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Source control using constructed pervious surfaces

Hydraulic, structural and water quality performance issues

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Summary

This book discusses the critical issues that should be considered when designing and constructing pervious pavements that are to be used as a technique for stormwater source control. It details the types of surfaces available and provides examples of developments that have used these techniques. The publication discusses issues for consideration relating to the hydraulic, structural and water quality performance of pervious surfaces. Finally, the book provides a design framework, which includes detailed recommendations for methods where necessary.

Source control using constructed pervious surfaces – hydraulic, structural and water quality performance issues

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Construction Industry Research and Information Association

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Glossary

Adsorption – The adherence of gas, vapour or dissolved matter to the surface of solids.

Aquifer – Layer of rock or soil that holds or transmits water.

Asphalt – CEN description of all mixtures of mineral aggregates bound with bituminous materials used in the construction and maintenance of paved surfaces. See Section 1.4.

Asphalt concrete – New CEN description of materials previously known as macadams and Marshall Asphalt. See Section 1.4.

Attenuation – Slowing down the rate of flow to prevent flooding erosion with a consequent increase in the duration of flow.

Base – CEN description of the lowest bound layer of an asphalt pavement known in UK as roadbase. See Section 1.4.

Binder course – CEN description of the second layer of an asphalt pavement known in UK as basecourse. See Section 1.4.

Bitumen – A hydrocarbon binder. A virtually involatile 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.

Boussinesq equation – A method of determining the stress induced at any point within the ground (assumed to be a semi-infinite homogeneous weightless elastic half space) by a load applied vertically to the surface. Developed by a French physicist and mathematician (Boussinesq, 1885).

Capping layer – A layer of unbound aggregate that is of lower quality than sub-base and is used to improve the performance of the foundation soils before laying the sub-base and to protect the subgrade from damage by construction traffic.

Carriageway – That part of the road used to carry vehicular traffic.

Catchment – The area contributing flow to a point on a drainage or river system.

CBR value – California Bearing Ratio; an empirical measure of the stiffness and strength of soils, used in road pavement design.

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.

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.

Controlled waters – Waters defined and protected under the Water Resources Act 1991, including inland freshwaters (relevant lakes and ponds, rivers and other water-courses), groundwater and coastal waters. For the full definition refer to the Water Resources Act 1991.

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

Elastic modulus – Also known as Young's Modulus or stiffness modulus; the ratio of stress divided by strain for a particular material.

Fines – Small soil particles less than 63 micron in size.

First flush – Pollutants collect on carriageway and hard surfaces in dry periods. The majority of these are believed to be washed off during the first part of a storm, known as the "first flush". The profile of the pollutants in the runoff is believed also to be dependent on the storm intensity. The profile of the delivery of the pollutants into the drainage system will depend on the relative times of concentration of the various parts of the catchment.

Floodplain – All land adjacent to a watercourse, over which water flows in times of flood (see Environment Agency's *Policy and practice for the protection of flood plains* for a fuller definition).

Footway – Area for pedestrians at the side of the carriageway.

Geocellular structure – A plastic box structure used in the ground.

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 which is permeable.

Groundwater Protection Zone (Source Protection Zone) – Area around public water supply borehole where groundwater must be protected from pollution. It is 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.

Gully – Opening in the road pavement that allows water to enter conventional drainage systems, usually covered by a metal grate.

Hydrograph – A graph showing changes in the rate of flow from a catchment with time.

Impermeable – Will not allow water to pass through it.

Infiltration – The passage of water through a surface, either the pervious surface or into the underlying ground.

Initial rainfall loss – The amount of rain that falls on a surface before water begins to flow off the surface.

Pavement, flexible – A pavement that behaves as a flexible mat under loads, for example asphalt or block paving.

Pavement, rigid – A pavement that acts as a rigid structure under loads, such as concrete slabs.

Percentage runoff – The proportion of rainfall that runs off a surface. See also **runoff**.

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 surface – A surface formed of material that is itself impervious to water but, by virtue of voids formed through the surface, allows infiltration 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.

Poisson's ratio – If an elastic material is subject to compression or tension the cross-sectional area will change as load is applied. Assuming axes are x, y and z, then if the load is applied along the x axis, the strain in the y and z direction is proportional to that in the x direction, but opposite in sign. The constant of proportionality is known as Poisson's ratio.

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 across the entire surface of the material forming the surface, such as grass and gravel surfaces, porous concrete and porous asphalt.

Return period – The frequency with which an event occurs. A 100-year storm is one that occurs on average once every 100 years; ie 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, and so has an annual probability of exceedance of 0.2 (1/500).

Road pavement – The load-bearing structure of a road. (Note: the path at the side of a road, commonly referred to as a pavement, is the footway.)

Runoff – Water flow over the ground surface to the drainage system. This occurs if the ground is impermeable or is saturated.

Runoff coefficient – A measure of the amount of rainfall that is converted to runoff.

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.

Soakaway – A subsurface structure into which water is conveyed to allow infiltration into the ground.

Source control – The control of runoff at or near its source.

Sub-base – The unbound layer of aggregate used immediately below the bound layers. It is laid on the soil (or capping layer) to provide a stable foundation for construction of the road pavement.

Subgrade – The soils onto which the road pavement is constructed.

SUDS – Sustainable urban drainage system: a sequence of management practices and control structures designed to drain surface water in a more sustainable fashion than some conventional techniques (also referred to as sustainable drainage system, SuDS).

Surface course – CEN description of the top layer of an asphalt pavement, known in UK as wearing course.

Time of entry – Time taken for rainwater to reach an inlet into the drainage system after hitting the ground.

Type 1 sub-base – Specification for the most commonly used sub-base material in conventional pavements, from *Specification for Highway Works*.

Void ratio – The ratio of open air space to solid particles in a soil or aggregate.

ABBREVIATIONS

A_d	total area to be drained, including any adjacent impermeable area
A_b	base area of infiltration system below pervious pavement
A_I	area of adjacent impermeable surface draining onto pervious surface
A_p	area of pervious pavement
AASHTO	American Association of State Highway and Transportation Officials
AOS	apparent opening size
ASTM	American Society for Testing of Materials
BSI	British Standards Institution
BRE	Building Research Establishment
C	shape factor
CBM	cement-bound material
CBR	Californian Bearing Ratio
CEN	Comité Europeén de Normalisation (European Committee for Standardisation)
CQA	construction quality assurance
D	rainstorm duration
D_s	effective particle size diameter
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
DBM	dense bitumen macadam
DMRB	*Design Manual for Roads and Bridges* (The Highways Agency, Scottish Executive Development Department, The National Assembly for Wales and The Department for Regional Development Northern Ireland)
e	void ratio of aggregate

E	Young's Modulus
EA	Environment Agency (England and Wales)
FHWA	Federal Highway Administration
G_s	specific gravity of soil or aggregate particles
h	thickness of aggregate or other storage medium below pervious pavement
h_{max}	maximum depth of water that will occur in the storage medium
i	rainfall intensity
k	coefficient of permeability
MSA	motorway service area
MTBE	methyl tert butyl ether
n	porosity of soil or aggregate
O_{95}	apparent opening size
Q	flow through outlet from storage below pavement
q	infiltration coefficient
r	rainfall ratio
SEPA	Scottish Environment Protection Agency
SUDS	sustainable urban drainage systems
TRL	Transport Research Laboratory (formerly Transport and Road Research Laboratory, TRRL, and Road Research Laboratory, RRL)
T	return period for storm event
USEPA	United States Environmental Protection Agency
V	maximum storage volume for water below pervious pavement
γ_d	dry unit weight of soil or aggregate
γ_w	unit weight of water
μ	viscosity
ν	Poisson's ratio

Foreword

This book is intended for use by developers, landscape architects, consulting engineers, local authorities, architects, highway authorities, environmental regulators, planners, sewerage undertakers, contractors and other organisations involved in the provision or maintenance of surface water drainage to new and existing developments. It discusses the critical issues that must be considered when designing and constructing pervious pavements that are to be used as a technique for stormwater source control.

Section 1 (Introduction) introduces the concepts of source control and the use of pervious surfaces to achieve this. It discusses the background to the development of pervious surfaces as a source control technique and identifies the relationship between this book and other publications from CIRIA and other organisations.

Section 2 (Constructed pervious surface drainage systems) identifies the types of pervious surfaces that have been used, both in the UK and abroad, including the layers used to provide storage below the surface. It gives a brief overview of the historical usage of pervious surfaces and identifies the design approaches that are used today.

Section 3 (Hydraulic performance issues) provides detailed information on matters relating to the hydraulic performance of pervious surfaces. This includes the issues to be considered in design, such as estimating rainfall and runoff from adjacent areas, calculating storage volumes and estimating the outflow hydrographs from the systems. It also looks at the long-term maintenance implications for these types of systems.

Section 4 (Structural performance issues) is concerned with the ability of pervious surfaces to carry the required loads from traffic. It looks at the current methods used to design road pavements and identifies the issues that are critical to the design of pervious surfaces. This includes ways of allowing for the use of different materials within the structure, the effects of frost and the effects of water storage on the foundation soils.

Section 5 (Water quality performance issues) deals with quality of water issuing from outlet pipes or infiltrating into the ground from pervious surface systems. It looks at the mechanisms and processes that occur within pervious surfaces to improve water quality. It also identifies the legislation that applies and the issues to be addressed to avoid causing pollution of either surface or groundwater.

Section 6 (Recommended design methodology) summarises the issues discussed and provides a framework for designing pervious surfaces, with detailed methods recommended where appropriate. A checklist of design considerations and information requirements is also provided. The importance of correct specification of materials is also discussed.

Appendix A1 provides case studies of the use of pervious surfaces for source control.

Appendix A2 discusses further research that is required.

Appendix A3 provides a design information checklist.

Appendix A4 provides information on maintenance requirements.

Appendix A5 discusses the factors that should be considered when deriving whole-life cost estimates for pervious pavements.

Appendix A6 gives additional detailed information relating to the water quality issues.

Appendix A7 looks at the adoption and legislation issues surrounding pervious surfaces.

Key sections

The recommended design methodology is set out in Figure 6.1. To assist the reader in finding the relevant text when following this flow chart, key sections of text have been highlighted throughout the book.

1 Introduction

1.1 WHAT IS SOURCE CONTROL?

Source control can be defined as the control of runoff at or near its source. It is one of a series of disciplines and techniques that can be employed to develop a sustainable drainage system effectively. A proven concept in the development of a sustainable drainage system is the surface water management train (Figure 1.1). This reinforces, and wherever possible follows, the natural pattern of drainage. Ideally, drainage design should prevent problems occurring rather than providing mitigation measures to control water quality and the volume and rate of discharge.

The surface water management train utilises source control to minimise the problems associated with the traditional approach to drainage design, by controlling runoff where it is generated and returning it to the natural environment as soon as is reasonable. At each stage in the management train the flow and quality characteristics of the runoff are improved until it can be discharged.

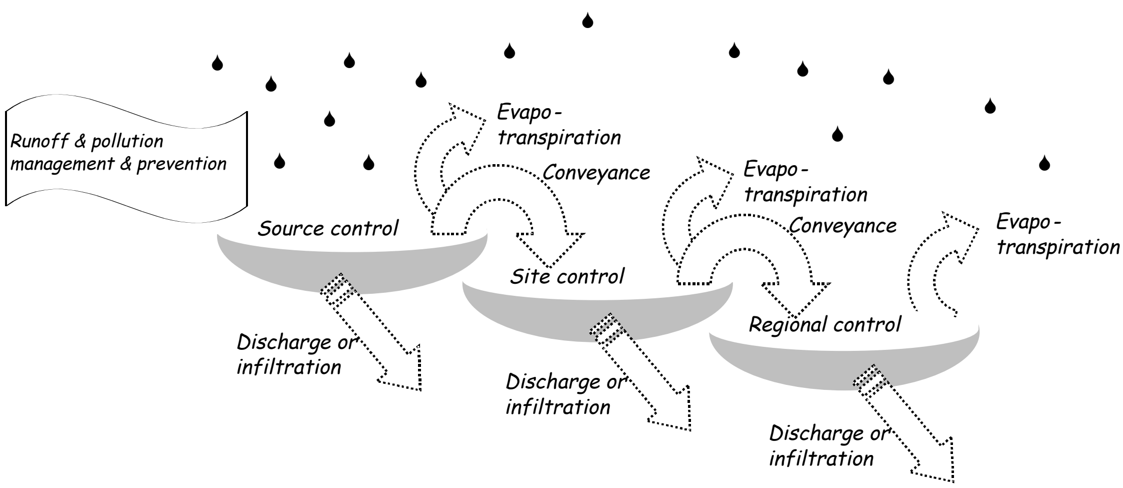

Figure 1.1 *Relationship between source control and overall surface water management train (CIRIA 2001a)*

Source control is to be preferred to controls elsewhere in the management train as it follows the natural drainage pattern, assigns the management of surface water to those causing the runoff and prevents problems arising rather than trying to mitigate them.

1.2 THE USE OF CONSTRUCTED PERVIOUS SURFACES AS A SOURCE CONTROL TECHNIQUE

As one of the primary methods of achieving source control, the use of pervious surfaces directly manages the quantity and quality of runoff at the earliest possible stage. Fundamental to the concept is the role played by the underlying layers for storage, infiltration (where possible), recycling and conveyance of surface water (Figure 1.2). These generally store and convey the surface water transmitted through the pervious surfacing (not the runoff). By definition, the runoff is that portion of the surface water that is NOT transmitted through the surfacing or subject to any other losses such as evaporation.

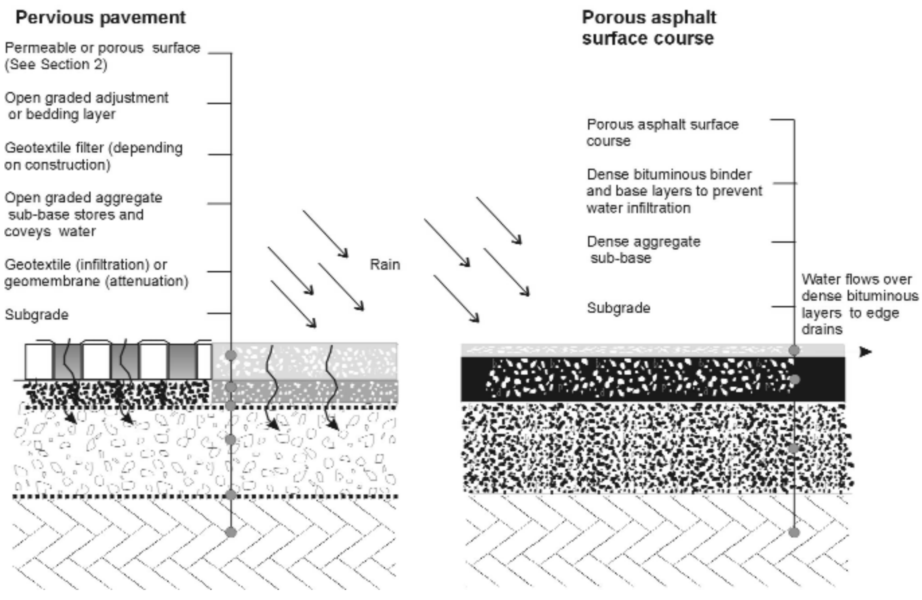

Figure 1.2 *Pervious pavement and porous asphalt surface course*

Constructed pervious surfaces remove or reduce the requirement for conventional drainage networks and ancillaries such as pipes, gully pots, manholes and interceptors.

The concept can be utilised for both infiltration and attenuation of surface water collected from paved (hard and soft landscaping) areas and roof catchments. As such it is suitable for incorporation into rainwater utilisation projects. Nevertheless, there are some limitations to the use of pervious surfaces (Box 1.1).

Box 1.1 *Locations for use of constructed pervious surfaces*

The use of constructed pervious surfaces as a source control technique is currently limited to highways with low traffic volumes, low axle loads and speeds less than 30 mph limit, car parking areas and other lightly trafficked or non-trafficked surfaces. Many developments have a substantial area for car parking, which can be constructed with a pervious surface to attenuate runoff into local sewers or watercourses.

In other countries, pervious surfaces have been used in some locations subject to heavy axle loads. The issues discussed in this publication will still be relevant, but at present such pavements should be designed on an individual basis in conjunction with experienced geotechnical and pavement engineers.

The Highways Agency will not use pervious pavement systems for roads under their control. The potential failure of pervious pavements on high-speed roads, the safety implications of ponding and disruption arising from reconstruction are matters of particular concern.

Infiltration techniques cannot be used below pervious surfaces in stormwater hotspots (Box 5.4).

1.3 BENEFITS OF CONSTRUCTED PERVIOUS SURFACES

The Environment Agency and Scottish Environment Protection Agency have policies to promote the use of SUDS, which are considered very important in reducing the effects of urban runoff on the environment (Box 1.2). This is reinforced by government planning guidance (PPG 25) that requires new developments to incorporate SUDS wherever possible. Pervious surfaces are an important source control technique that can be used either alone or together with other SUDS techniques.

Box 1.2 *Extracts from* Sustainable Urban Drainage, An Introduction *(SEPA and Environment Agency, 1999)*

> The Scottish Environment Protection Agency and the Environment Agency for England and Wales are working together to reduce pollution and flooding risk, and to promote more sustainable drainage systems in Britain. There is no need for the drainage from urban developments to damage our water resources. However, to protect our environments, the Agencies need the support and co-operation of a wide range of public and private organisations involved in urban development – including planning and highway authorities, sewerage undertakers, and developers. By working together, it will be possible to ensure that drainage from roads and urban areas is designed in a cost-effective and more sustainable manner.
>
> SUDS can be designed to fit into almost all urban settings, from hard surfaced areas to soft landscaped features, as a range of design options is available. Porous [pervious] pavement is an alternative to conventional paving in which water permeates through the paved structure rather than draining off it. Storage and filtering of the runoff water [occurs] and environmental benefits accrue.
>
> Widespread adoption of these [SUDS] techniques in new developments would see a long-term improvement in the quality of our urban rivers, contributing to a more varied and attractive urban environment built on a sustainable basis.
>
> *NB: the publication refers to porous, rather than pervious, surfaces.*

Planning Policy Guidance Note PPG3 requires housing developments to have a high density of dwellings. Industrial developments also usually require a high percentage of hard cover, and these issues are often perceived as a barrier to using SUDS techniques in urban situations. The use of pervious surfaces for car parks and similar areas is a valuable technique that should allow SUDS to be used more widely in urban situations, allowing the requirements of both PPG3 and PPG25 to be achieved.

The advantages of using pervious surfaces include:

- lower peak flows to watercourses, thereby reducing the risk of flooding downstream (Chapter 3)
- carefully designed, constructed and maintained surfaces lessen the effects of pollution in runoff on the environment (Chapter 5)
- they can be used in confined urban situations with a range of surface finishes that admit surface waters over their area of use
- a reduced need for deep excavations for drainage, which can have significant cost benefits, especially where disposal of contaminated soils is necessary
- as a drainage solution it is largely unrelated to the scale of the pervious surface, where the surface is often more than adequate to deal with the water falling on its own area
- flexibility – it is a solution that can be tailored so that construction costs suit the proposed usage and design life
- costs that are comparable to or lower than conventional surfacing and drainage solutions (providing all the costs are taken into account including items such as excavation and disposal of soils, discharge fees, cost of kerbs and gullies and removal of the need for large attenuation structures).

Pervious surfaces that are used in suitable locations and designed, constructed and adequately maintained following the guidance set out in this book should provide a cost-effective and durable source control technique.

Pervious surfaces may also appear as “soft” landscaping, as it is possible to “green” a surface using grass protection type systems. This ability has been recognised in Denmark, where there is a requirement on commercial/industrial areas for 15 per cent to be landscaping. This allows the inclusion of areas covered by grass protection systems, for example car parks.

In line with other hard surfacing products there is a range of surface colours and finishes for pervious surfaces, which offers choice to architects in site planning. The surface finish of pervious surfacing may vary from distinctly profiled (grass concrete) to smooth (porous macadam, porous or permeable paving blocks), making them suitable for a wide range of uses (Chapter 2).

In the broader planning of the urban landscape, the use of pervious structures for water storage for reuse may assist in the maintenance of plants, trees and shrubs. The use of stored rainwater, which is often less acidic, warmer and cheaper than treated mains water, is a further benefit available through the appropriate use of pervious structures.

Maintenance requirements for pervious pavements are no more onerous than those for conventional drainage, but they are different (Section 3.3 and Appendix A4). This should not prevent pervious surfacing being selected, as its other advantages in flood control, water reuse and groundwater recharge may have higher benefits, both on the curtilage and locality, as well as more widely in the environment. Pressure from regulators and planners may also mean that overall environmental considerations outweigh any perceived disadvantages and pervious pavements may be required to allow development to proceed.

1.4 DEFINITIONS

The terminology used regarding road pavements can be confusing due to differences between the United Kingdom, Europe and the USA. This is compounded by the use of some terms by the general public, for example tarmac as a general term for any tar- or bitumen-bound material.

The terms used in this publication are listed in Table 1.1 and accord with the forthcoming European standards being issued by the Comité Europeén de Normalisation (CEN).

Pervious surfaces within the context of source control provide the uppermost layer of pavement systems that are pervious throughout their entire construction depth. They allow water to infiltrate through the surfacing into the underlying sub-base and capping layers and, if required, into the foundation soils. Pervious surfaces for source control do not include conventional porous asphalt surfacing, which has been used in trials on some motorways and trunk roads to reduce spray and noise. This comprises a thin layer of porous asphalt over conventional impermeable materials (Figure 1.2).

Table 1.1 *Road pavement definitions adopted by CEN*

Road pavement	The load-bearing structure of a road (note the path at the side of a road, commonly referred to as a pavement, is the footway).
Carriageway	That part of the road used to carry vehicular traffic
Footway	Areas for pedestrians at the side of the carriageway
Bitumen	Hydrocarbon binder
Asphalt	All mixtures of mineral aggregates bound with bituminous materials used in the construction and maintenance of paved surfaces
Asphalt concrete	Macadams and Marshall Asphalt
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).
Surface course	Top layer of an asphalt pavement, known in UK as wearing course
Binder course	Second layer of an asphalt pavement, known in UK as basecourse
Base	Lowest bound layer of an asphalt pavement, known in UK as roadbase
Sub-base	Unbound layer of aggregate used immediately below bound layers
Capping layer	Unbound aggregate used to improve performance of foundation soils before laying sub-base

1.5 BACKGROUND TO PROJECT

Source control is a proven technique that can make a significant contribution to the improved management of surface water. The Environment Agency, SEPA, local authorities and the UK Government are actively promoting the widespread uptake of sustainable drainage techniques, as this will assist in the long-term reduction of flood risk, improve water quality, contribute to water resources locally and provide aesthetic and amenity benefits. Additionally, source control can assist with the recovery of depleted ground water levels (via infiltration) and the stabilisation of fluctuating river levels.

CIRIA's recent projects on best practice and design guidance on the implementation of sustainable drainage systems have identified various barriers to the use of source control, including a lack of specific guidance on scientific approaches to the design and construction of pervious surfaces. There has been minimal independent guidance on the subject and this lack of information has led, in some cases, to inappropriate design and misinterpretation of the structural and hydraulic performance requirements of constructed pervious surfaces.

In addition to the shortage of information, the traditional approach to pavement design has been to minimise the ingress of water into the underlying layers rather than to allow infiltration and storage under the surface.

1.6 PURPOSE AND SCOPE OF THIS BOOK

This publication provides authoritative guidance on the appropriate approach to the successful design and construction of pervious surfaces.

The book will also provide an improved understanding of the hydraulic, structural and water quality performance issues of constructed pervious surfaces based on information available. The current level of knowledge about some of the design and performance issues varies, and in some cases rigorous analysis is not possible. This is true in other areas of engineering and should not be a barrier to the use of pervious pavements. Where necessary, conservative assumptions and judgement based on observed performance can be used to allow the design to proceed.

The book provides sufficient design guidance to enable both specifiers and constructors of pervious pavements to adopt a more scientifically based approach to their use as an effective stormwater source control technique. Pervious pavements designed in accordance with the note should:

- deal with stormwater in an acceptable manner by helping to maintain runoff rates from developments at pre-development levels
- carry the required traffic loads without structural failure occurring
- minimise the risk of causing pollution to controlled waters.

This should facilitate the wider use of pervious surfaces as a source control technique and avoid failures due to inappropriate construction. The book explains how designers can ensure that the pervious surface and the construction below can effectively and safely store and transmit water while reliably supporting the design traffic loads.

It is not intended that this book should be a detailed guide to either hydraulic design of drainage systems or the structural design of pavements. It discusses only those aspects of hydraulic and structural design that are directly affected by the use of pervious surfaces as source control. Where necessary, reference is made to other publications that describe design methods suitable for application to pervious surfaces.

Sustainable urban drainage systems include other techniques, such as swales, infiltration trenches and lagoons, which are not covered by this book. Nor does it cover the design of porous asphalt surfacing layers used on high-speed roads (see Figure 1.2).

As a result of this work, further research needs have been identified. These are detailed in Appendix A2.

1.7 SOURCES OF INFORMATION

This publication has been compiled from information gained from undertaking a worldwide literature review covering all aspects of constructed pervious surfaces. In addition, consultation has been sought with a diverse range of consultants, contractors and manufacturers/distributors to gain the widest possible view.

The research has been reviewed and agreed by a dedicated steering group comprising experienced individuals from many disciplines.

1.8 ASSOCIATED PUBLICATIONS

This book provides independent guidance on the development of a more scientific approach to the design, construction and maintenance of constructed pervious surfaces.

The following publications are relevant in terms of additional information:

- *Barriers, liners and cover systems for containment and control of land contamination*, CIRIA Special Publication 124 (Privett *et al*, 1996). Provides information relating to the specification and construction of geomembrane liners.
- *Control of pollution from highway drainage discharges*, CIRIA Report 142 (Luker and Montague, 1994). Provides information on the water quality of highway runoff.
- *Infiltration drainage, manual of good practice*, CIRIA Report 156 (Bettess, 1996). Provides method of rainfall estimation and design method for infiltration below pervious pavements.
- *Sustainable urban drainage systems, design manual for Scotland and Northern Ireland*, CIRIA C521 (CIRIA, 2000a). Background information on design of pervious surfaces, as one element of a sustainable urban drainage system.
- *Sustainable urban drainage systems, design manual for England and Wales*, CIRIA C522 (CIRIA, 2000b). Background information on design of pervious surfaces, as one element of a sustainable urban drainage system.
- *Sustainable urban drainage systems, best practice manual*, CIRIA C523 (CIRIA, 2001a). Background information on pervious surfaces, as one element of a sustainable urban drainage system.
- *Planning Policy Guidance Note PPG25, Development and flood risk*. Department for Transport, Local Government and the Regions.