow than inflow. Often used to prevent flooding.
De-watering	The removal of groundwater/surface water to lower the water table.
Diffuse pollution	Pollution arising from land-use activities (urban and rural) that are dispersed across a catchment, or sub-catchment, and do not arise as a process effluent, municipal sewage effluent, or an effluent discharge from farm buildings.
Discharge consent	Permission to discharge effluent, subject to conditions laid down in the consent, issued by the relevant environment regulator.
Dissolved oxygen (DO)	The amount of oxygen dissolved in water. Oxygen is vital for aquatic life, so this measurement is a test of the health of a river. Used as a water quality indicator.
Down pipes	Pipes leading down from roof guttering to drains.
Dust	Airborne solid mater up to about 2 mm in size.
Duty of care	The implication of the duty of care is that toxic materials are monitored and administered by an appropriate system each time they pass from one individual to another, or from one process to another. Important information regarding the nature of the material and any appropriate emergency action should be passed on.
Ecology	All living things, such as trees, flowering plants, insects, birds and mammals, and the habitats in which they live.
Ecosystem	A biological community of interacting organisms and their physical environment.
Environment	Both the natural environment (air, land, water resources, plant, and animal life) and the habitats in which they live.
Environmental regulators	These include the Environment Agency (in England and Wales), the Scottish Environment Protection Agency, The Environment and Heritage Service in Northern Ireland, and the Department of Public Services in Jersey and Guernsey.
Erosion	The group of natural processes, including weathering, dissolution, abrasion, corrosion, and transportation, by which material is worn away from the earth's surface
Estuary	A semi-enclosed body of water in which seawater is substantially diluted with freshwater entering from land drainage.
Eutrophication	Water pollution caused by excessive plant nutrients that results in reduced oxygen levels. The nutrients are powerful stimulants to algal growth which in turn use up oxygen in water. The excessive growth, or "blooms", of algae promoted by these phosphates change the water quality in lakes and ponds which can kill fish.

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

Extended detention basin A detention basin where the runoff is stored beyond the time for attenuation. This provides extra time for natural processes to remove some of the pollutants in the water.

Fauna The animals found in a particular physical environment.

Fatigue Fatigue is loss of strength that occurs due to repeated application of traffic or other loads which may reduce the strength of the units in the long term.

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

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

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

Fines Small soil particles less than 63 micron in size.

First flush The initial runoff from a site or catchment following the start of a rainfall event. As runoff travels over a catchment it will collect or dissolve pollutants, and the "first flush" portion of the flow may be the most contaminated as a result. This is specially the case for intense storms and in small or more uniform catchments. In larger or more complex catchments pollution wash-off may contaminate runoff throughout a rainfall event.

Flood frequency The probability of a flowrate being exceeded in any year.

Flood plain Land adjacent to a watercourse that would be subject to repeated flooding under natural conditions. (see Environment Agency's Policy and practice for the protection of flood plains for a fuller definition).

Flood routing Design and consideration of above-ground areas that act as pathways permitting water to run safely over land to minimise the adverse effect of flooding. This is required when the design capacity of the drainage system has been exceeded.

Flora The plants found in a particular physical environment.

Flow control device A device used for the control of surface water from an attenuation facility, eg a weir.

Forebay A small basin or pond upstream of the main drainage component with the function of trapping sediment.

Formation level Surface of an excavation prepared to support a pavement

Freeboard Distance between the design water level and the top of a structure, provided as a precautionary safety measure against early system failure.

Foul drainage The infrastructure that drains the water and sewage that is discharged from within houses.

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

Geogrid	Plastic grid structure used to increase strength of soils or aggregates.
Geomembrane	An impermeable plastic sheet, typically manufactured from polypropylene, high density polyethylene or other geosynthetic material.
Geotextile	A plastic fabric that is permeable.
Green roof	A roof with plants growing on its surface, which contributes to local biodiversity. The vegetated surface provides a degree of retention, attenuation and treatment of rainwater, and promotes evapotranspiration. Sometimes referred to as an alternative roof.
Greenfield runoff	The surface water runoff regime from a site before development, or the existing site conditions for brownfield redevelopment sites.
Greywater	Waste water from baths, showers, sinks (kitchen sinks are excluded due to nutrient rich effluent), and domestic appliances before it reaches the sewer (or septic tank sewer).
Groundwater	Water that is below the surface of ground in the saturation zone.
Groundwater zone	Areas that influence water supply boreholes where protection groundwater must be protected from pollution. These are defined by reference to travel times of pollutants within the groundwater. See the Environment Agency's Policy and Practice for the protection of groundwater for specific details.
Grout	A fluid mixture of cement and water of such consistency that it can be forced through a pipe and placed as required. Various additives such as sand, bentonite, and hydrated lime may be in included in the mixture to meet certain requirements.
Grouting	The operation by which grout is placed.
Gully	Opening in the road pavement, usually covered by metal grates, which allows water to enter conventional drainage systems.
Gully erosion	The erosion of soils by surface runoff, resulting typically in steep-side channels and small ravines, poorly consolidated superficial material, or bedrock by streams or runoff water.
Habitat	The area or environment where an organism or ecological community normally lives or occurs
Hazard	A property, situation, or substance with potential to cause harm.
Heavy metal	Loosely, metals with a high atomic mass (sometimes given as metals with an atomic mass greater than that of calcium), often used in discussion of metal toxicity. No definitive list of heavy metals exists, but they generally include cadmium, zinc, mercury, chromium, lead, nickel, thallium, and silver. Some metalloids, eg arsenic and antimony, are classified as heavy metals for discussion of their toxicity.
Highways Agency	The government agency responsible for strategic highways in England, ie motorways and trunk roads.

Highways authority	A local authority with responsibility for the maintenance and drainage of highways maintainable at public expense. The equivalent in Scotland is a roads authority.
Highway drain	A conduit draining the highway on a highway maintainable at the public expense it is vested in the highway authority.
Hydraulics	Hydraulics is another term for fluid mechanics used in the context of water engineering, and is the study of flows. In the context of this report, hydraulics covers the storage, conveyance and control of flows within the proposed drainage network.
Hydrogeology	Hydrogeology is the study of water below the ground surface and geological aspects of surface water. In the context of this report, hydrogeology covers the dissipation of the rainfall-runoff beneath a permeable soil surface.
Hydrograph	A graph illustrating changes in the rate of flow from a catchment with time.
Hydrology	The study of the waters of the Earth, their occurrence, circulation, and distribution; their chemical and physical properties; and their relation with the environment, including their relation to living things.
Hyetograph	Temporal rainfall profile.
Impermeable	Will not allow water to pass through it.
Impermeable surface	An artificial non-porous surface that generates a surface water runoff after rainfall.
Infiltration (to a sewer)	The entry of groundwater to a sewer.
Infiltration (to the ground)	The passage of surface water into the ground.
Infiltration basin	A dry basin designed to promote infiltration of surface water to the ground.
Infiltration device	A device specifically designed to aid infiltration of surface water into the ground.
Infiltration trench	A trench, usually filled with permeable granular material, designed to promote infiltration of surface water to the ground.
Initial rainfall loss	The amount of rain that falls on a surface before water begins to flow off the surface.
Interception storage	The capture and infiltration of rainfall depths.
Interflow	Shallow infiltration to the soil, from where it may infiltrate vertically to an aquifer, move horizontally to a watercourse, or be stored and subsequently evaporated.
Interim Code of Practice	An agreed provisional document within the existing legislative framework that establishes good practice.
Invertebrates	Animals that lack a vertebral column. This includes many groups of animals used for biological grading, such as insects, crustaceans, worms, and molluscs.
Joint probability	The probability that two or more specific outcomes will occur in an event.

Lateral drain (a) That part of a drain which runs from the curtilage of a building (or buildings or yards within the same curtilage) to the sewer with which the drain communicates or is to communicate; or

(b) (if different and the context so requires) the part of a drain identified in a declaration of vesting made under section 102 or in an agreement made under section 104 of the Water Industry Act 1991.

Leaching The process during which soluble minerals may be removed from the soil by water percolating through it.

Leakage The flow of water from one hydrologic unit to another. The leakage may be natural (as through a semi-impervious confining layer) or manmade (as through an uncased well).

Legionella A bacterium named Legionella pneumophila that can cause legionnaires' disease (lung infection) in humans.

List I substance A controlled substance as defined under the Groundwater Regulations 1998 and the Dangerous Substances Directive (76/464/EEC). List I substances are considered the most dangerous in terms of toxicity, bio-accumulation and persistence. These controls prevent their discharge to the environment.

List II substance A controlled substance as defined under the Groundwater Regulations 1998 and the Dangerous Substances Directive (76/464/EEC). They are less toxic than List I substances but are still capable of harm, hence their discharge to the environment is limited.

Long-term storage Provided to allow volumetric runoff control during an event by discharging water very slowly during and after the storm event.

Macroinvertebrates Invertebrate animals of sufficient size to be easily visible to the unaided eye and to be retained in a net with a 1 mm mesh.

Macrophyte Plants easily visible to the naked eye.

Management train The management of runoff in stages as it drains from a site.

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

Model agreement A legal document that can be completed to form the basis of an agreement between two or more parties regarding the maintenance and operation of sustainable water management systems.

Morphology The characteristics, configuration, and evolution of a river.

Nature conservation bodies The four organisations that have regional responsibility for promoting the conservation of wildlife and natural features: Countryside Council for Wales, English Nature, Environment and Heritage Service (Northern Ireland), and Scottish Natural Heritage.

Noise Often defined as a sound that is not desired. Sound is a wave motion carried by air molecules between the source and the receiver, usually the ear.

Non-return valve A pipe fitting that limits flow to one direction only.

Nutrient	A substance providing nourishment for living organisms (such as nitrogen and phosphorus).
Off-line	Dry weather flow bypasses the storage area.
On-line	Dry weather flow passes through the storage area.
Open water	Clear water surface ie free from submerged or floating aquatic vegetation.
Organic pollution	A general term describing the type of pollution that, through the action of bacteria, consumes the dissolved oxygen in rivers. The effects of organic pollution are described by the levels of bio-chemical oxygen demand, ammonia, and dissolved oxygen found in a waterbody.
Orifice plate	Structure with a fixed aperture to control the flow of water.
Pathogen	An organism that causes disease.
Pathway	The route by which potential contaminants may reach targets.
Pavement	The road or car park surface and underlying structure, usually asphalt, concrete, or blockpaving. Note: the path next to the road for pedestrians (the UK colloquial term of pavement) is the footway.
Penstock	A sliding plate which moves vertically to vary the size of an aperture (or close it completely).
Percentage runoff	The proportion of rainfall that runs off a surface.
Percolation	The passing of water (or other liquid) through a porous substance or small holes (eg soil or geotextile fabric).
Permeability	A measure of the ease with which a fluid can flow through a porous medium. It depends on the physical properties of the medium, for example grain size, porosity, and pore shape.
Permeable pavement	A permeable surface that is paved and drains through voids between solid parts of the pavement.
Permeable surface	A surface that is formed of material that is itself impervious to water but, by virtue of voids formed through the surface, allows infiltration of water to the sub-base through the pattern of voids, for example concrete block paving.
Pervious surface	A surface that allows inflow of rainwater into the underlying construction or soil.
Phreatic surface	Groundwater surface.
Piped system	Conduits generally located below ground to conduct water to a suitable location for treatment and/or disposal.
Point source pollution	Pollution that arises from an easily identifiable source, usually an effluent discharge pipe.
Pollution	A change in the physical, chemical, radiological, or biological quality of a resource (air, water or land) caused by man or man's activities that is injurious to existing, intended, or potential uses of the resource.
Pond	Permanently wet depression designed to retain stormwater above the permanent pool and permit settlement of suspended solids and biological removal of pollutants.
Porosity	The percentage of the bulk volume of a rock or soil that is occupied by voids, whether isolated or connected.

Porous asphalt	An asphalt material used to make pavement layers pervious, with open voids to allow water to pass through (previously known as pervious macadam).
Porous surface	A surface that infiltrates water to the sub-base across the entire surface of the material forming the surface, for example grass and gravel surfaces, porous concrete and porous asphalt.
Porous paving	A permeable surface that drains through voids that are integral to the pavement.
Potable/mains water	Water company/utility/authority drinking water supply.
Prevention	Site design and management to stop or reduce the occurrence of pollution of impermeable surfaces and to reduce the volume of runoff by reducing impermeable areas.
Priority substances	Key substances identified as critical to control by a particular piece of legislation.
Proper outfall	An outfall to a watercourse, public sewer and in some instances an adopted highway drain. Under current legislation and case law, having a proper outfall is a prerequisite in defining a sewer.
Public sewer	A sewer that is vested and maintained by the sewerage undertaker.
Rainfall event	A single occurrence of rainfall before and after which there is a dry period that is sufficient to allow its effect on the drainage system to be defined.
Rainwater butt	Small scale garden water storage device which collects rainwater from the roof via the drainpipe.
Rainwater harvesting or rainwater system	A system that collects rainwater from where it falls rather than allowing it to drain away. It includes water that is collected use within the boundaries of a property, from roofs and surrounding surfaces.
Recharge	The addition of water to the groundwater system by natural or artificial processes.
Recurrence interval	The average time between runoff events that have a certain flow rate, eg a flow of 2 m/s might have a recurrence interval of two years.
Recycling	Collecting and separating materials from waste and processing them to produce marketable products.
Reed bed	Area of grass-like marsh plants, primarily adjacent to freshwater. Artificially constructed reed beds can be used to accumulate suspended particles and associated heavy metals, or to treat small quantities of partially treated sewage effluent.
Retention pond	A pond where runoff is detained for a sufficient time to allow settlement and biological treatment of some pollutants.
Return period	Refers to how often an event occurs. A 100-year storm refers to the storm that occurs on average once every hundred years. In other words, its annual probability of exceedance is 1 per cent (1/100). A 500-year storm is the storm expected to occur once every 500 years, or has an annual probability of exceedance equal to 0.2 per cent (1/500).

Riffle	A rocky shoal or sandbar lying just below the surface of a watercourse.
Riparian	Of, on, or relating to the banks of a natural course of water
Risk	The chance of an adverse event. The impact of a risk is the combination of the probability of that potential hazard being realised, the severity of the outcome if it is, and the numbers of people exposed to the hazard.
Risk assessment	"A carefully considered judgement" requiring an evaluation of the consequences that may arise from the hazards identified, combining the various factors contributing to the risk and then evaluating their significance.
Risk control	The definition of the measures necessary to control the risk, coupled with their implementation; the management of the risk. The risk management process must include the arrangements for monitoring the effectiveness of the control measures together with their review to ensure continuing relevance.
Road pavement	see Pavement.
Runoff	Water flow over the ground surface to the drainage system. This occurs if the ground is impermeable, is saturated or rainfall is particularly intense.
Runoff coefficient	A measure of the amount of rainfall that is converted to runoff.
Salmonid fishery	Waters in which game fish (such as salmon, trout, grayling, and whitefish) are found.
Scour	Localised erosion.
Section 38	An agreement entered into pursuant to Section 38 Highways Act 1980 whereby a way that has been constructed or that is to be constructed becomes a highway maintainable at the public expense. A publicly maintainable highway may include provision for drainage of the highway. (Drainage of highways is defined in section 100 (9) of the Highways Act 1980.)
Section 102 or 104	A section within the Water Industry Act 1991 permitting the adoption of a sewer, lateral drain or sewage disposal works by a sewerage undertaker. Sometimes referred to as S102 or S104.
Section 106 TCPA 1990	A section within the Town and Country Planning Act 1990 that allows a planning obligation to a local planning authority to be legally binding.
Section 106 WIA 1991	A key section of the Water Industry Act 1991, relating to the right of connection to a public sewer.
Sediments	Sediments are the layers of particles that cover the bottom of water-bodies such as lakes, ponds, rivers, and reservoirs.
Separate sewer	A sewer for surface water or foul sewage, but not a combination of both.
Sewer	A pipe or channel taking domestic foul and/or surface water from buildings and associated paths and hard-standings from two or more curtilages and having a proper outfall.

Sewerage undertaker	This is a collective term relating to the statutory undertaking of water companies that are responsible for sewerage and sewage disposal including surface water from roofs and yards of premises.
Sewers for Adoption	A guide agreed between sewerage undertakers and developers (through the House Builders Federation) specifying the standards to which private sewers need to be constructed to facilitate adoption.
Sewers for Scotland	The objective is the same as Sewers for Adoption (ie defining construction standards for drainage systems), but varying in technical legal detail.
Silt	The generic term for waterborne particles with a grain size of 4-63 mm, ie between clay and sand.
Single size grading (single size material)	The majority of the soil or aggregate particles are of one nominal size, although there may be small proportions of other sizes.
Site of Special Scientific Interest (SSSI)	An area of land or water notified under the Wildlife and Countryside Act 1981 (as amended) as being of geological or nature conservation importance in the opinion of Countryside Council for Wales, Natural England, Scottish Natural Heritage or the Environment and Heritage Service (Northern Ireland)
Soakaway	A sub-surface structure into which surface water is conveyed, designed to promote infiltration.
Soil	The terrestrial medium on which many organisms depend, which is a mixture of minerals (produced by chemical, physical and biological weathering of rocks), organic matter, and water. It often has high populations of bacteria, fungi, and animals such as earthworms.
Source control	The control of runoff at or near its source.
Source protection zone	See Groundwater protection zone
Special Area of Conservation (SAC)	Established under the EC Habitats Directive (92/43/EEC), implemented in the UK by The Conservation (Natural Habitats, &c.) Regulations 1994, and The Conservation (Nature Habitats, etc.) Regulations (Northern Ireland) 1995. The sites are significant in habitat type and species, and are considered in greatest need of conservation at a European Level. All UK SACs are based on SSSIs, but may cover several separate but related sites.
Storm	An occurrence of rainfall, snow, or hail.
Stormwater hotspot	Stormwater hotspots are defined in the USA as areas where land use or activities may generate highly contaminated runoff, or where groundwater is an important resource for drinking water abstraction.
Sub-base	A layer of material on the sub-grade that provides a foundation for a pavement surface.
Sub-catchment	A division of a catchment, to allow runoff to be managed as near to the source as is reasonable.
Sub-grade	Material, usually natural *in-situ*, but may include capping layer, below formation level of a pavement.

Substrate	An underlying layer; a substratum.
SUDS	Sustainable drainage systems: an approach to surface water management that combines a sequence of management practices and control structures designed to drain surface water in a more sustainable fashion than some conventional techniques.
Sump	A pit that may be lined or unlined and is used to collect water and sediments before being pumped out.
Surface course	European standard description of the top layer of an asphalt pavement currently known in UK as wearing course.
Surface water	Water that appears on the land surface, i.e. lakes, rivers, streams, standing water, and ponds.
Suspended solids	General term describing suspended material. Used as a water quality indicator.
Swale	A shallow vegetated channel designed to conduct and retain water, but may also permit infiltration. The vegetation filters particulate matter.
Time of entry	Time taken for rainwater to reach an inlet into the drainage system after hitting the ground.
Toxic material	Material capable of causing injury or death to flora or fauna, especially by chemical means; poisonous
Trash rack	Rack of bars installed to trap litter or debris to minimise risks of blockage of a conveyance path (eg pipe).
Treatment	Improving the quality of water by physical, chemical and/or biological means.
Turbidity	Reduced transparency of a liquid caused by the presence of un-dissolved matter.
Type 1 sub-base	Specification for the most commonly used sub-base material in conventional pavements, from the Specification for Highway Works.
Unconfined aquifer	An aquifer where the water table is exposed to the atmosphere through openings in the overlying materials.
Void ratio	The ratio of open air space to solid particles in a soil or aggregate.
Vortex flow control	The induction of a spiral/vortex flow of water in a chamber used to control or restrict the flow.
Waste	Any substance or object that the holder discards, intends to discard, or is required to discard.
Wastewater treatment works (WWTW)	Installation to treat and make less toxic domestic and/or industrial effluent.
Watercourse	A term including all rivers, streams, ditches, drains, cuts, culverts, dykes, sluices, and passages through which water flows.
Water Quality Treatment volume	The proportion of total runoff from impermeable areas that is captured and treated to remove pollutants.
Water table	The point where the surface of groundwater can be detected. The water table may change with the seasons and the annual rainfall.

Weir	Horizontal structure of predetermined height to control flow.
Well	Any excavation that is drilled, cored, bored, washed, fractured, driven, dug, jetted, or otherwise constructed when the intended use is for the location, monitoring, de-watering, observation, diversion, artificial recharge, or acquisition of groundwater, or for conducting a pumping aquifer test.
Wetland	Flooded area in which the water is shallow enough to enable the growth of bottom-rooted plants.
Wetted perimeter	The length of the line of contact between the liquid and the channel boundary at that section.
Whole life cost	The present day value of total costs of a structure throughout its likely operating life.

Abbreviations

ADAS	Agricultural Development and Advisory Service
AOD	Above Ordnance Datum
AOS	apparent opening size
AOS O95	apparent opening size, 95 percentile (BS)
ASTM	American Society for Testing and Materials
BAP	Biodiversity Action Plan
BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
BOD^5	Biochemical Oxygen Demand (after 5 days)
BPEO	Best Practicable Environmental Option
BRE	Building Research Establishment
BS	British Standard
BSI	British Standards Institution
BSRIA	Building Services Research and Information Association
CAA	Civil Aviation Authority
CAR	Controlled Activities Report
CBM	cement bound material
CBR	Californian Bearing Ratio
CCW	Countryside Council for Wales
CDM	Construction (Design and Management) Regulations (1994)
CEH	Centre for Ecology and Hydrology (formerly Institute of Hydrology)
CEN	Comité Europeén de Normalisation (European Committee for Standardisation).
CESMM3	Civil Engineering Standard Method of Measurement, Third Edition
CESWI	Civil Engineering Specification for the Water Industry
CFMP	Catchment Flood Management Plan
CIRIA	Construction Industry Research and Information Association
CIWEM	The Chartered Institution of Water and Environmental Management
CLEA	Contaminated Land Exposure Assessment
COD	Chemical Oxygen Demand
COMAH	Control of Major Accident Hazards Regulations 1999
COPA 1974	The Control of Pollution Act 1974
COPR	The Control of Pesticides Regulations 1986
COSHH	The Control of Substances Hazardous to Health Regulations 1988
CSO	Combined Sewer Overflow
CVM	contingent valuation method
CWI	catchment wetness index
d_{10}	Soil particle size such that 10 per cent of the sample consists of particles having a smaller nominal diameter.
d_{15}	Soil particle size such that 15 per cent of the sample consists of particles having a smaller nominal diameter.
d_{50}	Soil particle size such that 50 per cent of the sample consists of particles having a smaller nominal diameter.
d_{85}	Soil particle size such that 85 per cent of the sample consists of particles having a smaller nominal diameter.
DA	Drainage Assessment

DBM	dense bitumen macadam
DCLG	Department for Communities and Local Government
Defra	Department for Environment, Food and Rural Affairs
DETR	(the former) Department for Environment, Transport and the Regions
DIA	Drainage Impact Assessment
DMRB	Design Manual for Roads and Bridges (Highways Agency; Development Department, The Scottish Executive; National Assembly for Wales; and the Department for Regional Development, Northern Ireland Executive)
DO	dissolved oxygen
DoE	(former) Department of the Environment
DoE (NI)	Department of the Environment (Northern Ireland)
DPR	dynamic percentage runoff (%)
DTI	Department of Trade and Industry
DTLR	(the former) Department for Transport, Local Government and the Regions
DWI	Drinking Water Inspectorate
e	void ratio
E	Young's modulus
EA	Environment Agency (England and Wales)
EA 1995	Environment Act 1995 (c. 25)
EAWR	The Electricity at Work Regulations 1989
EC	European Commission
ECC	The Engineering and Construction Contract (ICE, 1995)
ECS	The Engineering and Construction Subcontract (ICE, 1995)
EIA	Environmental Impact Assessment
EHS	Environment and Heritage Service (Northern Ireland)
EMC	event mean concentration
EPA	Environmental Protection Agency
EPA 1990	Environmental Protection Act 1990 (c. 43)
EQS	Environmental Quality Standard
EU	European Union
FEH	Flood Estimation Handbook (developed by CEH Wallingford, formerly the Institute of Hydrology, and published in 1999)
FLL	Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (The Landscape Research, Development and Construction Society, Germany)
FSR	Flood Studies Report
FSSR	Flood Studies Supplementary Report
GBR	General Binding Rules
$\mathbf{h_{max}}$	maximum depth of water that will occur in the storage medium
HMIP	Her Majesty's Inspectorate of Pollution (superseded by Environment Agency)
HMSO	Her Majesty's Stationery Office
i	rainfall intensity
ICE	Institution of Civil Engineers
IChemE	Institution of Chemical Engineers
ICoP	interim code of practice
IDB	Internal Drainage Board
IMP	Integrated Management Practice
IoH	Institute of Hydrology (now Centre for Ecology and Hydrology)
IRL	initial runoff loss

ISO	International Organisation for Stardardisation
k	coefficient of permeability
LA	local authority
LDF	Local Development Frameworks
LNAPLs	light non-aqueous phase liquids
M5-2d	2 day rainfall of 5 year return period (mm)
M5-60	60 minute rainfall of 5 year return period (mm)
MAFF	Ministry of Agriculture, Fisheries and Food (superseded by Defra)
MSA	motorway service area
MTBE	methyl tert-butyl ether
n	Porosity
NAW	National Assembly for Wales
NRA	National Rivers Authority (superseded by the Environment Agency)
NSWG	National SUDS Working Group
NTU	nephalometric turbidity unit
ODPM	(the former) Office of the Deputy Prime Minister
Ofwat	Office of Water Services
PAH	polycyclic aromatic hydrocarbon
PIMP	percentage impermeability
PPG	Pollution Prevention Guidance
PPS 3	Planning Policy Statement 3: Housing
PPS 9	Planning Policy Statement 9: Biological and geological conservation
PPS 25	Planning Policy Statement 25: Development and flood risk (DTLR, 2001)
PPS	Planning Policy Statement
PR	percentage runoff
q	infiltration coefficient
Q	flow through outlet from storage below pavement
$\mathbf{Q_{bar}}$	the (arithmetic) mean annual maximum flood (m^3/s)
r	Jenkinson's r (M5-60min) / (M5-2d)
RDA	Regional Development Agency
RoSPA	Royal Society for the Prevention of Accidents
RPG	Regional Planning Guidance
RSS	Regional Spatial Strategy
S	Slope
SAC	Special Area of Conservation
SAAR	standard average annual rainfall (mm)
SE	Scottish Executive
SEPA	Scottish Environment Protection Agency
SNH	Scottish Natural Heritage
SMD	Soil Moisture Deficit
SNIFFER	Scotland and Northern Ireland Forum for Environmental Research
SPD	Supplementary Planning Document
SPG	Supplementary Planning Guidance
SPP	Scottish Planning Policy
SPR	Standard Percentage Runoff
SPZ	source protection zone
SSSI	Site of Special Scientific Interest
SUDS	sustainable drainage system
T	return period for storm event
TAN	Technical Advice Note (Wales)

TCPA	Town and Country Planning Act 1990
TON	total oxidised nitrogen
TPHs	total petroleum hydrocarbons
TRL	Transport Research Laboratory (formerly Transport and Road Research Laboratory, TRRL; and Road Research Laboratory, RRL)
TSS	total suspended solids
UDP	Unitary Development Plan
U.S. EPA	United States Environmental Protection Agency
V	maximum storage volume for water below pervious pavement
$\mathbf{V}_t$	water quality treatment volume
VOC	volatile organic compound
WA 1989	Water Act 1989
WA(NI) 1972	Water Act (Northern Ireland) 1972
WFD	Water Framework Directive
WIA 1991	Water Industry Act 1991 (c. 56)
WIA 1991 s106	Water Industry Act (c. 56), Section 106
WLC	whole life costing
WRA 1991	Water Resources Act 1991 (c. 57)
WRAS	Water Regulations Advisory Scheme
WWTW	waste water treatment works
γ_d	dry unit weight of soil or aggregate
γ_w	unit weight of water
µ	viscosity
n	Poisson's ratio
μm	micrometre (ie 1´10^{-6} m)

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Appendix A

Contents

Continued overleaf

Design examples

These design examples are based on the characteristics of real sites, with some adaptations to reflect drainage best practice and to demonstrate as many issues as possible. However, due to confidentiality concerns and a lack of data availability, most of the design criteria and calculations have been developed for the purposes of this guidance.

1. Residential development example: Rosetree Estate

1.1 DESIGN EXAMPLE

Rosetree estate is a 31 ha greenfield development site for residential development at a densities of 20 to 30 houses per hectare. The site will be developed in phases, but will drain to an integrated SUDS scheme that will discharge to the River Springbourne to the south of the site.

The river supports medium/good water quality, and has a River Ecological Classification of 2. The river passes through a public park and campsite just downstream before entering a more urban environment where existing flood risk is a critical concern.

The majority of the site overlies low permeability clay soils where maximum groundwater levels are within a metre of the ground surface. The ground levels to the north and south west of the site are higher. The soils in the south west are sandier and more permeable.

The groundwater beneath the site is not associated with source protection zones and is not considered vulnerable to pollution.

The hydrological characteristics of the region are:

SAAR (mm)	820
OIL factor	0.47
M5-60 (mm)	14
r (rainfall ratio)	0.25
Hydrological region	2.

1.1.1 Site details

The development masterplan has been predefined, with the area effectively being split into five subcatchments by distributor roads. To the south-west of the development the land has been designated as an area of public open space. Catchment characteristics for the site are summarised in Table A1.1.

Table A1.1 *Catchment development details*

Subcatchment	A	B	C	D	E	Roads	Open	Total
Area (ha)	7.5	5.5	8.2	3.6	3.4	1.5	1.4	31.1
PIMP (%)	55	55	60	40	55	100	0	54.3
Impermeable area (ha)	4.1	3	4.9	1.4	1.9	1.5	0	16.9

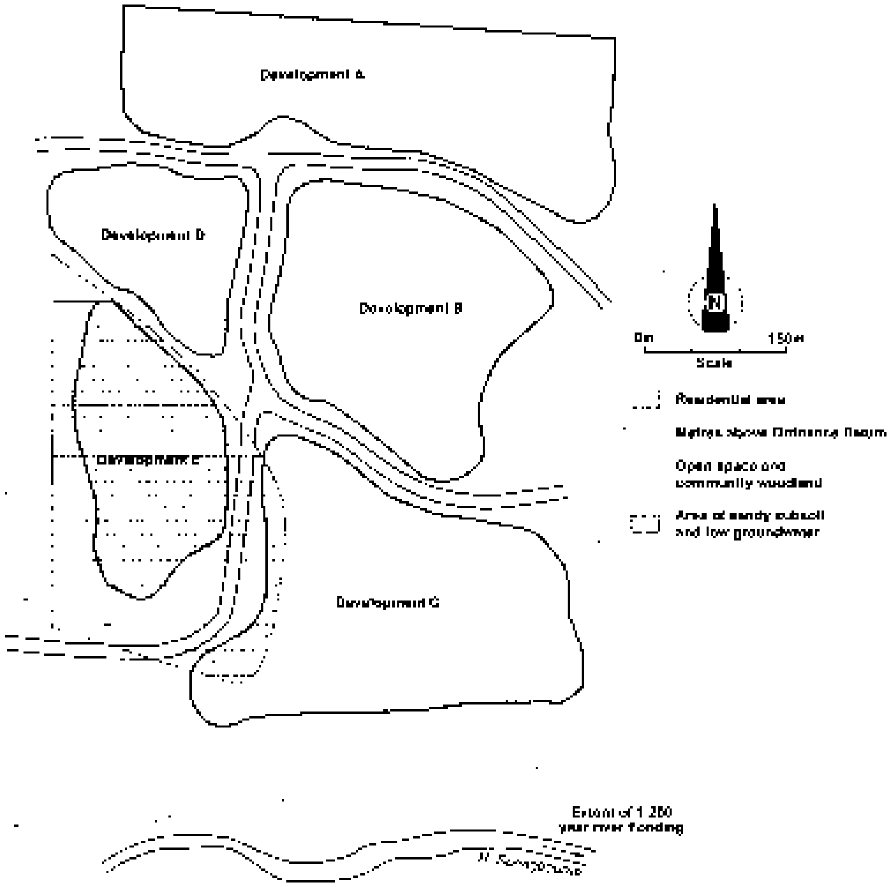

Figure A1.1 *The Rosetree Estate – site characteristics*

1.2 PLANNING AND AGREEMENT OF DESIGN CRITERIA

Discussions were held with the local authority, the sewerage undertaker and the environmental regulator, and continued from preliminary through to detailed design (as set out in Section 2.4 of this guidance document). This ensured that the proposed drainage system would meet all stakeholder requirements and that appropriate long-term maintenance agreements could be secured.

The characteristics of SUDS components and site constraints (see Chapter 5, Tables 5.2 to 5.9 and Figure 5.1) were reviewed to ensure a complete understanding of hydraulic, water quality, amenity and ecological constraints and opportunities was developed.

As a result of the discussions, design criteria (see Table 3.5) for the site were set as follows:

1.2.1 Hydraulic design criteria

- the development and the drainage system storage components are to be located outside the 1 in 200 year floodplain
- the general pipe drainage system to be designed to cater for the 30 year critical event for the site; roads should only to be used as overland flood flow routes for events above this level
- attenuation storage and runoff volume to be designed to cater for the 100 year critical event
- the joint probability risk associated with a 100 year event of river flooding levels and extreme rainfall on the site are to be evaluated
- risks associated with blockage at key locations are to be identified and accommodated appropriately (ie check implications of complete or partial blockage of pipes leaving depression points)
- overland flood flow routes are to be identified
- all housing floor levels are to be set at least 600 mm above the 100 year flood levels
- discharges from the site are to be limited to greenfield flow rates
- long-term storage is required to prevent an increase in downstream flood risk
- a 10 per cent allowance on rainfall is required for climate change
- a 10 per cent allowance is required for urban creep
- sewers to be designed to meet criteria in Sewers for Adoption 6th edition/Sewers for Scotland 2nd edition.

1.2.2 Water quality design criteria

This is a residential development. Therefore in accordance with Table 3.3, two levels of treatment are recommended. Discussions with the environmental regulator identified the following enhanced risks:

a) This is a large development relative to the catchment size.

b) The receiving stream water quality is good.

c) There is a public amenity area downstream.

Two levels of treatment were considered desirable for this site.

1.2.3 Amenity design criteria

There is limited space for surface water drainage which has high amenity value within the residential development zones themselves. It is therefore important to develop a drainage solution that is fully integrated with and complementary to the public open space areas, and that is visually attractive and safe for the public to enjoy.

1.2.4 Biodiversity design criteria

The river corridor, associated marsh areas, together with the adjacent woodland will maximise the ecological potential of any open surface water systems within the public open space. The design of any ponds/basins should incorporate best practice with respect to design, landscaping and management techniques to promote biodiversity.

1.3 SUDS SELECTION

SUDS characteristics were reviewed to allow appropriate selection of surface water drainage components for the site. The main constraints/opportunities driving SUDS selection are summarised in Table A1.2.

Table A1.2 SUDS *constraints/opportunities*

Characteristic	Constraint/opportunity
Development type	• phased development proposed, therefore solution requires particular consideration and provision for construction site runoff management; sediment management and water quality protection required before discharge to receiving river • receiving waters downstream act as recreational/amenity facilities, therefore pollution control is important; low risk of pollution after construction completed.
Soils	• infiltration is only possible in subcatchment E
Groundwater	• groundwater zoned as not being sensitive • groundwater too close to surface in all zones except subcatchment E.
Space available	• surface retention/detention/wetlands are possible as there is a large area of public open space • no space for swales adjacent to residential roads • no communal parking areas available for application of permeable pavement/geocellular systems.
Site topgraphic characteristics	• area comprises gently sloping terrain.
Ownership/ maintenance	• sewerage undertaker to adopt pipe network, designed to Sewers for Adoption • local authority will adopt surface drainage systems (detention basins and retention ponds) • infiltration systems serving private property owned by house occupier.
Community acceptability	• ponds provide opportunities for aesthetic enhancement, education and recreation if located in public open space • detention areas that fill infrequently can fulfil dual use (hydraulic and amenity) where they are located in public open space.
Cost	• pipe and storage system designed to minimise capital and maintenance costs.
Public safety	• health and safety risks reduced by appropriate design and location of components • public education and awareness raising required for surface water systems.
Biodiversity	• pond designed for biodiversity benefits • pond located suitably for natural development of native flora and fauna.

To take full account of all site constraints and opportunities, together with the benefits offered by a range of SUDS components, a SUDS scheme was designed which followed the pre-development drainage paths, using infiltration where possible. The drainage network was integrated with the landscape and public open space. This is shown in Figure A1.2.

The drainage solution proposed and implemented for the site was as follows:

- individual property and road soakaways – for Zone E; overflows not provided from the soakaways on the basis that flooding for more extreme events will not cause internal property flooding
- soakaways were designed to cater for the 1 in 10 year event
- detention basins with outlet hydraulic controls to provide 1 in 1 and 1 in 10 year flow control; pipe sizes downstream of detention basins and the pond were sized for the 1 in 100 year event to ensure all runoff from the site was controlled to the 100 year criterion

- detention basins – for Zones A, B, C & D and distributor roads to be located in public open space where there is good access, providing first stage treatment of the runoff and hydraulic attenuation
- temporary detention basin – for Zone E during construction
- retention pond to provide secondary treatment and attenuation for 100 year event for the whole site, and also amenity and biodiversity benefits
- roads to convey flows in excess of 30 year event
- long-term storage to be integrated with the retention pond
- SUDS components linked by conventional pipework
- landscaping to ensure that, for events greater than the 1 in 100 year, all flows drain towards on-site drainage systems to minimise risks of off-site flooding.

The final drainage design is shown in Figure A1.2.

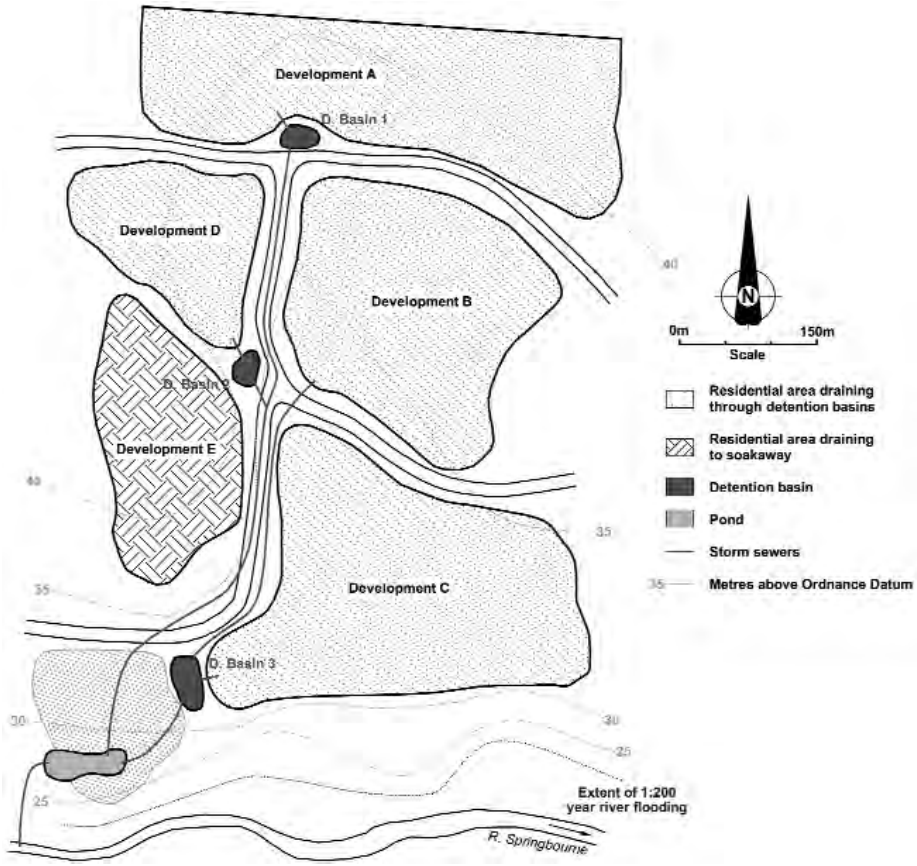

Figure A1.2 *Plan showing the designed SUDS drainage system*

1.4 INITIAL SYSTEM DESIGN

1.4.1 Catchment protection from increased flow rate and volume of runoff

In accordance with the criterion to control discharges to greenfield conditions (see Chapter 4 and Table 4.2).

Greenfield runoff rate analysis

The equation for calculating greenfield runoff rates is given in Box 4.2, and below:

$$QBAR_{rural} = 0.00108AREA^{0.89}SAAR^{1.17}SOIL^{2.17}$$

As discussed in Table 4.2, since the site is less than 50 ha, the formula should be applied for 50 ha and the result factored based on the ratio of areas.

$$\begin{aligned} QBAR_{rural} &= 0.00108 \times 0.5^{0.89}820^{1.17}0.47^{2.17} \\ &= 0.29\ m^3/s \\ &= 290.5\ l/s \\ &= 5.81\ l/s/ha \end{aligned}$$

For the 31.1 ha site, the total allowable QBAR = 5.81 × 31.1 = 181 l/s.

To get the 1, 10 and 100 year throttle rates, the FSR growth curve for Hydrological Region 2 is required (as set out in FSSR14). Growth curve factors for this region are:

1 year factor = 0.85
10 year factor = 1.42
100 year factor = 2.63

Greenfield limiting discharge rates for the site are given in Table A1.3.

Table A1.3 *Greenfield runoff rates*

Return period	Whole site	Detention basin 1	Detention basin 2	Detention basin 3
1 year	0.85 x 181 = 154 l/s	0.85 x 5.81 x 7.5 = 37 l/s	0.85 x 5.81 x 3.6 = 18 l/s	0.85 x 5.81 x 13.7 = 68 l/s
Q_{Bar}	181 l/s	44 l/s	21 l/s	106 l/s
10 year	1.42 x 181 = 257 l/s	1.42 x 5.81 x 7.5 = 62 l/s	1.42 x 5.81 x 3.6 = 30 l/s	1.42 x 5.81 x 13.7 = 113 l/s
100 year	2.63 x 181 = 475 l/s	2.63 x 5.81 x 7.5 = 115 l/s	2.63 x 5.81 x 3.6 = 55 l/s	2.63 x 5.81 x 13.7 = 209 l/s

As the detention basins are to be designed only to the 10 year event, the throttle rates for the 100 year event do not apply and relief overflows need to be provided to serve extreme events.

Attenuation storage of detention basins and retention pond

There are two methods of undertaking preliminary assessments of the attenuation storage volumes required for a site. The first uses the approach set out in the EA/Defra R&D Technical Report W5-074 *Preliminary rainfall runoff management for developments*. The second uses a simplified modelling approach that assumes a single, lumped development area, nodes and appropriate throttles to represent the storage system.

When using a simple model, the storage system is generally modelled with a limiting discharge throttle and an overflow. The volume passing over the overflow is then the storage required for that specific event and throttle. A range of different storm durations is used to determine the maximum spill volume. This method under-predicts the actual volume of storage needed as the head-discharge relationship of the hydraulic control(s) is not being represented properly. An additional allowance of 25 per cent should be applied to the first estimate of storage to allow for this approximation.

Using the EA/Defra approximate approach, the required attenuation storage volumes for the whole site are calculated as being:

Site 10 year attenuation storage volume = 3600 m^3

Site 100 year attenuation storage volume = 5200 m^3

Assuming a proportional distribution of storage to each of the detention tanks by paved area (and assuming the road area drains to detention basin 3).

Detention basin 1 (Area A) = (4.1 / 16.9) × 3600 = 873 m^3
Detention basin 2 (Area D) = (1.4 / 16.9) × 3600 = 320 m^3
Detention basin 3 (Areas B&C and distributor roads) = ((7.9+1.5) / 16.9) × 3600 = 2002 m^3

The sum total is not equal to 3600 m^3 as Area E is separately served by soakaways.

On this simplistic basis of volume distribution, the pond theoretically does not require a volume of storage for the 10 year event as all the water is attenuated by the detention basins.

A similar approach is used to distribute the 100 year storage volume. As the detention basins are only sized for the 10 year event, the pond needs to cater for all the additional volume of storage required.

Pond volume = 5200 – (DB1+DB2+DB3+Soakaway volume)
Pond volume = 5200 – (873 + 320 + 2002 + 680)
Pond volume = 1325 m^3

However as the pond is in series with the basins, the simple assumption that all units would be full for the critical 100 year event is unlikely. It has therefore been assumed that the difference between the 10 year and 100 year event requires a safety factor of around 25 per cent and this would be checked and modified during detailed design. This increases the required pond attenuation volume to 1700 m^3.

Table A1.4 *Site attenuation volumes*

	Whole site	Detention basin 1 (m^3)	Detention basin 2 (m^3)	Detention basin 3 (m^3)	Soakaways (m^3)	Pond (m^3)
RP = 10 year	3600	873	320	2002	680	–
RP = 100 year	5200	873	320	2002	680	1700

Long-term storage volume

Long-term storage is required to address the additional runoff caused by the development compared to the volume that would be contributed from the site in its greenfield state. This volume must be catered for as either infiltration storage or in storage with the ability to be discharged at rates of less than 2 l/s/ha.

An area adjacent to the retention pond has been designed, which can be drained back into the pond by natural infiltration, to come into operation for events larger than 1 in 10 years.

Long-term storage can be calculated using the equation in Box 4.10, given below:

$$Vol_{xs} = RD.A.10\left[\frac{PIMP}{100}(\alpha 0.8) + \left(1 - \frac{PIMP}{100}\right)(\beta.SPR) - SPR\right]$$

where:

Vol_{xs}	=	the extra runoff volume (m^3) of development runoff over greenfield runoff
RD	=	the rainfall depth for the 100 year, 6 hour event (mm)
PIMP	=	the impermeable area as a percentage of the total area
A	=	the area of the site (ha)
SPR	=	the "SPR" index for the FSR SOIL type
α	=	the proportion of paved area draining to the network or directly to the river (values from 0 to1) with 80 per cent runoff – assume 1.0
β	=	the proportion of pervious area draining to the network or directly to the river (values from 0 to1) – assume 0.5

The value for β is assumed as 0.5, meaning that 50 per cent of the pervious area is considered likely to contribute to runoff to the pond, while 50 per cent is trapped in gardens as local temporary ponding. It has been assumed that α equals 1 which means that all paved areas will drain to the pond. Losses (other than that catered for by the runoff factor of 80 per cent) are assumed to be zero.

It has been assumed that only about 30 per cent of the Development E (say 1.0 ha) is included in the determination of long term storage since soakaways will address most of the runoff.

RD	=	55.2 mm
A	=	28.7 ha
PIMP	=	55
α	=	1.0
β	=	0.5
SPR	=	0.47
Vol_{xs}	=	1204 m^3.

Note: that this volume is relatively small compared to the total attenuation volume requirements, although it is large relative to the attenuation volume in the pond. This is because the greenfield runoff volume for SOIL class 4 is high and therefore the increase in runoff due to development is relatively modest.

Long-term storage is not additional to the attenuation storage volume, but it is effectively an element of it. As the pond draws down at the end of the event, this volume is left behind in the depression to infiltrate naturally into the ground and the pond, though the provision of land drainage will be needed as the soil is relatively impermeable. This storage can form part of the pond attenuation storage for events greater than a 10-year return period.

Soakaway sizing

Infiltration tests were undertaken across Zone E to determine infiltration rates in the area. Since the area is large, three boreholes were drilled and groundwater levels were monitored for six months over winter. The minimum depth to groundwater was 2.8 m and soakaway tests yielded an average value for the hydraulic conductivity of 1.4×10^{-4} m/s.

The procedure described in Section 4.7 of this document is followed to design the property and road soakaways.

Each soakaway will be required to drain a paved area of 150 m^2 (whether road area or houses) and will be filled with granular material of porosity 0.35. *In-situ* infiltration tests have established a soil infiltration rate of 1.4×10^{-4} m/s (0.50 m/h). The diameter of the proposed soakaways is 2.5 m. As the cylindrical soakaway has both vertical sided infiltration as well as from the base, the procedure described in Box 4.16 is used. A factor of safety of 5 has been selected.

1. The effective infiltration coefficient:

   q = 0.50/5 = 0.10 m/h
2. Effective porosity, n = 0.35
3. Ad = 150 m^2 drained to each soakaway
4. First calculate b from [b = $Pq/(A_b n)$; see Box 4.16]

   r = 1.25 m,

   A_b = 4.91 m^2,

   P = 7.85 m,

Therefore b = (7.85 × 0.10)/(4.91 × 0.35) = 0.46 h^{-1}.

5. Values of a [= $A_b/P - A_D i/(Pq)$; see Box 4.16] are calculated for a range of storm durations and intensities
6. Value of h_{max} [$h_{max} = a(e^{(-bD)} - 1)$; see Box 4.16] are calculated for a range of storm durations and intensities.

Table A1.5 *Critical duration event for soakaway design*

Duration, D (h)	Intensity, i, (mm/h)	a (m)	b (h^{-1})	Hmax (m)
0.25	42.00	–7.33	0.46	0.80
0.5	28.33	–4.68	0.46	0.96
1	19.00	–2.97	0.46	1.10
2	12.10	–1.67	0.46	1.00
4	7.9	–0.87	0.46	0.73

The largest value of h_{max} is 1.10 m which occurs during a 1 hour storm. The depth of soakaway required is, therefore, 1.1 m. As the minimum depth to annual maximum groundwater levels over zone E is at least 2.8 m, this is acceptable. This provides an unsaturated soil depth below the soakaway of 1.0m with a freeboard between the maximum water level and the ground surface of 0.7 m. The minimum unsaturated depth required is 1.0 m so the design of the proposed soakaway is acceptable.

The time taken for this soakaway to drain down to half full may be found from
[time = n h_{max}/(2q); see Box 4.18]

$t_{1/2}$ = 0.8hr.

This is less than 24 hours and is therefore acceptable.

As one soakaway serves 150 m^2 the number of soakaways needed to serve Development E is 126 (for 1.9 ha). The storage provided by 126 soakaways of depth 1.1 m is 680 m^3. Alternatively smaller soakaways could be used for serving individual houses as roof areas per house is in the region of 50 m^2. In general it is preferable to serve each property with individual soakaways.

1.4.2 River water quality protection

Water quality volume for the pond

As presented in Section 3.3 and 4.5.6, this can be provided via interception storage and/or treatment volume (Vt). In Zone E, interception storage is provided via infiltration. Due to the high development density and low soil permeability elsewhere, the runoff treatment volume will be provided as the permanent pool of the retention pond. Due to the relatively low pollution risk of the site, 1.0 x Vt provided as a single pond was considered appropriate.

Section 4.5.6 states that Vt can be assessed using a rainfall depth value between 11 and 15 mm, or the equation in Box 4.12 can be used. A runoff factor of 80 per cent from paved areas for 15 mm of rainfall has been assumed.

Excluding Zone E and public open space areas, the extent of paved surfaces draining to the river:

$$\text{Paved area} = (16.9 - 1.9) \times 10\,000 = 150\,000 \text{ m}^2.$$

Using 15 mm rainfall depth, the volume of treatment storage required is:

$$Vt = 150\,000 \times 0.015 \times 0.8 = 1800 \text{ m}^3.$$

Alternatively using the equation for Vt in Box 4.12:

$$Vt\ (\text{m}^3/\text{ha}) = 9 \times D\ (SOIL/2 + (1\text{-}SOIL/2) \times I)$$

where:

D = M5-60 = 14 mm
I = average impervious fraction for contributing area = 0.55
SOIL class = 4 with an SPR of 0.47

$$Vt = 9 \times 14 \times (0.47/2 + (1\text{-}0.47/2) \times 0.55) = 82.62 \text{ m}^3/\text{ha}.$$

$$Vt \text{ for the site} = 82.62 \times 27.7 = 2289 \text{ m}^3$$

A permanent pond volume of 1800 m^3 was selected as treatment is already being provided by detention basins upstream.

1.5 COMPONENT DIMENSIONS

1.5.1 Detention basin 3

The design of basin 3 is included as an example. The designs for basins 1 and 2 will be similar.

The detention volume required = 2002 m^3 (Table A1.4).
The outlet control = 113 l/s for a 10 year event. (Table A1.3).

Outlet orifice size based on orifice formula for say 1.8 m head (Box 19.1):

$$Q = Cd \cdot A_0 \cdot (2gh)^{0.5}$$
$$113 \times 10^{-3} = 0.6 \cdot A_0 \cdot 5.94$$
$$A_0 = 0.032 \text{ m}^2$$

An orifice of diameter 195 mm is needed. This is large enough to ensure the risk of blockage is minimal as long as suitable precautionary measures are taken.

An overflow is provided to spill larger events. This should be sized to cater for the critical 100 year event without overtopping of the basin. This can only be sized properly using modelling to take account of the basin attenuation. However an indicative size could be based on the runoff flow rate based on a constant rainfall intensity (say 10 mm/hr due to the long critical duration of the basin) applied to the paved area of the catchment (7.9 ha plus the roads of 1.5 ha = 9.4 ha) and a design head over a weir (say 300 mm). The weir length can then be calculated.

The design flow rate is:

$$Q = \text{Area} \times \text{percentage runoff} \times \text{rainfall rate}$$
$$Q = 9.4\text{x}10^4 \cdot 0.8 \cdot 0.01 / 3600 \text{ m}^3/\text{s}$$
$$Q = 0.208 \text{ m}^3/\text{s (208 l/s)}$$

As this, together with the throttled outlet (113 l/s) is significantly greater than the 100 year throttle flow rate of 209 l/s (Table A1.3) this estimate is probably not too far wrong. However it is not particularly conservative. Therefore the calculated weir length should be considered to be a minimum design length. As stated previously, detailed modelling will establish the actual length required.

Using the formula for a thin plate weir (see Box 19.18):

$$Q = 0.59. \ b. \ h^{3/2} \cdot g^{1/2}$$
$$0.208 = 0.59. \ b \cdot 0.3^{1.5} \cdot 9.81^{0.5}$$
$$L = 0.68 \text{ m}$$

The initial weir crest design length was therefore set at 1.0 m.

The total area available for the basin is 1350 m^2 (30 m × 45 m). Assuming allowable side slopes of 1:4 (to meet safety requirements) gives a maximum depth of 1.81 m (say 1.8 m) and a base area of around 875 m^2 (23 m × 38 m) for 2002 m^3. Flatter gradients would require the basin to be deeper and the base area to be smaller. For aesthetic reasons side slopes were varied within safe ranges.

Figure A1.3 shows the elevation/volume relationship for the detention basin. The level at the base of the basin is set at 30.00 m AOD, so the top water level needs to be at 31.800 m AOD.

The spillway weir is set at 31.80 m AOD to pass forward higher flows. The detention basin crest must provide a freeboard above the 100 year event. Assuming the spillway is designed to operate with a maximum head of 300 mm and a freeboard allowance of 500 mm is provided, the crest of the detention basin can be set at a level of 32.60 m.

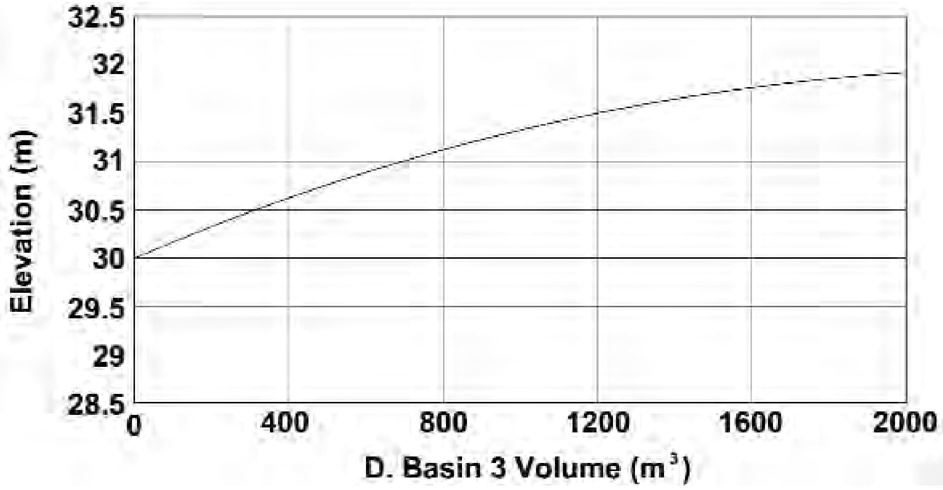

Figure A1.3 *Detention basin 3 volume – elevation plot*

Figure A1.4 shows a schematic of the hydraulic aspects of the detention basin. The inlet pipe terminates above the base of the basin (normally set at about the 1 year event level) to prevent regular backing up of stormwater.

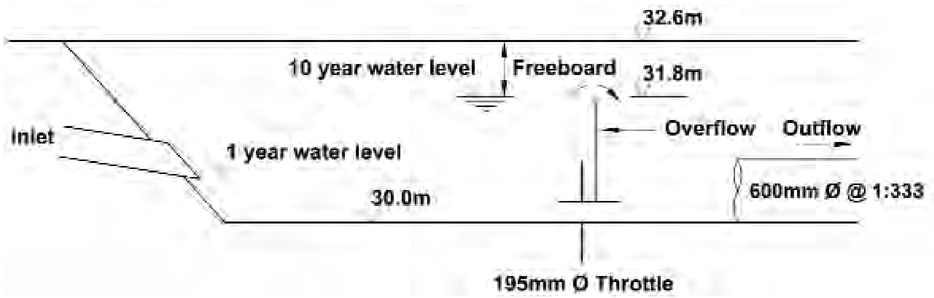

Figure A1.4 *Cross section through detention basin 3*

Figure A1.5 shows a schematic of the plan area of the detention basin. A shallow berm is included which facilitates sediment deposition upstream and acts as a flow spreader across the base of the detention basin to maximise treatment opportunities.

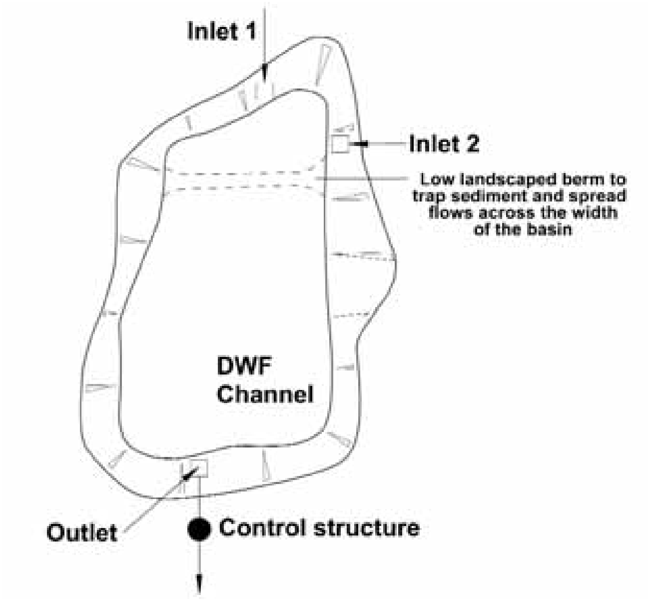

Figure A1.5 *Plan of detention basin 3*

The inlet pipes draining the developments include erosion protection to prevent scour.

The outlet channel (downstream of the throttle and overflow weir) will be sized generously since its function is to convey the 100 year flow to the pond downstream, some of which will have had limited attenuation having passed over the overflow weir. Detailed modelling is required to establish the conveyance capacity required having taken account of the attenuation effect of the basin.

1.5.2 Retention pond

The permanent pond volume is 1800 m^3 (see Section A.1.4.2). The attenuation volume for the 10 year event is theoretically nil, with the 100 year storage requiring an estimated 1700 m^3 (Table A.1.4).

The topography of the site suggests that the base of the pond should be around 24.4 m AOD with the outflow control set at 26.0 m and an overflow level of around 27.0 m AOD. This provides a permanent pool with a maximum depth of 1.6 m, ensuring a large area of the pond remains as open water which is aesthetically more pleasing than one that is vegetated. Figure A1.6 shows the depth storage relationship of both the permanent pool and attenuation storage.

The elevation-storage relationship for the pond was developed iteratively through an assessment of ground contours, side slopes and maximum depth as it was important to provide an aesthetically appealing looking pond. The final pond size which provided the necessary volume was approximately 25 m × 80 m at the 100 year top water level. This included taking account the long-term storage volume, and aquatic and safety benches.

The freeboard increased the total plan area of the pond with an allowance of 600 mm. A spill weir structure 5 m wide set at the 100 year maximum water level was provided to cater for more extreme events and any blockage of the outlet structure.

The outlet control maximum flow rate for the 100 year event is 475 l/s (Table A1.3). With a maximum head of 1.0 m, an orifice control with a diameter of 362 mm is required. Checks should be made that the orifice control provides outflow rates of the order of 257 and 154 l/s for the 10 year and 1 year critical events. As the orifice is relatively large, a more complex arrangement can be developed with two orifice controls set at different levels so that outflow rates are managed more accurately.
It should be noted that as the basins only provide effective flow control for up to the 10 year event, the inflow rate into the pond will be very different for bigger events.

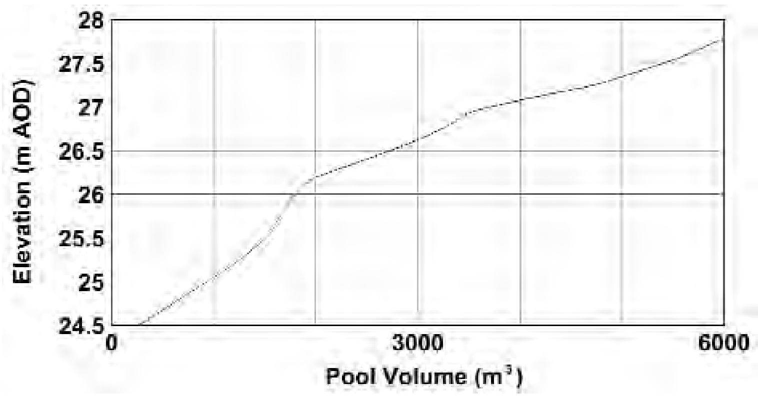

Figure A1.6 *Depth storage relationship of the pond*

The following figures show a section and plan of the proposed pond.

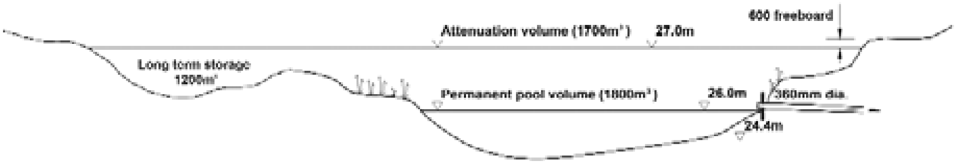

Figure A1.7 *Schematic showing pond section*

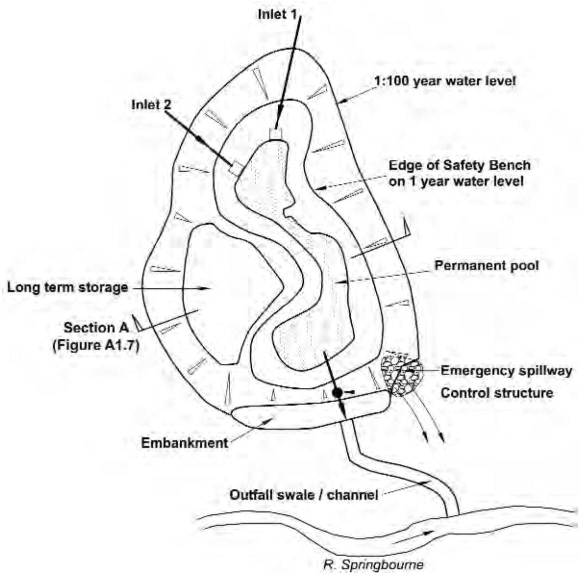

Figure A1.8 *Pond plan*

The dam structure needs to be designed according to normal practice for embankments. The emergency overflow structure should usually not be located across the embankment to prevent risk of collapse during its operation in an extreme event.

1.6 DETAILED SYSTEM DESIGN

A detailed model of the contributing catchment and drainage system is required in order to check that all criteria have been achieved. The calculations above provide initial sizing information and allow a first estimate to be modelled, which can then be refined to minimise costs and determine an accurate solution. The particular checks that should now be made with the detailed model are as follows:

- greenfield discharge rates from the site are achieved for 1, 10 and 100 year
- the long-term storage is fully mobilised for the critical 100 year event
- no unplanned flooding on the site for the critical site event
- pipes comply with Sewers for Adoption criteria
- no flooding of property from the site drainage system for the 100 year critical site event
- no flooding of property for key "blockage" scenarios
- The possible impact and performance of the pond for the maximum 100 year river level for a range of return period events. (A joint probability analysis may be required depending on this assessment).

2. Commercial development example: The Medipark

2.1 DESIGN EXAMPLE

The Medipark is a 7.2 ha, greenfield site comprising a proposed low density, commercial development. The site is located on well-draining soils with an underlying geology that is suitable for infiltration systems. The site is currently used for agriculture and, since it is underlain by coarse drift material and there is no runoff except during extreme events, a similar minimal runoff regime will be required post-development. The site is located on a hillside, and the development has been designed with an access road and six individual commercial plots that will be developed independently. There is public open space allocated to the south of the site.

Initial feasibility studies identified the presence of local springs to the south of the site, but a hydrogeological vulnerability risk assessment confirmed the local aquifer to be at least 20 m below ground level and the springs to be non-vulnerable in that they discharge to a local closed landfill site. The hydrogeological risk assessment concluded that the recharge to the aquifer was not within site boundaries and that an aquitard (barrier to free water movement) provided a significant level of protection to any potential future water supplies.

The commercial developments were to be limited to office space only, and therefore the risks of pollution from site runoff were low to medium. The watercourse serving the catchment is located some distance from the site, has medium/poor water quality, and is not vulnerable to flooding.

A plan of the development site is given in Figure A2.1 which shows the six planned sites and the access road.

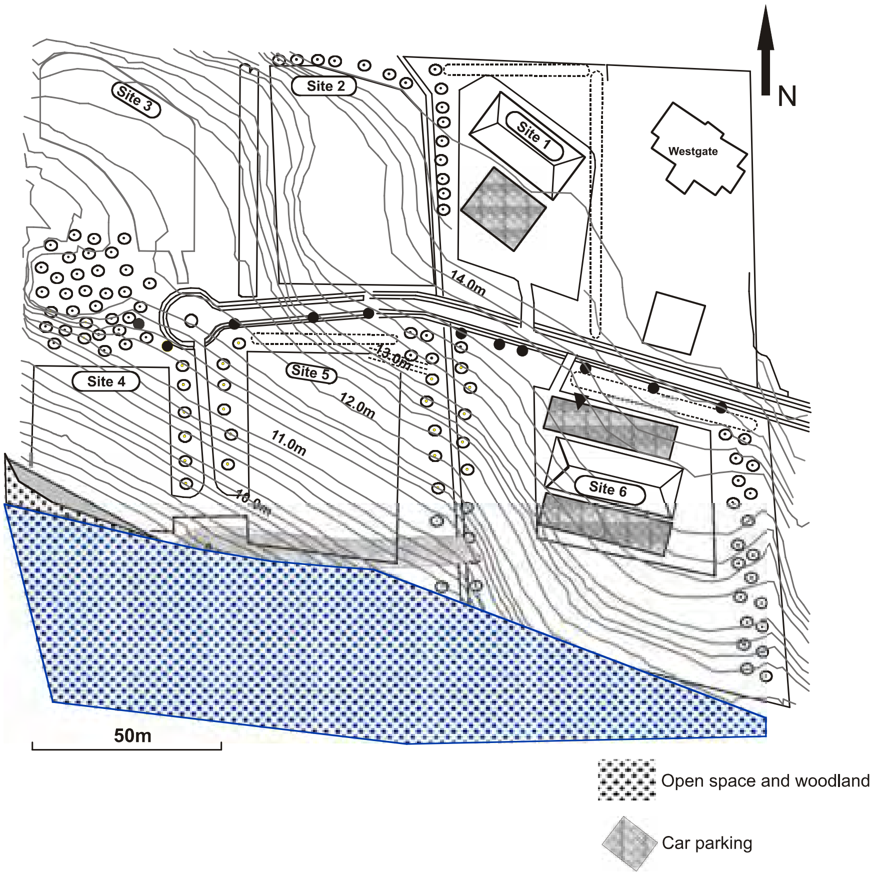

Figure A2.1 *The Medipark site*

2.2 PLANNING AND AGREEMENT OF DESIGN CRITERIA

Discussions were held with the local authority, the sewerage undertaker and the environmental regulator, and continued from preliminary through to detailed design (see Section 2.4).

The sewerage undertaker is not responsible for surface water at this site since all surface water is disposed of via infiltration. However, the site operators had to enter into agreements with the sewerage undertaker for foul sewer connections.

The characteristics of SUDS components and site constraints (see Chapter 5, Tables 5.2 to 5.9 and Figure 5.1) were reviewed to ensure a complete understanding of hydraulic, water quality, amenity and ecological constraints and opportunities was developed.

As a result of the discussions, design criteria (see Table 3.5) for the site were set as follows:

2.2.1 Hydraulic design criteria

- infiltration of surface water runoff should be maximised and there should be zero runoff from the site for events up to 1 in 30 year
- individual plot facilities should dispose of the rainwater from roofs, access roads and parking areas for a 1 in 10 year event
- surface water runoff in excess of the 1 in 10 year event should be conveyed to an infiltration unit serving the whole site

- flows in excess of the 1 in 30 year event can be allowed to discharge from the site via planned overland flow paths to the receiving stream as further natural attenuation features on the hill-side will act to manage these design flows
- all properties to be set at least 600 mm above flood levels for the 100 year critical duration event
- interception storage and long-term storage is not relevant as most of the runoff at the 100 year event is infiltrated
- 10 per cent allowance is normally required for climate change although for this example it has not been given specific consideration.

2.2.2 Water quality design criteria

Road and carpark runoff should be pre-treated prior to infiltration to prevent blinding of infiltration surfaces and to minimise pollution risks to groundwater.

2.2.3 Amenity design criteria

There are no specific amenity requirements associated with the development. However, it is important that the appearance of the drainage components fits in with the overall landscaping of the site is visually attractive from office windows and, ideally, provides a recreational and amenity area for office employees during breaks from their work.

2.2.4 Biodiversity design criteria

There are no specific biodiversity requirements associated with the development. However, appropriate planting and landscape management of the surface water drainage systems and open space areas should be given full consideration to maximise opportunities for biodiversity benefits at the site.

2.3 SUDS SELECTION

SUDS characteristics were reviewed to allow appropriate selection of surface water drainage components for the site. The main constraints/opportunities driving SUDS selection are summarised in Table A2.1.

Table A2.1 *SUDS constraints/opportunities*

Characteristic	Constraint/opportunity
Development type	• commercial low density development • phased development is proposed, therefore full consideration of construction site runoff management is required.
Soils	• highly permeable, suitable for use of infiltration units.
Groundwater	• infiltration systems must be protected from direct road runoff • groundwater not vulnerable.
Space available	• there is significant space available adjacent to car parks, roads and within each of the six sites for most forms of drainage components.
Site topography characteristics	• low vulnerability to downstream flooding • steep catchment.
Ownership/maintenance	• drainage ownership for the access road with the local authority • drainage of commercial properties to be operated and maintained by a site property management company • drainage facility in public open space with the local authority.
Cost	• infiltration trenches considered more space efficient and cost effective than unlined permeable pavement systems.
Safety	• maximum depth of temporary storage is to be 0.5 m.

The drainage solution proposed was as follows:

- infiltration trenches – for each commercial plot, designed to infiltrate the 1 in 10 year event with upstream filter strips for effective pre-treatment
- swales to serve excess flows from sites 1, 2 and 3 for events greater than 1 in 10 years
- soakaways – to infiltrate 1 in 10 year runoff from the access road; since the area is relatively lightly trafficked, trapped gully pots were considered to be sufficient pre-treatment for the soakaways
- infiltration basin – to infiltrate excess runoff from the sites during the 1 in 30 year event
- landscaping – to ensure flows in excess of the 10 and 30 year event have safe overland flow routes within the site and off site respectively.

The final drainage design is shown in Figure A2.2.

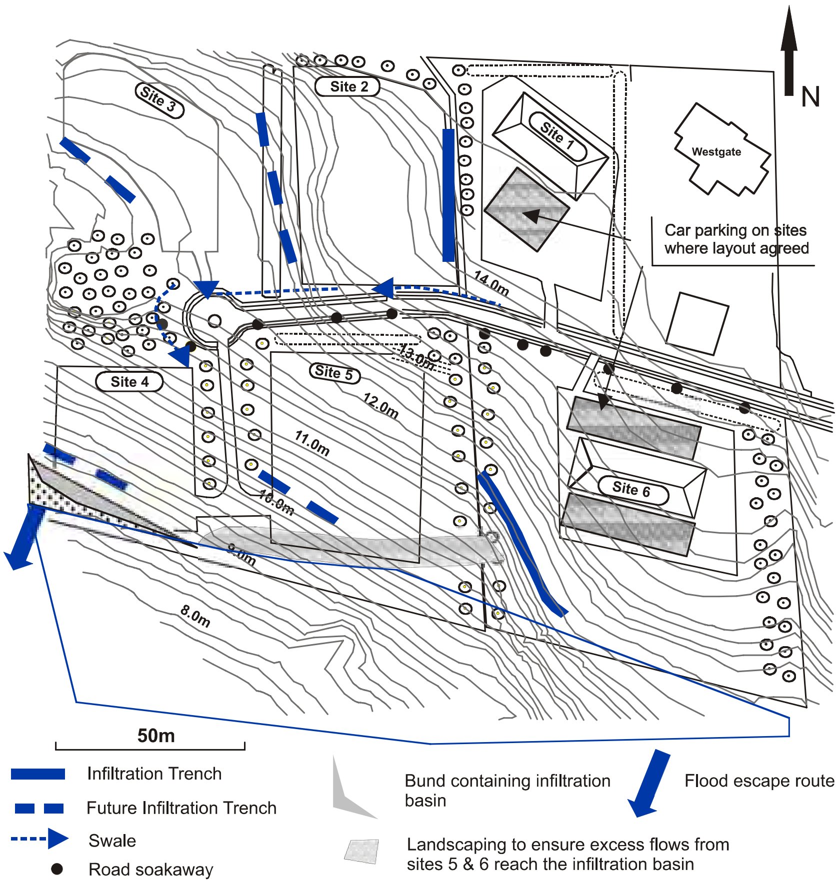

Figure A2.2 *Medipark site layout*

2.4 INITIAL SYSTEM DESIGN

2.4.1 Infiltration trenches (Site 1)

Infiltration tests were undertaken across the site (see Section 4.7 of the guidance document) to measure the soil infiltration rates. The minimum infiltration rate measured on the site was 0.00044 m/s (1.58 m/h). For each test, the water drained from the trial pit in less than 10 minutes, indicating very high infiltration rates.

The characteristics for Site 1 are detailed in Table A2.2.

Table A2.2 *Development characteristics – Site 1*

Area of roofs	1090 m^2
Area of pavements	1200 m^2
Total paved area drained	2290 m^2
Infiltration rate	1.58 m/h
Depth to groundwater table	>20 m

There is a zero runoff requirement for each plot for events up to the 1 in 10 year return period. The procedure for designing an infiltration trench is described in the equations and procedures set out in Boxes 4.16 and 4.17 of the guidance document.

The infiltration trench is therefore required to drain an area of 2290 m^2 and the trench will be filled with granular material with an effective porosity, n, of 0.33. The width and the depth of the trench need to be established. As an initial starting point, the width of the trench is assumed to be 1.0 m. The length is dictated by site layout as a maximum of 70 m. A factor of safety of 5 was chosen in consultation with the site owners and operators and the environmental regulators to avoid potential car park flooding (see Table 4.8).

1. The effective infiltration coefficient = 1.58/5 = 0.32 m/h
2. Effective porosity, n = 0.33
3. A_d = 2290 m^2
4. Base area = 70 m^2,
5. Perimeter = 142 m,

$$[b = Pq/(A_b n)]$$
$$b = (142 \times 0.32)/(70 \text{ x } 0.33) = 45/23 = 1.97h^{-1}$$

6. Values of a and hmax are calculated for a range of storm durations and intensities, as given in Table A2.3.

$$a = A_b/P - A_d i/(Pq)$$

$$h_{max} = a(\ e^{(-bD)} - 1)$$

Table A2.3 *Depth of infiltration trench*

Duration (min)	i (mm/h)	a(m)	hmax (m)
10	75	–3.32	0.92
15	60	–2.56	0.99
30	39	–1.49	0.93
60	25	–0.78	0.67

7. The largest value of hmax is 0.99 m which occurs during a 15 minute storm. This means that the depth of trench required is at least 1.0 m.
8. The time taken for this soakaway to drain down to half full may be found
   [time = n h_{max}/(2q); see Box 4.18] as follows:
   t1/2 = 0.2 hr = 12 min.

This is significantly less than 24 hours and is therefore acceptable.

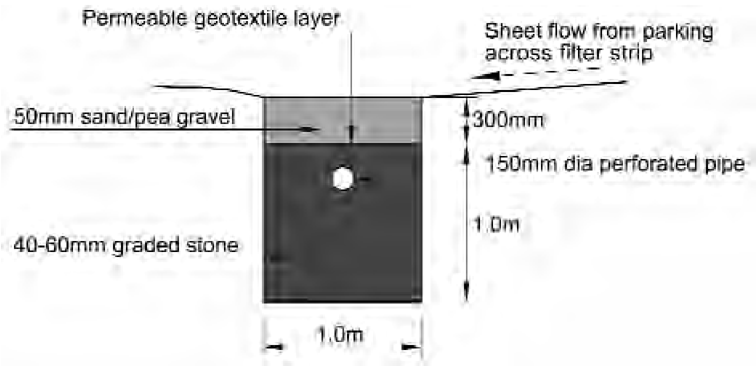

Figure A2.3 *Infiltration trench cross section*

The perforated pipe acts as a high level emergency overflow as well as the inflow distributor. It will have a diameter of 150 mm with a manhole at the downstream end to enable cleaning by jetting. The ground profile will be such as to direct flows in excess of the 1 in 10 year storm towards the downstream conveyance swale and infiltration basin. This will also act as a failsafe mechanism should lack of maintenance result in the trench becoming blocked.

The roof drainage is connected to the infiltration trench through a closed system to prevent ingress of debris. The design also includes a sediment sump on the inlet from the roof drainage. The 50 mm sand/pea gravel layer above the filter material will also act as secondary treatment in preventing ingress of fine material from the car park.

2.4.2 Conveyance swale

The swale shown in Figure A2.4 is designed to convey flows in excess of the 10 year event from Sites 1, 2 and 3 and also to serve the access road. The landscaping of each site will ensure that when the infiltration trenches overflow, the excess water flows overland to the swale.

Figure A2.4 *Conveyance swale*

The swale is required to convey flows up to the 1 in 30 year event. Modelling is required to determine accurate values of flow rate and velocities. Relevant details are given in the Table A2.3.

Table A2.4 *Swale characteristics*

Area served by swale (Sites 1, 2 & 3)	9520 m^2
Length of swale	150 m
Elevation of inlet and outlet 12.0 m & 11.10 m AOD	Longitudinal slope = 0.006
Bottom width to suit available space	Side slopes 1:4
Grass may not be cut frequently so take a conservative value for Manning n (see Section 10.3)	1.50 m 0.2 to 0.3

However, for the purposes of checking the swale design, flow rates for each of the required return periods were determined using a simple runoff model that assumes 100 per cent runoff from the roofs and car parks (total area 9520 m^2). The excess flows for the 30 year return period runoff rate can only be determined by detailed modelling, but assuming a conservative rainfall intensity of 50 mm/hr from the roofs and car parks from sites 1, 2 and 3 this gives a runoff rate of 132 l/s as shown below:

$$Q = \frac{9520 \times 0.050}{3600} = 132 \text{ l/s}$$

The calculated flow characteristics using Manning's equation (Box 4.9) results in the following values:

Table A2.5 *Swale flow characteristics*

Flow	132 l/s
Depth	0.25 m
Velocity	0.2 m/s

A profile of the designed conveyance swale is shown in Figure A2.5. The swale will be maintained such that the base and side slopes are kept free of woody vegetation.

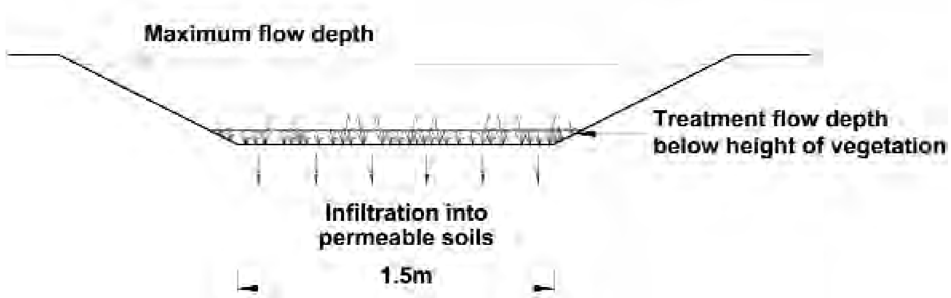

Figure A2.5 *Sample conveyance swale cross section*

2.4.3 Infiltration basin

The purpose of the infiltration basin on this development is to store and dispose of runoff for events between 1 in 10 and 1 in 30 year. The infiltration basin is located at the lowest point on the site which is also the natural surface water collection point at the site. Figure A2.6 shows the general concept of the system.

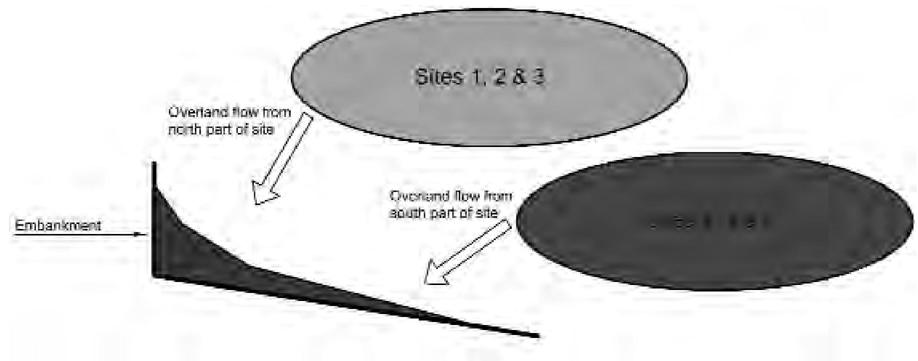

Figure A2.6 *Extreme events flow route schematic*

The monitoring boreholes installed at the site showed that the highest winter groundwater level was 4.3 m AOD. The base of the basin was set at 8.7 m AOD which is 5.2 m above the highest groundwater level.

There are no watercourses in the immediate vicinity and flows in excess of the 1 in 30 year event will overflow from the infiltration storage area and flow through fields and down road without damage to properties en-route. The basin embankment will be designed for extreme event flows over its crest.

The infiltration storage site will also serve as the car park area for site 4 since it will be flooded very infrequently.

Flows in excess of the 10 year event start passing forward from the infiltration trenches, but the trenches will still cater for much of the 30 year event runoff. This makes the design of the infiltration basin quite complex and an estimate of its size can only be achieved using a computer drainage model. A model of the site was run for a range of durations for the 30 year return period and the results were as follows:

Table A2.6 *Inflow and volume data for the infiltration basin*

Return period 30 year
Max inflow = 480 l/s
Attenuation volume = 1580 m^3

The dimensions of the basin, which were assessed iteratively from the site topography, were as follows:

Maximum depth = 0.5 m
Plan area = 5760 m

The infiltration basin drains down through its base and needs to be designed to empty completely from the 1 in 30 year event in 24 hours. Based on an infiltration rate of 0.000022 m/s, the drain-down time was estimated to be 5.3 hours which is satisfactory.

2.5 DETAILED SYSTEM DESIGN

A detailed model of the contributing catchment and drainage system is required in order to check that all criteria have been achieved. The calculations above provide initial sizing information which can then be refined to optimise the system. The calculations are generally conservative and a detailed model will show the additional performance benefits of the system.

The specific checks that must be made with a detailed model are as follows:

- no unplanned flooding on the site for the 30 year critical site event (short duration, high intensity event)
- no flooding of property from the site drainage system for the 100 year critical site event (short duration, high intensity event)
- no flooding of property for a range of "blockage" scenarios
- no spillage from the temporary storage infiltration basin for events less than the 1:30 year event.

3. Industrial units example: The distribution hub

3.1 DESIGN EXAMPLE

This is a 2 ha brownfield site that is being developed as a distribution hub to contain warehousing, overnight truck parking and a prestigious office development. The pollution risks associated with runoff from the warehouse forecourts and parking areas are significant due to the type of distribution products involved (these include oils and paints) and the density of heavy lorry traffic expected on the site.

The development is high density, thus a high proportion of the site being paved with limited space available for surface water drainage. The site slopes gently to the east.

The receiving stream supports medium/good water quality and requires appropriate protection. There are no particular flood risks to people or property downstream of the site, but land adjacent to the site is part of the floodplain.

The site comprises soils of very low permeability. However, the groundwater that exists at depth (>20 m) below the site forms part of an important local aquifer and is highly vulnerable to pollution.

A plan of the development site is given in Figure A3.1. The four business activities in sites F1 to F4 are as follows:

F1 – An oil and paint warehouse
F2 – A warehouse for books and newspapers
F3 – An office building and company headquarters
F4 – Truck parking.

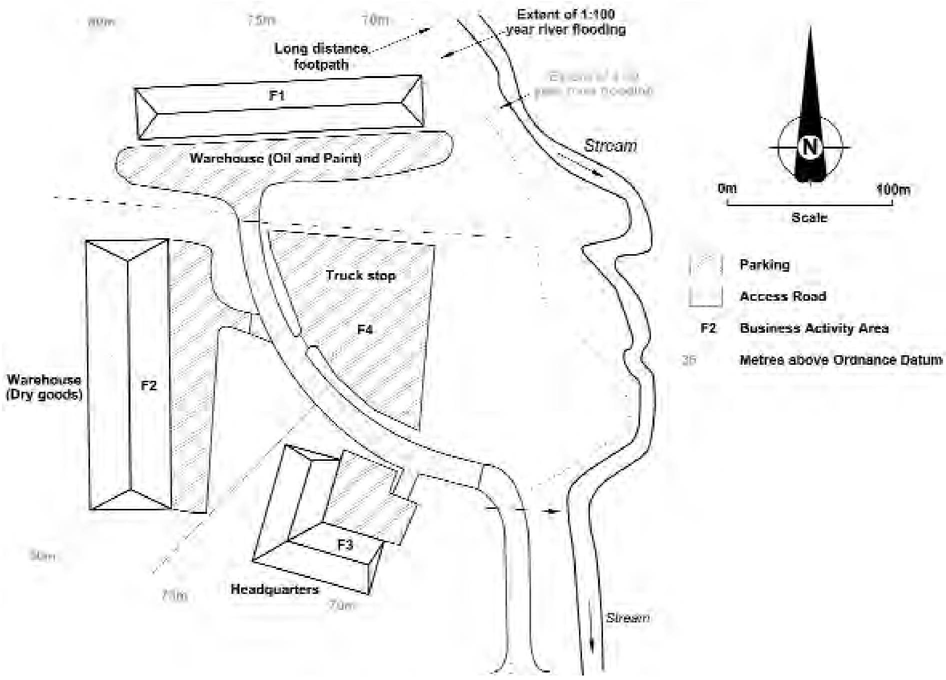

Figure A3.1 *Distribution hub site plan*

3.2 SITE DETAILS

The sub-catchment details and hydrology for the site are summarised in Table A3.1.

Table A3.1 *Catchment area details*

Sub-catchment	F1	F2	F3	F4	Roads	Total
Area (ha)	0.55	0.5	0.35	0.6	0.25	2.25
PIMP (%)	0.5	0.5	0.5	0.5	1	
Impermeable Area (ha)	0.28	0.25	0.18	0.3	0.25	1.26

The hydrology of the area can be summarised as follows:

SAAR (mm)	1000
SOIL factor	0.47 (4)
M5-60 (mm)	14
Ratio r	0.3
Hydrological region	1

3.3 PLANNING AND AGREEMENT OF DESIGN CRITERIA

Discussions were held with the local authority, the sewerage undertaker and the environmental regulator and continued from preliminary through to detailed design (as set out in Section 2.4 of this guidance document). This ensured that the proposed drainage system would meet all stakeholder criteria and that appropriate long-term maintenance agreements could be secured.

The characteristics of SUDS components and site constraints (see Chapter 5, Tables 5.2 to 5.9 and Figure 5.1) were reviewed to ensure a complete understanding of hydraulic, water quality, amenity and ecological constraints and opportunities was developed.

As a result of the discussions, design criteria (see Table 3.5) for the site were set as follows:

3.3.1 Hydraulic design criteria

- the drainage system is to be designed to cater for the 100 year critical event for the site, with discharge from the site to be limited to the greenfield equivalent
- the performance of the system (particularly the operation of the final pond) during periods of high river flood levels combined with extreme rainfall on the site are to be evaluated
- Risks of blockage at key locations need to be assessed (ie check implications of complete or partial blockage of pipes leaving depression points)
- Overland flood flow routes to be identified and all property floor levels set at least 600 mm above 100 year flooding levels
- Long-term storage is not required as downstream flooding is not an issue.

3.3.2 Water quality design criteria

This is an industrial development and for areas which are assessed as having a high pollution risks, a minimum of three levels of treatment are recommended (see Table 3.3) with the capability for accidental spillages to be isolated in upstream components. The treatment requirements proposed are set out in detail in Table A3.2.

Table A3.2 *SUDS treatment proposals for the development hub site*

Site area	Sources of pollution	Level of treatment required
F1	Roof runoff Loading area runoff	Limited pollution, attenuation only Loading areas for oil and paints, high pollution risk, three levels required, with no infiltration at the first level.
F2	Roof runoff Loading area runoff	Limited pollution, attenuation only Loading areas for dry goods plus heavy lorry traffic, two/three levels required, with no infiltration at the first level.
F3	Roof runoff Car park runoff	Limited pollution, attenuation only Light vehicular traffic only, high frequency of movement, two levels required.
F4	Truck parking	Heavy trafficking by large lorries, two/three levels required, with no infiltration at the first level.
	Site access road	Heavy trafficking by large lorries, two/three levels required, with no infiltration at the first level.

3.3.3 Amenity design criteria

The site owner requested that the surface water drainage solution should be aesthetically attractive for office employees, offering amenity and recreational benefits for their working environment.

3.3.4 Biodiversity design criteria

The river corridor will maximise the ecological potential of any surface water systems on the site, particularly any situated adjacent to the floodplain. The design of any ponds/basins should incorporate best practice with respect to landscaping and management techniques to promote biodiversity.

3.4 SUDS SELECTION

SUDS characteristics were reviewed to allow appropriate selection of surface water drainage components for the site. The main constraints/opportunities driving SUDS selection are summarised in Table A3.3.

Table A3.3 *SUDS constraints/opportunities*

Characteristic	Constraint/opportunity
Development type	• permeable pavements unsuitable for warehousing and truck stop due to the risks of spills and heavy lorry trafficking.
Soils	• soil is clay so minimal infiltration is possible.
Groundwater	• no infiltration due to pollution risk to groundwater; all systems should therefore be lined (clay or synthetic liner).
Space available	• there is room for a retention pond adjacent to the river floodplain; this would provide enhanced amenity and biodiversity benefits as well as good final treatment of runoff • some open space is available directly adjacent to the offices and parking areas • large industrial buildings suited to the use of green roofs.
Site topography characteristics	• receiving stream requires protection from pollution, but is less vulnerable to flooding • site gradients range from moderate to gentle and therefore do not limit drainage options.

Table A3.3 *SUDS constraints/opportunities (continued)*

Characteristic	Constraint/opportunity
Ownership/ maintenance	♦ all subsurface pipework, to be adopted by the sewerage undertaker; swales, filter strips, retention pond, detention basins and bioretention systems to be maintained by private site management company.
	♦ roadside swales should convey site drainage so that sources of pollution can be identified, facilitating prosecution if necessary.
	♦ use of filter trenches was rejected due to the high density of lorry traffic and the risk of trench damage or deterioration in performance due to lorries accidentally driving on the trench surfaces.
Community acceptability	♦ aesthetically pleasing solutions are preferred
Cost	♦ architectural and planning constraints precluded the use of green roofs in this instance.
Public safety	♦ pond and detention basins are acceptable in public open space.
Biodiversity	♦ apond would provide good biodiversity benefits.

The drainage solution adopted therefore comprised the following components:

- treatment swales with check dams to provide first level treatment for pavement runoff from the two warehouse areas and access road
- detention basins – to attenuate roof and pavement runoff to the 1 in 10 year event; this reduces the on-site attenuation storage volumes required. The basins also provide second level treatment for the pavements of both warehouse areas
- filter strip with a treatment swale – to provide two levels of treatment for the truck loading area
- bioretention area (and associated detention) – to provide vegetated open space for treatment and attenuation of flows from office roof and car park runoff; also provides amenity and biodiversity benefit
- retention pond to provide tertiary treatment, and attenuation for the 1 in 100 year event
- conventional pipework to convey flows from detention basins to the pond.

The drainage design is shown in Figure A3.2.

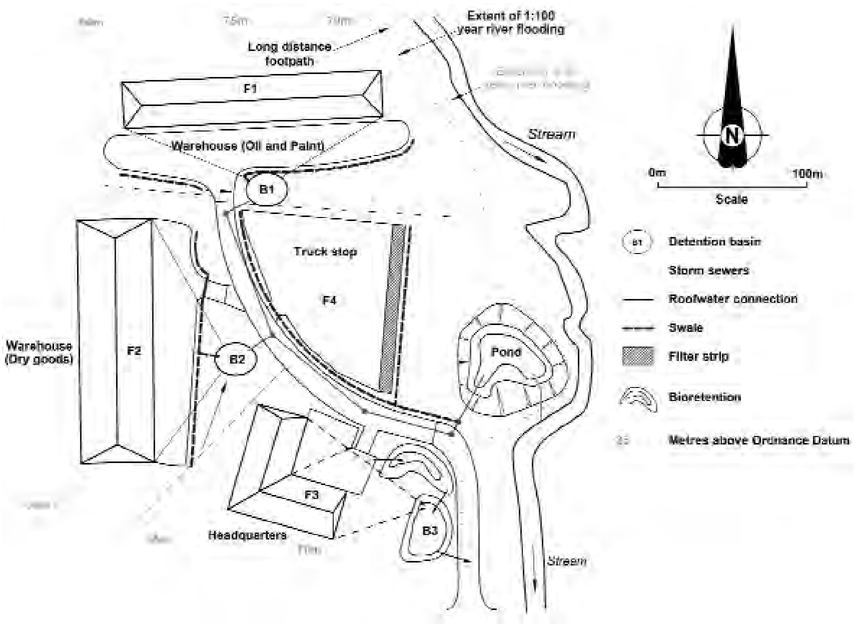

Figure A3.2 *Distribution hub – drainage layout*

3.5 INITIAL SYSTEM DESIGN

3.5.1 Catchment protection from increased flow rate and volume of runoff

Greenfield runoff rate analysis

The equation for calculating greenfield runoff rates is given in Box 4.2, and below:

$$QBAR_{rural} = 0.00108 AREA^{0.89} SAAR^{1.17} SOIL^{2.17}$$

As discussed in Table 4.2, as the site is less than 50 ha, the formula should be applied for 50 ha and the answer factored based on the ratio of areas.

$$\begin{aligned} QBAR_{rural} &= 0.00108 \times 0.5^{0.89} 1000^{1.17} 0.47^{2.17} \\ &= 0.366 \text{ m}^3/\text{s} \\ &= 366 \text{ l/s} \\ &= 7.33 \text{ l/s/ha} \end{aligned}$$

To get the 1, 10 and 100 year throttle rates, the FSR growth curve for Hydrological Region 1 is required (as set out in FSSR14). Growth curve factors for this region are:

1 year factor = 0.8
10 year factor = 1.45
100 year factor = 2.48

Greenfield limiting discharge rates for the site are in Table A3.4.

Table A3.4 *Greenfield runoff rates*

Return period	Whole site to pond	F1	F2	F3	F4
1 year	0.8 x 7.33 x 2.25 = 13.2 l/s	0.8 x 7.33 x 0.55 = 3.2 l/s	0.8 x 7.33 x 0.50 = 2.9 l/s	0.8 x 7.33 x 0.35 =2.1 l/s	0.8 x 7.33 x 0.6 = 3.5 l/s
10 year	1.45 x 7.33 x 2.25 = 23.9 l/s	1.45 x 7.33 x 0.55 = 5.8 l/s	1.45 x 7.33 x 0.50 = 5.3 l/s	1.45 x 7.33 x 0.35 = 3.7 l/s	1.45 x 7.33 x 0.6 = 6.4 l/s
100 year	2.48 x 7.33 x 2.25 = 40.9l/s	–	–	2.48 x 7.33 x 0.35 = 6.4 l/s	–

It should be noted that the outflow throttle rates are well below what can be achieved using an orifice of 150 mm. Outlet control solutions will need to be agreed with the adopting authority but options are presented in Chapter 19.

3.5.2 Attenuation storage

There are two methods of undertaking preliminary assessments of the required attenuation storage volumes required. The first uses the approach set out in the EA/Defra R&D Technical Report W5-0741A P*reliminary rainfall runoff management for developments*. The second uses a simple hydrodynamic modelling approach that uses a single, lumped development area and appropriate throttles.

Using the EA/Defra approach, the required attenuation storage volumes for the site are given in Table A3.5.

Table A3.5 *Preliminary estimation of attenuation volume*

	Attenuation storage volumes (m³)				
Return period	F1	F2	F3	F4	Pond
1 year	24	22	10	(26)	N/A
10 year	48	45	18	(51)	N/A
100 year	(59)	(54)	23	(65)	(234 – u/s storage 93) x 1.3 = 183

( ) attenuation not required to this return period

As the retention pond is downstream of the detention basins for F1 and F2 (which are sized to the 10 year event), the reduction in hydraulic efficiency will require the storage volume for the pond to be slightly greater than just taking the difference in the computed volumes. In this case a factor of 1.3 has been used. Detailed design will subsequently establish the exact storage requirements of the pond.

3.5.3 River water quality protection

Surface water treatment is provided by the permanent pool in the pond (sedimentation, bio-chemical and other processes) and also filtration and adsorption provided by swales and detention basins. It was felt that the pollution risk justified having more than $1 \times Vt$ for the sizing of the permanent pool, but that upstream SUDS allowed this to be limited to $2 \times Vt$ and provided as a single pond (see Table 17.2).

Treatment storage can be calculated using either 15 mm rainfall depth, or the equation in Box 4.12. 80 per cent runoff from paved areas is assumed.

The extent of paved surfaces draining to the river via the pond is:

Paved area = $(1.26 - 0.18) \times 10\,000 = 10\,800$ m^2.

Using 15 mm rainfall depth, treatment storage volume is:
$Vt = 2 \times 10\,800 \times 0.015 \times 0.8 = 259$ m^3

Alternatively using the equation for Vt from Box 4.10:
$Vt\ (m^3/ha) = 9 \times D\ (SOIL/2 + (1\text{-}SOIL/2) \times I)$

I = average impervious fraction for contributing area = 0.5

$Vt = 9 \times 14 \times (0.47/2 + (1\text{-}0.47/2) \times 0.5) = 77.81\ m^3/ha$

As Vt is applied to the whole catchment area and not the impervious area, the total volume of pond treatment storage = $2 \times 77.81 \times (2.25 - 0.35) = 295$ m^3.

A Vt of 300 m^3 was selected following discussions with the environmental regulator. This volume provides effective final polishing together with high amenity and biodiversity benefits.

3.5.4 Filter strip design

The filter strip provides the first level of treatment for the runoff from the lorry park and operates as an initial filter to the conveyance swale. Chapter 8 gives details for designing filter strips. The filter strip enables pollutants (particularly oils and heavy metals) to be easily seen and trapped early in the treatment train.

There is space available for a 12 m wide strip on the downstream side of the lorry park. A schematic of the proposed filter strip is shown in Figure A3.3 and design details are given in Table A3.6.

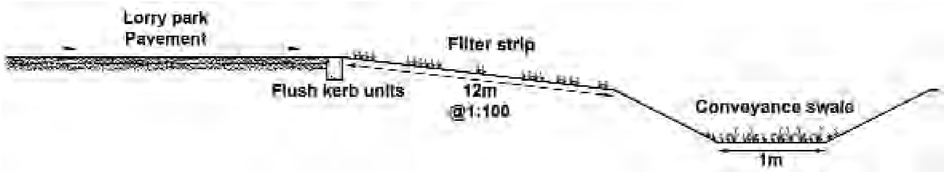

Figure A3.3 *Filter strip serving the lorry park*

Assuming a time of concentration (critical event duration) of 10 minutes, the rainfall intensity for this hydrological region for a 1 year event is 29 mm/hr.

Table A3.6 *Filter strip design data*

Lorry park parking area	0.30 ha
Q1 yr assuming a runoff coefficient of 90%	0.029/3600 x 0.6x10^4 x 0.9 = 43.5 l/s
Length of filter strip (length of side of parking area)	120 m
q = flowrate per metre length of filter strip = Q1 yr/filter strip length	0.363 l/s
Width (in direction of flow)	12 m
Manning n used	0.25
Slope	1 in 100

Checks can then be made that the 1 year treatment event will flow at a depth of <50 mm (ie below the height of the vegetation), with a velocity of less than 0.3 m/s to promote settlement.

From Box 8.1:

$$V = \frac{d^{2/3} S^{1/2}}{n}$$

Assuming a Manning's n value for below grass flow of 0.25, gives the following results:

d (mm)	V (m/s)	Q (m³/s)
2	0.006	1.52
5	0.012	7.02
10	0.019	22.28
15	0.024	43.79

This means design criteria for the treatment event are met.

A check is also required that velocities remain below 1.5 m/s for extreme flows to prevent erosion.

Assuming a rainfall intensity of 75 mm/hr for the extreme event:

$$Q = ((0.075/3600 \times 0.6\text{x}10^4 \times 0.9\times103)$$
$$= 112.5 \text{ l/s}$$

An extention of the above calculations gives:

d (mm)	V (m/s)	Q (m³/s)
25	0.034	102.6

This means design criteria for the extreme event are also met.

3.5.5 Bioretention design

The bioretention system proposed includes a vegetated treatment system for low levels of stormwater pollution from the carpark, together with an associated detention basin to attenuate roof runoff and large events. The roof water from the office building can drain directly to the detention basin since it needs minimal treatment. Attenuated flows from the detention basin pass directly to the stream.

The parking area is sloped so that runoff from the roadways and parking drains to the bioretention area. The bioretention area has a raised outlet. When full, it overflows into the detention basin area, though its normal operation is to dispose of the water via infiltration and evapotranspiration. As the soil in the catchment is clay, an under-drain is connected to the outlet manhole.

Table A3.7 *Catchment characteristics*

Subcatchment	Area
Total hard surface area	0.18 ha
Roof area	0.11 ha
Parking and road area	0.07 ha

A schematic of the drainage system for Area F3 is shown in Figure A3.4.

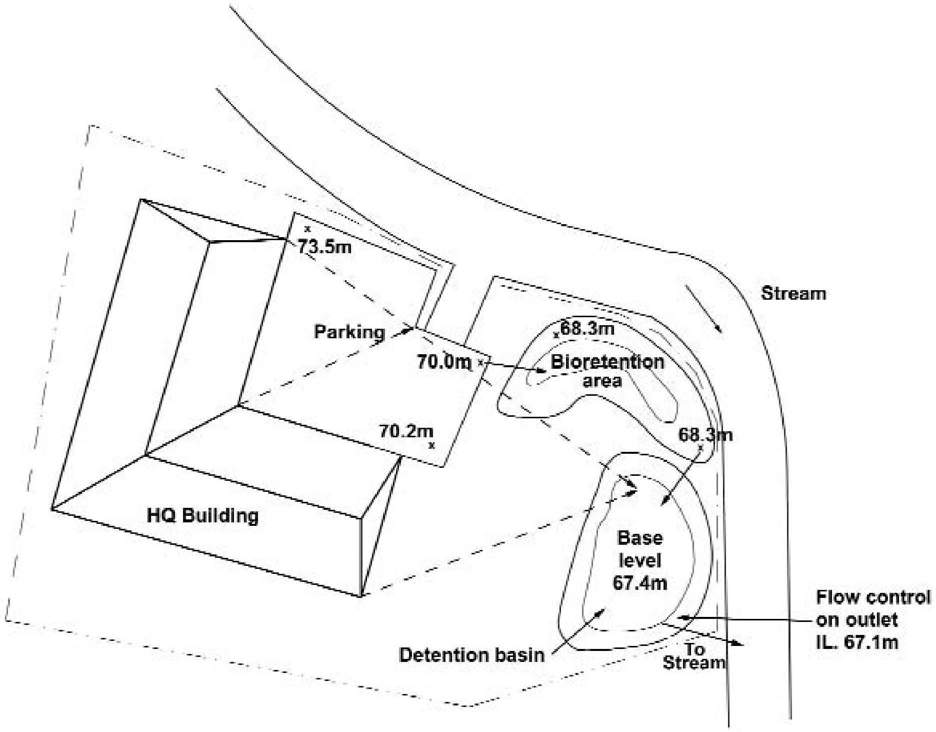

Figure A3.4 *Layout of headquarters showing bioretention area and detention basin*

The bioretention system is designed to provide sufficient area to temporarily store the water quality treatment volume as a layer of not more than 150 mm depth on the surface.

Table A3.8 *Design data for bioretention unit*

Filter bed depth	0.8 m
Coefficient of filter bed soil permeability	0.000002 m/s
Half of maximum allowable surface water depth	0.075 m
Required time to half drain (48 h)	172 800 s

Using the fixed rainfall depth approach given in Section 4.5.6 and assuming 80 per cent runoff, the water quality treatment volume is calculated as follows:

$V_t = 0.07 \times 10{,}000 \times 0.015 \times 0.8 = 8.4 \text{ m}^3$

Using the equation from Box 11.1, the required filter surface area is calculated as follows:

$$A_f = \frac{V_t\,(L)}{k(h+L)t}$$

Where:

A_f = Surface area of filter bed (m^2)
V_t = Water quality treatment volume (m^3)
L = filter bed depth (m)
k = coefficient of permeability of filter medium for water (m/s)
h = average height of water above filter bed (half maximum height) (m)
t = Time required for water quality treatment volume to percolate through filter bed(s)

Therefore:

$$A_f = \frac{8.4\,(0.8)}{(0.000002)(0.075+0.8)172800} = 22 \text{ m}^2$$

A design check using the simpler relationship of 5 per cent of the drainage area multiplied by the runoff coefficient:

$A_f = (5/100)*(0.07 \times 10\,000) \times 0.8 = 28 \text{ m}^3$

The bioretention provided was an area of approximately 3 × 9 m.

3.5.6 Detention basin design for site F3

The function of the detention area is to attenuate all of the runoff from the roofs and the excess from the bioretention system. From simple modelling:

Attenuation storage volume required for 1 year event = 10 m^3
Attenuation storage volume required for 30 year event = 18 m^3
Attenuation storage volume required for 100 year event = 23 m^3

A schematic with initial elevations is presented in Figure A3.5. This will require confirmation through detailed modelling.

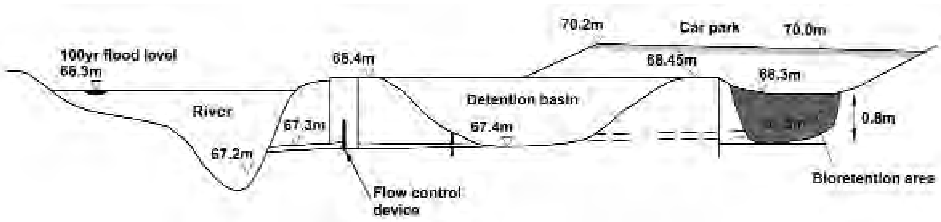

Figure A3.5 *Section through bioretention area and detention basin*

3.5.7 Swale design

A swale must cater for two hydraulic conditions.

(1) Effective treatment is provided with depths of flow preferably below 100 mm with a maximum velocity of 0.3 m/s. These conditions should be provided for events up to a 1 year event.

(2) Adequate hydraulic capacity for conveying flood flows for a 30 year event and without causing significant risk of erosion. This means that velocities should preferably be lower than 1.0 m/s for this event.

Swales serve the site at a range of gradients. The two situations which need checking are:

- the swale serving F4 lorry parking area, at a 1:500 gradient, serving 0.3ha
- the swale serving the road, at a maximum gradient of 1:20, serving an area of 0.25ha.

It is assumed that the critical duration/time of concentration for the bottom end of each of the swales is of the order of 10 minutes. It was then established that the 10 minute 1 year rainfall intensity is 29 mm/h and the 30 year rainfall intensity is 63 mm/h.

Taking the swale cross-section as having a 1.0 m base and 1:4 side slope with a maximum depth of 0.4 m the critical calculations to be carried out using the Manning's equation are:

Swale at 1:500 (adequacy of capacity due to the shallow nature of the system):

- the depth for the 30 year event.

Swale at 1:20 (adequacy of treatment velocity and depth, and erosion protection due to the steep nature of the system):

- the velocity for the 30 year event
- the velocity for the 1 year event.

<u>Swale at 1:500</u>

The runoff rate for the lorry park is:

Q = Area × rainfall intensity × runoff coefficient

$Q = 0.3 \times 104 \text{ x } 63 / (1000 \times 60 \times 60) \times 0.8$

$Q = 0.042 \text{ m}^3/\text{s}$

Using Manning's equation given in Box 4.9:

$$Q = \frac{1}{n} A R^{2/3} S^{1/2}$$

Maximum conveyance area of swale cross-section is = 1.04 m^2

Maximum perimeter of conveyance area is = 4.3 m

n for depth of flow at 0.4 m, say 0.1

S is = 0.002

The capacity of the swale is therefore $(1/0.1) \times 1.04 \times (1.04/4.3)^{2/3} \times (0.002)^{1/2}$

$= 0.18\ m^3/s$

Therefore the swale capacity is far greater than the maximum flow rate for the 30 year event.

Swale at 1:20

The flow rate for the 1 year event is:

Q = Area × rainfall intensity × runoff coefficient

$Q = 0.25 \times 104 \times 29 / (1000 \times 60 \times 60) \times 0.8$
$Q = 0.016\ m^3/s$

The flow rate for the 30 year event is:

Q = Area × rainfall intensity × runoff coefficient

$Q = 0.25 \times 104 \times 63 / (1000 \times 60 \times 60) \times 0.8$
$Q = 0.035\ m^3/s$

Using Manning's equation, different depths can be tested (assuming n = 0.25 for depths of <100 mm and 0.1 for depths >100 mm):

d (mm)	Q (m^3/s)	v (m/s)
10	0.000	0.040
20	0.001	0.063
30	0.003	0.080
40	0.004	0.096
50	0.007	0.109
60	0.009	0.121
70	0.012	0.132
80	0.015	0.143
90	0.019	0.152
100	0.023	0.162
150	0.051	0.510

This shows that the 1 year event will have a depth of between 80 and 90 mm and a velocity of approximately 0.25 m/s which is acceptable.

This shows that the 30 year event will have a depth of between 100 and 150 mm and a velocity of less than 0.5 m/s which is also acceptable.

3.6 DETAILED SYSTEM DESIGN

A detailed model of the contributing catchment and drainage system is required in order to check that all criteria have been achieved. The calculations above provide initial sizing information and allow a first estimate to be modelled, which can then be refined to achieve the required results. The particular checks that should now be made with the detailed model are as follows:

- greenfield discharge rates achieved for 1, 10 and 100 year
- no unplanned flooding on the site for the 30 year critical site event (short duration, high intensity event)
- no flooding of property from the site drainage system for the 100 year critical site event (short duration, high intensity event)
- no flooding of property for key “blockage” scenarios
- possible impact and performance of the pond for the maximum 100 year river level for a range of return period events (a joint probability analysis may be required depending on this assessment).

4. Superstore example

4.1 DESIGN EXAMPLE

A superstore development is proposed for a 1.3 ha brownfield site. The drainage system for the site will need to manage the runoff from the following areas:

- large roof
- extensive car park
- delivery area where lorries park while unloading
- rubbish storage site for the store and on-site canteen
- access road within parking area
- petrol station.

The site is located on impermeable clays, with a gentle slope towards the south, and is situated a short distance from the floodplain of the receiving watercourse.

A plan of the development site is given in Figure A4.1.

Major superstores can have large hydrological and water quality impacts due to their size and related activities. The delivery and waste disposal areas and petrol station pose particular pollution risks which must be effectively managed as the river supports sites of ecological importance downstream of the store.

Table A4.1 details the sizes of the various areas of the development.

Table A4.1 *Sizes of the sub-catchment areas of the superstore site*

Sub-catchment	Impermeable area (m^2)	Description
G1	500	Service road for deliveries
G2	3500	Superstore roof
G3	5000	Customer car park
G4	2500	Petrol station canopy, surround and access road
Total site	11 500	

Table A4.2 *Catchment hydrological characteristics*

Parameter	Value
SAAR	950 mm
SOIL factor	0.4 (type 3)
M5–60	16 mm
r	0.24

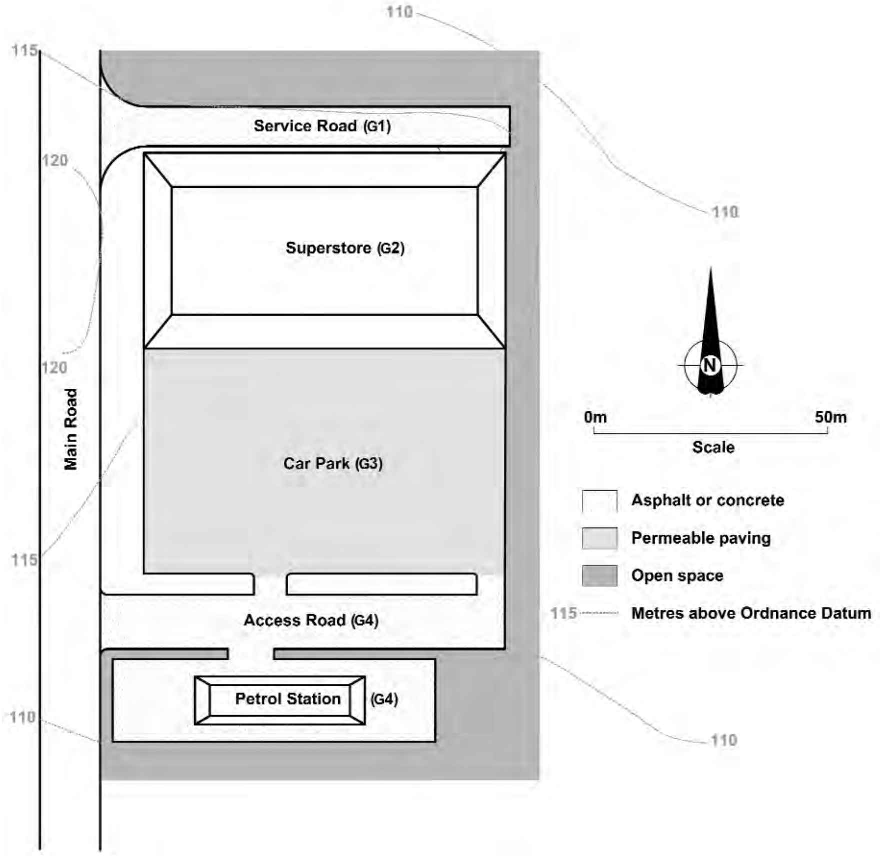

Figure A4.1 *Layout of superstore site*

4.2 PLANNING AND AGREEMENT OF DESIGN CRITERIA

Discussions were held with the local authority, the sewerage undertaker and the environmental regulator, and continued from preliminary through to detailed design as set out in Section 2.4 of this guidance document.

Maintenance of the drainage system will be the responsibility of the superstore operator who will enter into agreements for both the foul sewer connection and for conveyance of surface water from the site.

The characteristics of SUDS components and site constraints (see Chapter 5, Tables 5.1 to 5.9 and Figure 5.1) were reviewed to ensure a complete understanding of hydraulic, water quality, amenity and ecological constraints and opportunities was developed.

As a result of the discussions, design criteria (see Table 3.5) for the site were set as follows:

4.2.1 Hydraulic design criteria

- the receiving watercourse is prone to flooding and there are a significant number of properties downstream of the site at risk; therefore strict criteria were imposed such that runoff from the proposed development for a 1 in 10 year event should be restricted to the greenfield site 1 in 2 year runoff, and the 1 in 100 year event should be controlled to the 1 in 10 year greenfield flow rate
- the site is classed as brownfield with contaminated soils and therefore no infiltration is permitted

- safe flood flow paths across the site for events greater than 30 years
- all property to be set at least 600 mm above the 100 year flood levels
- long-term storage is required to minimise flood volumes discharged to the receiving watercourse
- 10 per cent factor is required for climate change.

4.2.2 Water quality design criteria

As this is a mixed commercial and industrial development, it is categorised as being a high risk site for pollution. In consultation with the environmental regulator, it was agreed that three levels of treatment should be provided for the service road and the areas around the filling station, noting that the forecourt itself must drain to the foul sewer. Only two levels of treatment are required for the car parking and its access road. Attenuation is needed only for the roof runoff from the store. Table A4.3 shows the pollution risks and treatment for each sub-catchment of the site. It should be noted that the regional wetland downstream will provide a 3rd level of treatment.

Table A4.3 *Pollution sources and treatment*

Sources of runoff	Mechanism of pollution	Level of on site treatment required
Service road used for commercial vehicles	Spillages of food/other products, standard vehicular pollution, slight risk of vehicular spills.	Two treatment levels required.
Roof runoff from superstore	Limited pollution.	Attenuation only.
Car park and access road	Minor spillages of products, standard vehicular pollution, slight risk of vehicular spills.	Two treatment levels required.
Petrol station roof	Limited pollution.	Attenuation only.
Petrol station access and around forecourt	Frequent minor and occasional more serious petrol/diesel spillages (some risk that not all spills will be intercepted by the foul system), standard vehicular pollution.	Two treatment levels required.

4.2.3 Amenity design criteria

There is a need to ensure drainage solutions are aesthetically attractive although their use as recreational facilities will not be encouraged.

4.2.4 Biodiversity design criteria

There are no specific biodiversity requirements associated with the development. However, appropriate design and management of surface water drainage systems and open space areas will automatically provide biodiversity benefits.

4.3 SUDS selection

SUDS characteristics were reviewed to allow appropriate selection of surface water drainage components for the site. The main constraints/opportunities driving SUDS selection are summarised in Table A4.4.

Table A4.4 *SUDS constraints/opportunities*

Characteristic	Constraint opportunity
Development type	• commercial and industrial site – fairly high pollution risk.
Soils	• type 3, potentially contaminated brownfield site – no infiltration allowed.
Groundwater	• depth to groundwater greater than 4 m.
Space available	• limited amount of green space, drainage opportunities around periphery of site.
Catchment characteristics	• receiving watercourse vulnerable to pollution • receiving watercourse vulnerable to flood risk requiring a high degree of runoff control.
Ownership/maintenance	• surface drainage on site to be operated and maintained by site owner.
Public safety	• health and safety risks need to be considered as the store and car park will attract a large number of people (including children).
Biodiversity	• consider systems that maximise opportunities for flora and fauna.
Cost	• cost is not a constraint to meeting design criteria.

The drainage solution adopted is considered in the context of the four sub-areas which are shown in Figure A4.2.

There is a service road area for delivery vehicles unloading materials for the superstore (area G1). There is potential pollution from the trucks and from accidental spillages. It is proposed that these risks are controlled at source by a treatment swale, giving the first level of treatment. The swale will be lined with a clay liner to prevent infiltration of polluted runoff. The swale will then discharge into a detention basin after picking up the discharge from the car park.

The superstore roof (area G2, Figure A4.2) has a minimal pollution risk, but its hydrological impact is significant and it will therefore either be attenuated within the detention basin or else by draining through the permeable pavement (assuming the capacity is sufficient). This latter option would minimise flow rates through the detention basin and maximise treatment processes in this component. If the detention basin is used as the attenuation component then the discharges from the pavement would be piped adjacent to the swale as shown in Figure A4.2. If the pavement is used, then the roof water would need to be discharged into the pavement sub-base using upstream debris traps and energy dissipating devices.

The main parking area (area G3) will have permeable paving (Type C, Figure 12.1) to provide pollution control and some flow attenuation. There will be conventional roadways for access and between the parking spaces which will drain to the permeable paving. The pavement could be designed to lie above a granular sub-base, or above modular, geocellular system units. The latter would provide an increased storage availability (but reduced treatment), and it may then be possible to drain the roof runoff into the sub-base system. The standard granular sub-base option has been used for the purposes of this design example.

The forecourt of the petrol station will be connected directly to the foul sewer via a petrol interceptor but the access road, canopy and hard standing in the vicinity which is not served by the foul sewer also present a pollution risk and the surface water runoff requires treatment (area G4). This will be provided by an adjacent lined treatment swale and the detention basin.

The whole site is considered to have a high risk of pollution and a third level of treatment is provided by the regional wetland to which the detention basin drains. Table A4.5 summarises the SUDS hierarchy for the site.

Table A4.5 *SUDS water quality treatment hierarchy for the site*

Source	Level of treatment required	First level SUDS	Second level SUDS	Third level of SUDS
Service road	First and second level.	Swale.	Detention basin.	
Roof runoff	Attenuation only.	Permeable pavement (only if sufficient capacity is available).	Detention basin.	
Car parking	First and second level.	Permeable pavement.	Detention basin.	
Filling station forecourt	None.	None – drains to foul sewer.		
Filling station canopy and access road	First and second level.	Swale.	Detention basin.	
Whole site	Three.	Swales, pavement.	Detention basin.	Off site regional wetland.

The required location of the detention basin is at the lowest point of the superstore site, as far as possible from people using the store. Should the basin outlets become blocked, the overflow would pass directly towards the wetland and not endanger people or property.

The detention basin will provide a location for marsh loving plants. The small area of public open space in which a detention basin is to be located should attract a variety of flora and fauna.

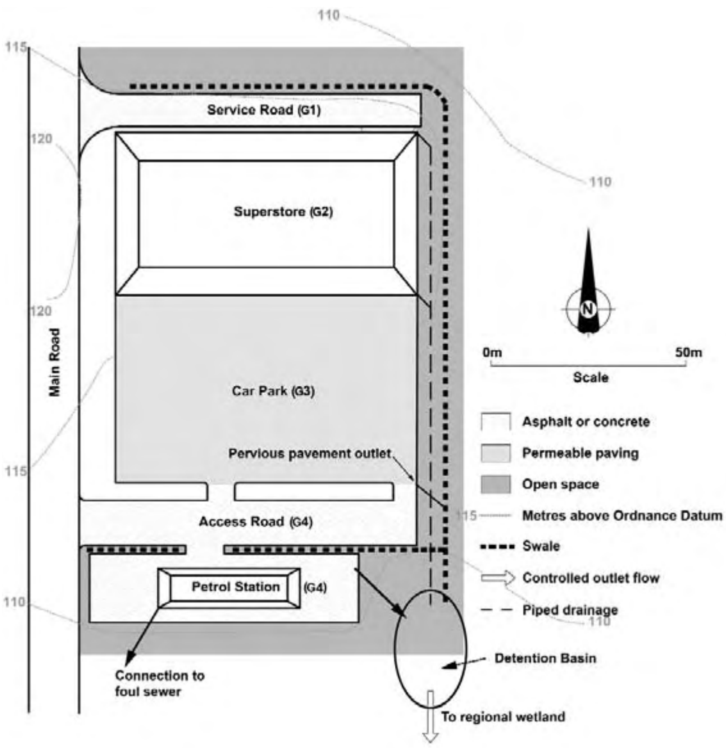

Figure A4.2 *Superstore drainage layout*

4.4 INITIAL SYSTEM DESIGN

4.4.1 Protection from increased flow rate and volume of runoff

Greenfield runoff rate analysis

The equation for calculating greenfield runoff rates is given in Box 4.2, and below:

$$QBAR = 0.00108AREA^{0.89}SAAR^{1.17}SOIL^{2.17}$$

As discussed in Table 4.2 of this guidance document since the site is less than 50 ha, the formula should be applied for 50 ha and the answer factored based on the ratio of areas. The data in Table A1.1 were used to determine the flows in Table A4.6. To get the 1, 2, 10 and 100 year throttle rates, the FSR growth curve for Hydrological Region 2 is required (as set out in FSSR14). Growth curve factors for this region are:

1 year factor = 0.85
2 year factor = 0.91
10 year factor = 1.42
100 year factor = 2.63

These factors give the greenfield runoff rates shown in Table A4.6.

Table A4.6 *Greenfield runoff rates*

Flow rate	Value
QBAR for 50 ha	243 l/s
QBAR for 1.05 ha	5.1 l/s
$Q_{2\ yr}$	4.6 l/s
$Q_{10\ yr}$	7.2 l/s
$Q_{100\ yr}$	13.4 l/s

The flow rate from the detention basin needs to be limited to 7.2 l/s for the 100 year event.

Pervious pavement hydraulic design

The pervious pavement serves the car park and associated access roads. The outlet control could be higher or lower than the 10 year greenfield rate for the pavement area with the difference being provided by the detention basin downstream. However the greater the throttle applied to the pavement (to maximise the value of the storage provided), the smaller the detention basin can be. In addition, as long term storage is needed, this can be provided by the pavement if the discharge rate is less than 2 l/s/ha.

From Figure 12.8 in the main document, assuming a throttle rate of 2 l/s/ha (= 1 l/s), with a value for "r" of 0.24, it is likely that there will be sufficient capacity in the pavement to manage the additional 3500 m^2 from the roof runoff, within a pavement depth of the order of 360 mm.

The approach given in Interpave's guide to the design, construction and maintenance of concrete block permeable pavements (Interpave, 2005), gives a depth requirement for hydraulic capacity of between 400 and 450 mm, depending on whether you use the summary table in the main text or the formulas given in the appendices. However, this is a conservative estimate as the procedure assumes zero outflow from the system during the event.

Hydraulic modelling using proprietary software confirms that 380mm sub-base depth is appropriate and conservative.

Vehicle loadings are likely to be Category 2 (Table 12.4) = 2,000 kg, and a load partial safety factor (Table 12.5) of 1.6 is assumed. Therefore the factored loading = 2000 × 1.6 = 3200 kg, which (from Table 12.6) equates to a total sub-base thickness requirement of 300 mm (assuming a material partial safety factor of 1.0).

The hydraulic depth requirement is therefore the key influence on the design.

Storage volume > Inflow – Outflow

Normal depth of storage medium is 380 mm.
Voids ratio is 0.4
Area of pervious pavement is 0.5 ha

Therefore storage volume for water is:

$V = 0.38 \times 0.4 \times 0.5 \times 10^4$
$V = 760\ m^3$

If the rainfall depth for a 24 hour, 100 year storm with climate change is 110 mm, then the volume of runoff assuming an 80 per cent runoff coefficient is:

$V_{in} = 0.110 \times 0.5\ x\ 104 \times 0.8$
$V_{in} = 440\ m^3$

Volume of outflow in 24 hours is:

$V_{out} = 0.001 \times 24 \times 3600$
$V_{out} = 86\ m^3$

This shows that storage is significantly greater than the difference between inflow and outflow, (760 >> 440 – 86), long-term storage for the site can be provided by the permeable pavement assuming that 760 m^3 is equal to or larger than the long-term storage volume.

Long-term storage is the 6 hour 100 year event (plus 10 per cente factor for climate change). Using the equation given in Box 4.11, Long-term storage volume = (69/1000) × 1.15 × 104 × 0.8 = 635 m^3

This is less than the storage available in the permeable pavement and the system is therefore considered to have met the volumetric runoff reduction requirement.

The outlet from the permeable pavement should connect to the perforated pipe laid in the adjacent enhanced swale and hence pass to the detention basin.

Detention basin hydraulic design

The detention basin provides the necessary attenuation of flows from the whole site. The outflow rates must meet those calculated in Table A4.6 with the maximum discharge rate of 7.2 l/s for the 100 year event.

The determination of the attenuation volume needed cannot use the approach set out in the EA/Defra R&D Technical Report W5-0741A *Preliminary rainfall runoff management* *for developments* as it is based on flows being throttled to greenfield rates for equivalent return periods. In addition, as the permeable pavement (which serves half the site) has been designed to throttle the outflow to a flow rate which is less than that required by the runoff criteria, the detention basin needs to be sized only to address the attenuation requirements for the remainder of the site.

A simple lumped model was therefore built with runoff from all paved surfaces with the contribution from the permeable pavement limited to 1 l/s. The total storage volume of water in the basin for the critical duration event is 183 m^3.

The general layout of the detention basin is shown in Figure A4.3.

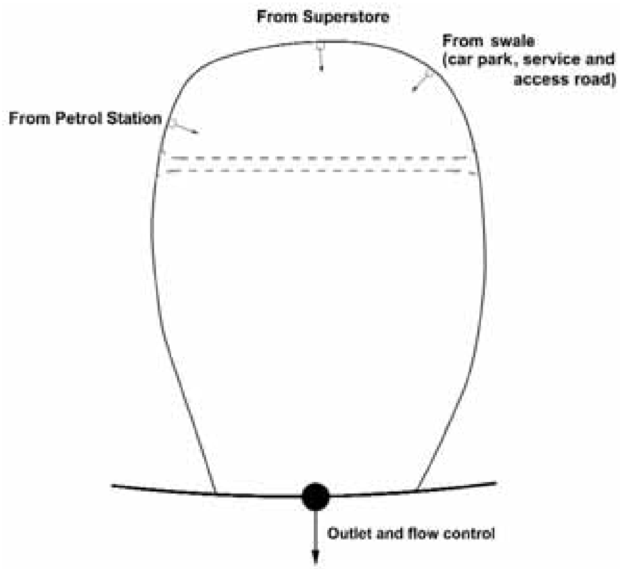

Figure A4.3 *Plan of detention basin*

Drain-down time of the detention basin

The time to drain the detention basin is:

Drain time = $(183 / 7.3 \times 10^{-3}) / 3600$
Drain time = 7.0 hours

Area/level initial assessment for the detention basin

The ground level ranges from 109.5 m to 108.5 m across the detention basin site. Maximum depth of water for the 100 year event has been set at 2 m with an additional 500 mm freeboard.

Assuming the detention basin approximates to a square based pyramid with approximately 1:5 side slopes, the storage provided is:

Volume = $0.33 \times 2.0 \times (5 \times 2.0 \times 2)^2$
Volume = 264 m^3

This is greater than the storage volume required of 183 m^3 and therefore the detention basin can be less deep than 2.0 m. The plan area required for the basin can be provided within an area of 25 × 25 m. Detailed calculations are required to provide this volume whilst ensuring that the detention basin has a length/width ratio of 3 or more.

4.4.2 Stormwater treatment analysis

Water quality treatment is being provided by the detention basin (by sedimentation primarily), by the swale (by filtration and bio-degradation) and the pervious pavement (by sorption, filtration and bio-degradation).

There is no design analysis for water quality processing for the pervious pavement. Similarly, for the detention basin, as long as the flow path between the inlet is maximised and velocities are low (which is the case with such high levels of attenuation), there is no analysis needed to check for water quality treatment.

However the swale should normally be checked for flow velocity for the 1 year event. The velocity needs to be less than 0.3 m/s with a depth of flow of less than 100 mm. However as this is an enhanced swale the flow will pass down through the base into the gravel bedding below. As the area served by the swale is so small, the flows will also be small and a velocity check is not required.

4.5 COMPONENT DIMENSIONS AND CONTROLS

4.5.1 Swale dimensions and controls

The swale is sized as a standard swale with a 1m base and side slopes of around 1:4 for ease of maintenance. The filter bed is 300 mm deep, overlying a pea gravel bed of 150 mm in which a perforated drain pipe is laid. The filter bed is a sandy loam to encourage bacterial seeding to provide treatment. To prevent infiltration, the unit is lined in clay or a butyl (or similar) lining.

There are no control structures on the swale. The swale varies in gradient from 1:400 to 1:20 as it passes towards the detention basin. In this later section, check dams at 10 m intervals will be provided by coarse stone to control any surface flow (assuming the filter bed has become blinded).

The perforated drain can be any size and 100 mm is taken as appropriate. Geotextile and suitable bedding material will ensure the pipe does not block with sediment over time.

4.5.2 Permeable pavement dimensions and controls

The permeable pavement will be constructed as a standard permeable pavement using a standard design granular media mix for good structural support (see Chapter 12).

The outlet control, to limit the outflow to 1 l/s with a head of around 350 mm requires a very small orifice. To protect this orifice from blockage a sump and baffle arrangement will be provided at the outlet point together with a safety overflow arrangement.

Using the standard orifice equation (see Box 19.1):

$$Q = 0.6 \times A_0 \times (2gh)^{0.5}$$

Therefore diameter of orifice = 28 mm

This orifice size is below normal acceptable limits, though it is considered workable. If the drainage operator considers this unacceptable, then the orifice can be increased with a consequent increase in discharge. This means that the detention basin would have to increase in size and the long-term storage would need to be provided adjacent to the detention basin. This solution would be significantly more expensive to construct.

The permeable pavement will be lined with a suitable synthetic liner to prevent infiltration and mobilisation of any contaminants if they are believed to exist.

4.5.3 Detention basin dimensions and controls

The dimensions of the detention basin have been determined approximately as part of the hydraulic analysis.

The controls of the discharge from the detention basin need to limit the 1:100 year flow to 7.3 l/s, and an overflow is required to cater for flow rates from more extreme events and the consequences of any blockage to the outlet control.

Assuming an orifice control is needed to control the flow rate to 7.3 l/s with a maximum head of 1.5 m:

$0.0073 = 0.6 \times A_0 \times (2gh)^{0.5}$
Diameter = 53 mm.

As with the pervious pavement, this is smaller than what is normally acceptable (80 to 150 mm depending on the adopting authority). However this is probably acceptable if a high level of protection is provided to prevent blockage taking place. A manhole will be provided on the receiving pipe immediately downstream of the detention basin so that the storage unit can be pumped out if blockage should occur at any time.

The flow rate constraints for more frequent events should be approximately complied with due to the reduced head for such events. Altering the depth storage relationship can be done to get closer agreement with the design criteria. However the orifice size is too small to consider using alternative shapes or the use of two orifices to get a better agreement with the flow rate criteria.

The overflow structure will be at least 1.0 m in width to minimise the additional head needed to discharge extreme flows. In practice it is likely to be 3 to 4 m as it will also serve as an access point for maintenance vehicles/equipment.

4.6 DETAILED SYSTEM DESIGN

Once the preliminary sizing has been completed, a detailed model of the superstore drainage system is required in order to confirm that all criteria have been achieved. The calculations above provide initial sizing information and allow a first estimate to be modelled, which can then be refined to achieve the required results. The particular checks that should now be made with the detailed model are as follows:

- greenfield discharge rates achieved for 2 and 10 years (as close as reasonably possible)
- the pervious pavement storage is adequate to serve the 100 year critical duration event.

Appendix B

Contents

Infiltration testing

1 SOIL INFILTRATION TEST PERFORMANCE

The hydraulic properties of a soil are site-specific. Some soils, such as sands, have high infiltration coefficients while others, such as clays, have low infiltration coefficients. The infiltration coefficient for a soil is an important element of the hydraulic design of an infiltration system. At present, the only reliable method of determining the infiltration coefficient for a particular site is to carry out an infiltration test on site. The site test will provide an estimate of the infiltration coefficient, but for the purposes of design additional issues need consideration that affect the confidence in the coefficient determination:

- is the test pit representative of the full size system?
- would the infiltration coefficient be different for different antecedent soil moisture conditions?
- will the infiltration coefficient reduce in time due to clogging of the system by fine sediments?

These uncertainties are generally allowed for in the design process by the incorporation of a factor of safety.

Number of test pits

The method of determination of the soil infiltration characteristics at a site must give representative results for the whole of the proposed infiltration surface and where the surface is large, several pits should be dug.

If preliminary calculations indicate that one of the dimensions of the infiltration system will be larger than 25 m then a second test pit should be used. For larger systems, further test pits should be required every 25 m. If the soil is fissured or there is reason to suspect that the soil characteristics may vary across the proposed system location, then the distance between test pits should be reduced to 10 m.

If more than one test pit is used, then the mean value of the infiltration coefficients determined in the different test pits should be used in the design calculations.

Size of test pit

The test pit should be at the same approximate depth as the elevation of the proposed infiltration surface. This implies that for a plane infiltration system, such as an infiltration pavement, a relatively shallow test pit will normally be required while for a large soakaway a deeper test pit is likely to be more appropriate.

The size of the test pit should be related to the size of the area to be drained to the infiltration system. If the area to be drained is less than 100 m^2, the pit should be at least 0.5m^3. If the area to be drained is greater than 100 m^2 then the pit should be at least 2 m^3. Ideally, the pit should be 0.3 to 1 m wide and 1 to 3 m long with vertical sides trimmed square.

Any smearing to the sides or base of the test pit caused by excavation machinery should, if possible, be removed by hand (taking appropriate safety precautions), as smearing could significantly reduce the recorded infiltration coefficient.

a) Test procedure

The test procedure described here is based on that described in BRE Digest 365. A lot of water will be needed for the tests and a water bowser may be required. The inflow should be rapid so that the pit can be filled to its maximum effective depth in a short time. Care must be taken that the inflow does not cause the walls of the pit to collapse.

1. Excavate a trial pit of the appropriate size.
2. Record the wetted area of the internal surface of the pit including both the sides and base when the pit would be half full of water.
3. Fill the pit with water.
4. Reecord the water level and time at frequent intervals as the pit empties of water.
5. Repeat the test twice more, preferably on the same day.

Testing to full depth may not be appropriate if:

i) The trial pit is deep and it would be difficult to supply sufficient water for a full-depth soakage test.
ii) In the completed infiltration system, infiltration will only take place from the lower layers.

In these cases, the test may be conducted at less than full depth. The calculation of the soil infiltration coefficient should then be based upon the actual maximum water depth achieved. However, determinations of the soil infiltration rate may be lower than those from the full-depth test as relationships between depth of water in the pit, the effective area of outflow and the infiltration rate can vary with depth by a factor of as much as 2, even when soil conditions themselves do not vary.

If necessary for stability, the pit should be filled with granular material and a full-height perforated, vertical observation tube should be positioned in the pit so that water levels can be monitored. In this case, the volume used to calculate the infiltration coefficient (Vp75–25) should be multiplied by the porosity of fill material.

b) Analysis of test results

The time taken for the pit to empty from 75 per cent to 25 per cent of the depth of the pit should be determined, t_{p75-25}.

The storage volume of the pit between 75 per cent and 25 per cent of the depth should be determined, V_{p75-25}.

The area of the base and sides of the pit at 50 per cent of the depth should be determined, a_{p50}.

The soil infiltration coefficient, q is given by:

$$q = \frac{V_{p75-25}}{a_{p50} \times t_{p75-25}}$$

The smallest value of q obtained from all the tests carried out in the pit should be used.

Where multiple test pits are used, the mean value of the infiltration coefficients determined in the different test pits should be used in the design calculations.

Appendix C

Contents

Geotextile and geomembrane specifications

1 GEOTEXTILES

Geotextile layers are an important element in many SUDS components, as either a filtration or separation layer or to provide structural strength, and are placed between fill components or between fill and subsoil. Designers need to take careful account of geotextile properties in the selection and specification of geotextiles.

There is significant variability in the physical properties and performance of commercially available geotextiles. They can vary in thickness from a few microns to tens of millimetres; they can be manufactured from a diverse range of raw material (eg polyethylene, polypropylene, polyesters), and can be any blend of these with various mixtures of virgin or recycled material. Geotextiles can be woven, non-woven, needle-punched or thermally bonded, all with different pore sizes and permeability.

Important aspects to consider for geotexiles are described in the following table:

Geotextile property	Characteristic
Pore size	The pore size should be specified to assist in filtration and prevent migration of fine soil particles.
Permeability and breakthrough head	The geotextile should not limit flow of water in the system. It should therefore have a similar or greater permeability than the surrounding materials. Monofilament woven or needle punched non-woven fabrics are likely to be most appropriate. With certain thermally bonded geotextiles, an initial head of water is required before the geotextile will allow fluids to pass through. This is known as the 'breakthrough' head. In practice, this means that if a designer specifies a geotextile layer requiring filtration capabilities, at a distance of 130 mm beneath the surface layer of a pervious block surface, flooding will occur to a depth of 70 mm if the breakthrough head of the selected geotextile is 200 mm.
Puncture resistance	The geotextile should be able to resist the punching stresses caused by loading on sharp points of contact.
Tensile strength	The geotextile should have sufficient strength to resist the imposed forces from traffic or other loading.
Chemical/uv tolerance	The geotextile should be manufactured from a suitable material that will withstand all naturally occurring chemical and microbial effects, and relevant levels of exposure to ultra-violet light.

There are a large number of British Standards relating to geotextiles and geotextile-related products. BS EN 13252 (2001) *Geotextile and geotextile-related products – Characteristics required for use in drainage systems* should be a standard reference for SUDS projects.

Interpave state the following characteristics for use in permeable pavement structures (Interpave, 2005). However, individual manufacturers should always be consulted.

Characteristics	Standard	Woven filter	Non-woven filter
Weight	EN 965	≥ 200 g/m²	≥ 400 g/m²
Ultimate tensile strength Longitudinal Transverse	EN ISO 10319	 ≥ 30 KN/m ≥ 30 KN/m	 ≥ 15 KN/m ≥ 15 KN/m
Strain at nominal tensile strength Longitudinal Transverse	EN ISO 10319	 ≤ 25% ≤ 25%	 ≤ 70% ≤ 70%
CBR Puncture	EN ISO 12236	≥ 2000N	≥ 3000N
Opening size	EN ISO 12956	≥ 0.2 mm	≥ 0.1 mm
Water permeability	EN ISO 11058	≥ 200 x 10^{-3} m/s	≥ 6 x 10^{-3} m/s

The tensile properties of the material should be verified in accordance with EN ISO 10319 and the production of the geosynthetic should be EN ISO 9001 certified. Each roll of the geotextile should have at least one identification label with roll number and product type in accordance with EN ISO 10320, and carry a CE mark.

Adjacent rolls of geotextile should be overlapped by at least 300 mm where rolls run parallel to the direction of flow and 600 mm overlap should be provided between edges of rolls of geotextile running perpendicular to the flows.

Impermeable geomembranes

Care should be taken when specifying and selecting an impermeable geomembrane at locations where infiltration is unacceptable. This is particularly critical if the geomembrane is to provide protection to sensitive aquifers beneath. The material specified should be able to withstand the rigours of installation and possess the physical characteristics to resist:

- puncture
- multi-axial elongation stress and strains associated with settlement
- environmental stress cracking over the system design life.

It is essential to seal the joints between adjacent sheets of impermeable geomembranes correctly. Geomembranes designed to be impermeable should be seamed using proprietary welding techniques. The integrity of joints is just as important as the selection of the geomembrane, eg a correctly specified geomembrane would not be fit for purpose if jointed with tape, as the integrity of the system would then rely on the mechanical properties of the tape. It is also important to be able to demonstrate the integrity of the joints by non-destructive testing. Advice on seam testing is given in CIRIA publication R124 (Privett *et al*, 1996).

It is recommended that heavy duty geotextiles be placed both above and below the geomembrane to provide further assurance of the integrity of the installed systems.

Quality assurance

All material should be protected from ultra-violet light and from vehicular trafficking.

A comprehensive quality assurance protocol should be in place for geotextile and geomembrane components during the construction phase. It should include, as a minimum, material delivery inventories, documented storage conditions, non-destructive seam-testing results and visual inspection reports for each element.

All systems should be installed in accordance with specific manufacturers' instructions.