



Drainage
Design

CD 531

Reservoir pavements for drainage attenuation

(formerly HD 221/18)

Version 0.1.0

Summary

This document provides requirements and guidance for the design of reservoir pavements to be used on motorway and all-purpose trunk roads.

Application by Overseeing Organisations

Any specific requirements for Overseeing Organisations alternative or supplementary to those given in this document are given in National Application Annexes to this document.

Feedback and Enquiries

Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated National Highways team. The email address for all enquiries and feedback is: Standards_Enquiries@highwaysengland.co.uk

This is a controlled document.

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Latest release notes

Document code	Version number	Date of publication of relevant change	Changes made to	Type of change
CD 531	0.1.0	November 2021	Core document	Incremental change to requirements

Numerous editorial amendments including minor clarifications to abbreviations, terms and definitions and terminology related to smart motorways. Additional notes included on abutting reservoir and conventional pavements.

Previous versions

Document code	Version number	Date of publication of relevant change	Changes made to	Type of change
CD 531	0	March 2020		

Foreword

Publishing information

This document is published by National Highways.

This document supersedes HD 221/18 which is withdrawn.

Contractual and legal considerations

This document forms part of the works specification. It does not purport to include all the necessary provisions of a contract. Users are responsible for applying all appropriate documents applicable to their contract.

Introduction

Background

Government strategy, planning policy and legislation introduced through the 2000/60/EC [Ref 4.I] (WFD) EU Directive 2000/60/EC reflect the implications of climate change, the associated changes to flood risk and the need to address both flood risk and pollution risk to surface water and groundwater.

Impermeable surfaces such as paved roads and parking areas are often cited as one of the major causes of increased stormwater runoff, potentially overloading drainage systems and receiving waterbodies.

In reservoir pavements, rainfall percolates through the pervious road surfacing, or (depending upon the design) runoff is diverted via gullies, edge drains and pipes into a porous subbase material (reservoir). Here, rain water accumulates before it slowly percolates into the soil subgrade or discharges through drains into the main surface water drainage system.

Reservoir pavements offer alternative drainage systems with many benefits:

- 1) they reduce storm surges and the rate of runoff to drainage system outfalls;
- 2) they provide a potential reduction in the risk of runoff contributing to flooding;
- 3) in certain applications, they may eliminate the need for kerbing, gullies, pipework and balancing ponds;
- 4) they offer reduced land-take as significant parts of the system lie beneath the road surface;
- 5) where pervious road surfaces are used, the use of reservoir pavements potentially reduces noise, glare and spray; and,
- 6) they attenuate pollutants associated with road runoff or can be designed to filter out or trap these pollutants.

The type of reservoir pavement structure adopted depends upon a range of site specific conditions, including:

- 1) the topography of the ground;
- 2) the nature, condition and permeability of the subgrade; and,
- 3) the sensitivity of receiving waterbodies.

Traditionally reservoir pavements have been used for lightly trafficked areas. However, for wider application on the road network, the provided designs of reservoir pavements may ultimately be applied to more heavily trafficked roads.

Using only a thin bound road surfacing, block paving (or a similar pervious surface) or using an unbound granular road surfacing, reservoir pavements can also be utilised in the verge and other areas that are only occasionally trafficked.

To encourage the wider adoption of reservoir pavements on motorways and all-purpose trunk roads, Highways England sponsored a research programme to assist the development of advice on the use of reservoir pavements within the strategic road network, TRL PPR 482 [Ref 1.I], with specific attention to designs for heavy traffic. This involved reviewing existing practices and the construction of short trial sections of reservoir pavement using different design configurations, including sealed drainage systems and those draining into the underlying ground. The hydraulic and structural performances of these test reservoir pavements under traffic were studied to assess their potential to attenuate runoff and their suitability for inclusion on motorways and all-purpose trunk roads. The outcomes of these studies have been used to inform this document.

Assumptions made in the preparation of this document

The assumptions made in GG 101 [Ref 13.N] apply to this document.

Mututal Recognition

Where there is a requirement in this document for compliance with any part of a "British Standard" or other technical specification, that requirement may be met by compliance with the Mutual Recognition clause in GG 101 [Ref 13.N].

Abbreviations and symbols

Abbreviations

Abbreviation	Definition
CBGM	Cement bound granular material
CBM	Cement bound material
CBR	California bearing ratio
CGA	Coarse granular aggregate
CIRIA	Construction Industry Research and Information Association
EPA	Environmental protection agency
EqIA	Equality impact assessment
HBM	Hydraulically bound mixture
HDM	Heavy duty macadam
MCHW	Manual of Contract Documents for Highway Works
msa ₈₀	Million standard axles (in the UK a 80-kN standard axle is used)
SuDS	Sustainable Drainage System
UKAS	United Kingdom Accreditation Service
WFD	2000/60/EC [Ref 4.I] (EU Directive 2000/60/EC)

Symbols

Symbol	Definition
Ab	Base area of infiltration system beneath reservoir pavement (subbase)
Ad	Total pavement area (m ²) to be drained including any impermeable areas adjacent to the reservoir pavement
D	Rainfall duration (h)
E	Dynamic modulus
ff	Flexural strength
i	Rainfall intensity (depth/time expressed as mm/h or m/h depending on need)
n	Porosity (of subbase)
q	Infiltration coefficient of the subgrade from percolation tests (m/h)
R	Ratio of the drained area to base area of reservoir pavement, Ad/Ab

Terms and definitions

Term	Definition
CBR value	California Bearing Ratio; an empirical measure of the stiffness and strength of soils, used in road pavement design
Cement bound granular mixture	a granular hydraulically bound mixture where cement is the binder
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
Elastic modulus	also known as Youngs Modulus or stiffness modulus; the ratio of stress divided by strain for a particular material
Environmental protection agency	The relevant national body responsible for managing the quality of water bodies
Geocellular tank	a number of geocellular units joined together to form a tank that performs the required design function, such as sub-surface storage
Geocellular unit	plastic structure used to form geocellular tanks
Membrane	an impermeable plastic sheet, typically manufactured from polypropylene, high-density polyethylene or other geosynthetic material
Geotextile	a plastic fabric which is permeable
Groundwater	all water which is below the surface of the ground in the saturation zone (below the water table) and in direct contact with the ground or subsoil
h _{max}	the maximum depth of water that will occur in the reservoir pavement (subbase)
Hydraulically bound mixture	a mixture which sets and hardens by hydraulic reaction
Infiltration	the passage of water through a surface, either the pervious surface or into the underlying ground
Open graded	a description of the particle size distribution of a particulate material that is designed so that the compacted material contains interconnected void spaces to increase its permeability to water
Permeability	a measure of the ease with which a fluid can flow through a porous medium NOTE: Permeability depends on the physical properties of the medium; for example grain size, porosity and pore shape
Porosity	the percentage of the bulk volume of a rock or soil that is occupied by voids, whether isolated or connected
Porous pavement	a porous pavement allows water to infiltrate across its entire surface, for example porous concrete

(continued)

Term	Definition
Permeable pavement	a permeable pavement is formed of a material that is itself impermeable but that is laid to provide a void space through the surface to the subbase NOTE: for example: concrete block paving designed to allow water at the surface to penetrate through joints or voids between the blocks into the underlying structure)
Pervious pavement	any type of road surfacing that allows direct downward water infiltration
Road surfacing	the uppermost layer of a road pavement providing a wearing course over the underlying base
Smart motorway	motorways that use variable mandatory speed limits to increase capacity and smooth the flow of traffic
Subbase	an unbound or bound layer laid on top of the subgrade (or a capping layer) in traditional construction to provide a stable foundation for construction of the road pavement
Subgrade	the soils onto which the road pavement is constructed
Sustainable drainage systems (SuDS)	a sequence of management practices and control structures designed to drain surface water in a more sustainable fashion than some conventional techniques

1. Scope

Aspects covered

- 1.1 For hydraulic design, this document shall be read in conjunction with descriptions of other drainage solutions provided in CG 501 [Ref 5.N], CD 521 [Ref 12.N], CD 524 [Ref 11.N], CD 533 [Ref 8.N], CD 532 [Ref 26.N], CD 529 [Ref 6.N], CD 530 [Ref 7.N] and CD 523 [Ref 9.N].

NOTE 1 This document provides requirements and advice on reservoir pavements used for drainage attenuation. Reservoir pavements constitute a Sustainable Drainage System (SuDS) and form one of a number of possible drainage solutions identified in the suite of drainage requirements and advice documents shown.

NOTE 2 This document has been produced in collaboration with the Environment Agency. Reservoir pavements are outside the remit of the Reservoirs Act 1975 Reservoirs Act c.23 [Ref 17.N].

- 1.2 For structural design of the road pavement, this document shall be read in conjunction with requirements and advice given in CD 226 [Ref 3.N], CS 228 [Ref 20.N], CS 229 [Ref 2.N], CD 236 [Ref 22.N] and CD 225 [Ref 4.N].

- 1.3 The design of reservoir pavements cannot be prescribed, and design shall be developed individually, appropriate to site specific constraints.

NOTE This document provides guidance on the application, hydraulic design and structural design of reservoir pavements. Additional benefits for pollution control are outlined in Appendix A.

Implementation

- 1.4 This document shall be implemented forthwith on all schemes involving the use of reservoir pavements on the Overseeing Organisations' motorway and all-purpose trunk roads according to the implementation requirements of GG 101 [Ref 13.N].

NOTE 1 In the current situation of incomplete knowledge on their design, materials, construction and performance, newly established reservoir pavements are to be used to acquire information and thereby build up confidence in their performance prior to use in other situations.

NOTE 2 Opportunities to incorporate reservoir pavements as full-scale trial sites are encouraged to provide feedback to the Overseeing Organisation leading to improvements in design advice.

Use of GG 101

- 1.5 The requirements contained in GG 101 [Ref 13.N] shall be followed in respect of activities covered by this document.

2. Application and reservoir pavement types

Overview

2.1 Prior to undertaking drainage design, an assessment of the flood and pollution risk from highway runoff shall be undertaken in accordance with LA 113 [Ref 18.N].

2.2 The design of reservoir pavements shall accommodate the need for other buried services.

2.3 Where a reservoir pavement is to be constructed alongside, or in the vicinity of a conventional pavement, measures shall be developed to prevent water from entering the conventional pavement from the reservoir pavement and its subsurface and associated drainage system components.

NOTE *Water from the reservoir pavement (including leaks from a tanked reservoir) entering the conventional pavement can damage its structure and weaken the subgrade.*

2.4 Installation of reservoir pavements shall be avoided over moisture susceptible subgrades.

NOTE *Although reservoir pavements can be constructed on all soil types, the risk of destabilisation of the pavement foundation (subbase and subgrade) is reduced by their construction on non-moisture susceptible subgrades.*

2.4.1 Where subgrades have been rendered non-moisture susceptible by treatments such as soil stabilisation, reservoir pavements may be installed.

2.5 The design thickness of the subbase layer shall be the larger of that determined by the hydraulic and structural design procedures.

2.6 Irrespective of other constraints, a minimum subbase thickness of 350 mm shall be used in the design to ensure that there is sufficient reserve water storage capacity.

NOTE *The CERTU design guide CERTU (Porous pavements) [Ref 8.I] recommends that a minimum thickness of 350 mm be used to ensure that there is sufficient reserve capacity, even for more arid areas.*

Application

2.7 Reservoir pavements shall only be permitted in locations outside the main trafficked lanes of motorway and all-purpose trunk roads.

2.8 Reservoir pavement systems shall be utilised only in the following locations:

- 1) in hard shoulders of motorways;
- 2) in central reservations, including those with concrete barriers, where moisture susceptible subgrades beneath adjacent conventional pavements constructed with dense (low permeability) materials are isolated from wetted subgrades of reservoir pavements;
- 3) parking areas including motorway service areas;
- 4) isolated emergency areas, and motorways emergency access and egress areas;
- 5) laybys;
- 6) approaches to toll booths in occasionally or lightly trafficked areas (as new build only);
- 7) as a replacement of granular drains to avoid stone scatter;
- 8) all occasional trafficked areas in the confines of junctions, including those areas with hatched road markings;
- 9) within the confines of roundabouts; or,
- 10) within verges, foot ways and cycleways and other non-trafficked areas.

NOTE 1 *Reservoir pavement systems can be used where the hard shoulder is a purpose-built extension of the running lane but not as a retrofit to an existing hard shoulder.*

NOTE 2 *For the design of reservoir pavements, the confines of roundabouts means those areas within the inscribed circle and the entry flare of roundabouts (refer to CD 116 [Ref 7.I]).*

Design configurations

2.9 The design of reservoir pavement systems with pervious road surfacing shall comply to one of three basic configurations in Table 2.9.

Table 2.9 Design configurations

Reservoir pavement type	Description
Type I (full infiltration)(equivalent to Type A CIRIA C753 [Ref 24.N]).	Rainfall passes through a pervious road surfacing, into a porous subbase (which provides the reservoir layer) and then is "discharged" by infiltration into the subgrade beneath.
Type II (partial infiltration)(equivalent to CIRIA Type B)	The flow path is as Type I, but the subgrade has insufficient infiltration capacity to allow dissipation of all design storm events. NOTE: Type II requires a drainage system at the founding level of the subbase to convey discharge to a receiving drainage system.
Type III (no infiltration)(equivalent to CIRIA Type C)	An impermeable flexible membrane is placed below and around the sides of the subbase preventing discharge into the subgrade. NOTE: The subbase requires a drainage system as per type II.

NOTE 1 In lower permeability soils, type II reservoir pavements prevent water levels in the subbase reservoir layer rising and causing potential stability problems in the overlying road surfacing.

NOTE 2 Type III reservoir pavements can be used (subject to other limitations) where the subgrade is unsuitable as receptor of infiltrating drainage.

NOTE 3 Guidance for the design of reservoir pavements can be found in the CIRIA SuDS manual, CIRIA C753 [Ref 24.N], which identifies three basic configurations (types A to C) each with pervious road surfacing.

NOTE 4 Design configurations featuring pervious road surfacing are shown schematically in Appendix B Figures B1 to B3.

NOTE 5 Advantages and disadvantages of the different configurations and typical applications (with reference to specific site conditions) are given in Appendix C.

2.10 The design of reservoir pavement systems with conventional impermeable road surfacing shall comply to one of three basic configurations in Table 2.10:

Table 2.10 Design configurations

Reservoir pavement type	Description
Type IV:(full infiltration)	Road runoff enters an edge drain and is redirected draining by gravity into the underlying reservoir layer (subbase), usually via pipes set at appropriate intervals and then is "discharged" by infiltration into the subgrade beneath.
Type V:(partial infiltration)	Road runoff enters the edge drain and is redirected into the underlying subbase. NOTE: Type V requires a drainage system at the founding level of the subbase to convey discharge to a receiving drainage system.
Type VI: Impermeable road surfacing, no infiltration	Road runoff enters the edge drain and is redirected into an underlying subbase around and below which is placed an impermeable flexible membrane, preventing discharge into the subgrade. NOTE: The subbase requires a drainage system as type V.

NOTE 1 *The three basic configurations of reservoir pavement can be reproduced using conventional impermeable road surfacing (asphalt or concrete) with edge drains collecting runoff for re-injection into the underlying subbase (reservoir layer) from side drains.*

NOTE 2 *Design configurations are shown schematically in Appendix B, Figures B4 to B6.*

NOTE 3 *Advantages and disadvantages of the different configurations and typical applications (with reference to specific site conditions) are given in Appendix C.*

Reservoir pavement components

2.11 The design of the reservoir pavement shall include all components necessary to match the selected configuration.

2.12 All types of reservoir pavements shall include the following:

- 1) a trimmed subgrade layer, lightly rolled to maximise infiltration;
- 2) a subbase (reservoir layer) consisting of essentially single size coarse granular aggregate (CGA) with 30-40% air voids (by volume); and,
- 3) a blinding layer consisting of a single-size aggregate about one fifth of the aggregate size used within the reservoir layer.

NOTE 1 *The reservoir layer temporarily stores stormwater while it infiltrates into the subgrade or is discharged via pipework.*

NOTE 2 *Where the infiltration capacity of the subgrade is insufficient to drain the design storm, perforated drainage pipes are needed in conjunction with overflow pipes.*

NOTE 3 *A geotextile can be used instead of the blinding layer. This stabilises the surface for the paving construction equipment.*

2.12.1 The selection of components for the design of the reservoir pavement may vary according to the chosen configuration.

2.13 Pervious surface reservoir pavement types (I-III) shall include open-graded asphalt and/or cement-bound layers with interconnecting voids of base, binder course and road surfacing.

NOTE *Reservoir pavement types (I-III) allow water to flow through the road surfacing into the reservoir layer (subbase).*

- 2.14 For reservoir pavement types III and VI with no infiltration to subgrade, an impermeable membrane shall be used on the subgrade and up the sides of the subbase to form a tank and include piped drainage to an outlet.

Sediment management

- 2.15 Where edge drains are used with an impermeable surface (reservoir pavement types IV-VI), sediments shall be controlled and contained.

NOTE *Uncontrolled and uncontained sediments introduced directly into the subbase compromise the efficiency of the subbase reservoir.*

Topography and slope

- 2.16 Where longitudinal slopes in the subgrade and/or foundation layers exceed 5%, reservoir pavement systems shall be avoided.

NOTE 1 *Site topography can restrict drainage design.*

NOTE 2 *Gradients greater than 5% with a permeable subbase can lead to water welling-up through the road pavement at the bottom of a slope. International research identifies that a gradient less than 5 % offers the most effective solution. See CERTU (Porous pavements) [Ref 8.I] NAPA Information Series 131 [Ref 12.I].*

NOTE 3 *Where a reservoir pavement is desired at a location with a gradient steeper than 5%, impermeable barriers (or buffers) within the subbase layer can be used to parcel the reservoir pavement area into smaller sections, each with its own drainage outlet CIRIA C753 [Ref 24.N].*

NOTE 4 *The use of buffers to create smaller sections within a reservoir pavement adds considerably to the complexity of a design.*

- 2.17 For pervious road surfacing that is designed to pass rainfall straight through their complete depth, a flat cross gradient shall be permitted.

- 2.17.1 On flat ground the subgrade should be shaped or the natural undulations in the ground topology used to provide a slight gradient of the order of 1%.

NOTE *Although a cross-fall is not required at the surface, experience has shown that road surfacing drains more efficiently and water does not stagnate when there is a slight slope (that is around 1%) in the subgrade. See CERTU (Porous pavements) [Ref 8.I].*

Use of geocellular units

- 2.18 Proposed use of geocellular tank systems as an alternative to a porous subbase material shall be subject to consultation and agreement.

- 2.18.1 A geocellular system may be used as an alternative to a porous subbase material, but only if the location of the proposed reservoir pavement is within an agreed predefined area.

- 2.19 Where proprietary geocellular units are used these shall meet the technical requirements set out in CIRIA C737 [Ref 21.N].

NOTE *In SuDS applications geocellular tanks usually comprise built-up modular systems, including the cell unit(s), inspection access points, inflow/outflow pipework, interception chambers (for sediment and other pollutants) and flow controls. Manufacturers of these units provide full design guidance.*

- 2.20 Only those systems that have been subject to testing in accordance with the requirements for strength and deformation as set out in CIRIA C737 [Ref 21.N] shall be accepted.

- 2.21 Where geocellular systems are used, test procedures and results shall be accredited by a United Kingdom Accreditation Service (UKAS) certification schemes in accordance with MCHW 104 PAS [Ref 15.N].

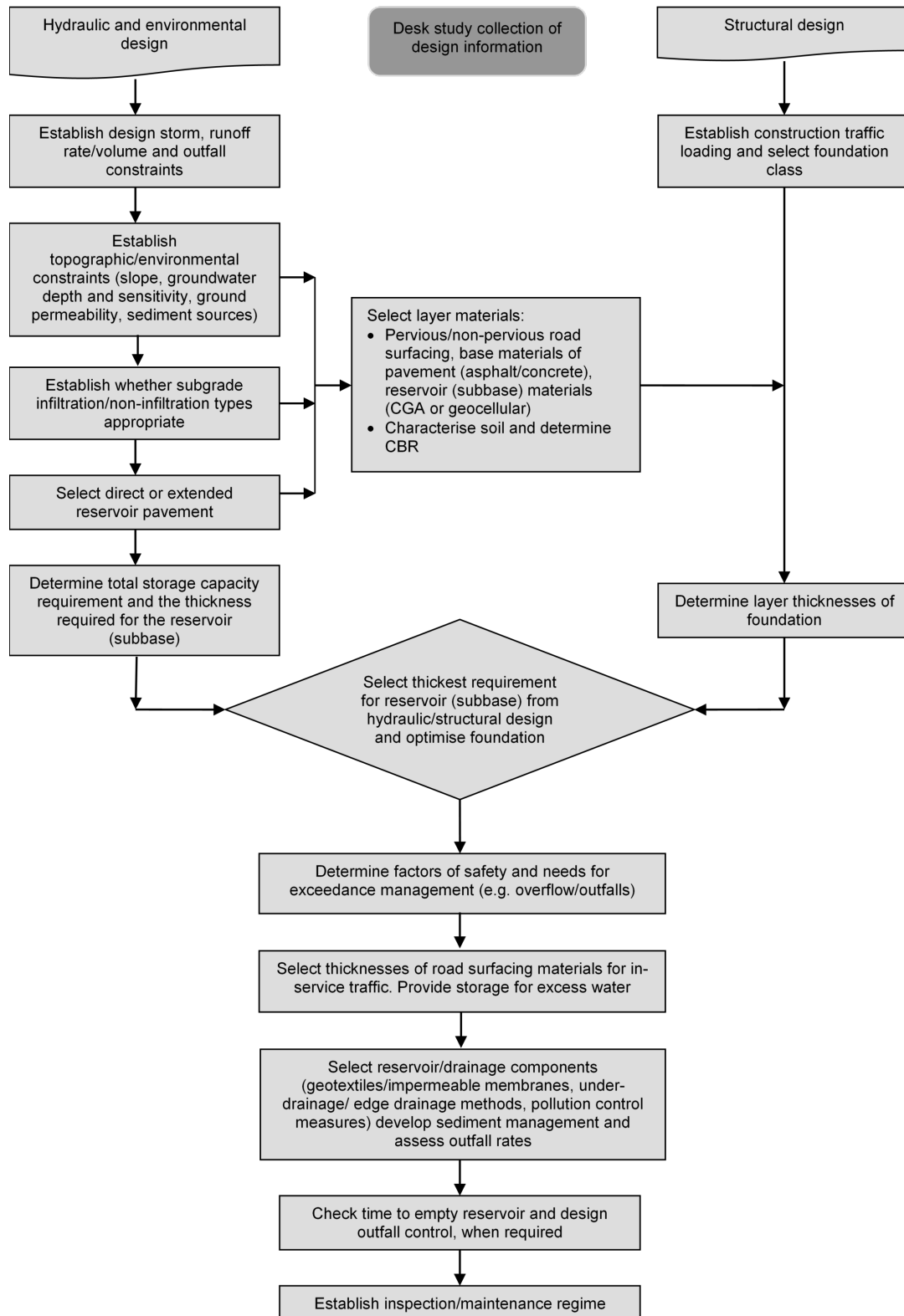
3. Reservoir pavement type selection

3.1 The design of the reservoir pavement and the chosen design configuration shall be based on site specific conditions, including the following factors:

- 1) topography of the ground;
- 2) limitations and constraints from any existing drainage systems;
- 3) the nature of local rainfall, including rainfall volume and intensity;
- 4) proximity, levels and vulnerability of waterbodies;
- 5) soil characteristics (mechanical and hydraulic);
- 6) traffic to be carried by the reservoir pavement;
- 7) local availability of porous materials; and,
- 8) depth of reservoir pavement layers.

NOTE *The flow chart in Figure 3.1N provides a series of decision steps to help establish the most suitable design for reservoir pavement site-specific factors .*

Figure 3.1N Design process flow chart



4. Hydraulic design principles

- 4.1 The fundamental hydraulic design processes for reservoir pavements that shall be followed are:
- 1) determination of the design storm;
 - 2) confirmation that the rate of infiltration through the pervious surface is sufficient (reservoir pavement types I-III only);
 - 3) determination of the internal catchment and the expected hydraulic loading;
 - 4) determination of the storage capacity required to manage the design storm;
 - 5) development of sediment management measures;
 - 6) determination of the outlet capacity and approach (either by infiltration into the soil or by provision of subbase drainage pipes or a combination of these methods);
 - 7) incorporation of edge collector drains, pipework, sediment management devices and other conventional drainage components used in the design (all reservoir pavement types); and,
 - 8) management of exceedance events.

NOTE *A worked example of the hydraulic design process is provided in Appendix D.*

Design storm

- 4.2 The design storm for reservoir pavement drainage systems shall be to a minimum of the 1:10 year storm.

NOTE 1 *Design storms for conventional road drainage systems are identified in CG 501 [Ref 5.N] however these design storms are intended for positive drainage systems and are not appropriate for the design of reservoir pavements. Further advice is available in CIRIA C582 [Ref 16.I] and CIRIA C753 [Ref 24.N] which also suggest at minimum a 1:10 year design storm.*

NOTE 2 *The critical storm duration for volume can differ from the critical storm duration for intensity. Both volume and intensity are to be included in determining the capacity of the reservoir pavement*

Infiltration through the surface

- 4.3 Where adopting a pervious road surfacing (reservoir pavements types I to III), the design of both the road surfacing and underlying subbase shall establish downward infiltration of the design storm rainfall.

NOTE *The hydraulic design of pervious asphalt, concrete or concrete block road surfacing is essentially identical. Although there are a number of other factors to be considered in their design, the primary design criteria are the amount (volume and intensity) of rainfall expected, the road surfacing characteristics and the underlying subgrade properties.*

- 4.4 The design of the pervious road surfacing shall include for a 90% loss in surface permeability due to clogging of the pervious surface.

NOTE 1 *The allowance for a loss in surface permeability follows best practice in CIRIA C582 [Ref 16.I].*

NOTE 2 *Values of infiltration rates of pervious road surfacing comprised of pervious asphalt and block paving given in the literature are presented in Table 4.4N2. The infiltration rates of these road surfacing are significantly in excess of a high 1:10 year storm intensity (of the order hundreds of mm/h).*

Table 4.4N2 Rates of water infiltration through various road surfacing

Road surfacing	Infiltration rate (mm/hr)		Typical 1:10 year storm (mm/h)	Reference
	Typical (new build)	Design ¹		
Pervious asphalt	1500 to 2000	150 to 200	100	Water 2018 [Ref 21.I]
	7000 to 9000	700 to 900		Knappenberger, T et al [Ref 10.I]
	10,000 to 39,000 ²	1,000 to 3,900		CIRIA C582 [Ref 16.I]
Concrete block paving	4,000	400	100	CIRIA C753 [Ref 24.N]
	1,000 to 5,000	100 to 500	100	CIRIA C582 [Ref 16.I]
Note 1 To allow for 90% loss of in surface permeability, CIRIA C582 [Ref 16.I] design values of infiltration rate are 10% of typical infiltration rates.				
Note 2 The exceptionally high infiltration rate (39,000 mm/h) is quoted in CIRIA C582 [Ref 16.I] for measurements taken in Nottingham for a pervious asphalt comprising 10 mm-gap graded aggregate and is a mean value after 4.5 years with no maintenance.				

Subsurface storage capacity

- 4.5 The storage volume required for the retention of water generated by the design storm shall be determined.

NOTE 1 The internal storage volume, and thus thickness of the subbase reservoir (which depends on the void ratio), is calculated from the steady state mass balance of inflow and outflow from the reservoir pavement (that is storage volume = volume of rainfall during storm – volume of outflow during storm).

NOTE 2 Temporary storage balances water inflow into the subbase reservoir and the rate of discharge out of the system. The need for this balance can be due to constraints from the natural infiltration rate into the subgrade (as identified by site specific infiltration tests) or due to a need to limit the discharge rate into a receiving system, whether this flow is to an existing drainage system or a natural water course.

- 4.6 The minimum thickness of the subbase to provide storage capacity shall be determined through the calculation of h_{max} , the maximum depth of water that occurs in the subbase.

- 4.6.1 For a reservoir pavement system that allows infiltration out of the bottom of the reservoir, the method of determining the required storage volume for plane infiltration systems from CIRIA R156 [Ref 9.I] should be used, as given in Table 4.6.1:

Table 4.6.1 Method of determining the required storage volume for plane infiltration systems

$h_{max} =$	$(Ri - q).D/n$
Where:	
$R =$	ratio of the drained area to base area of reservoir pavement, A_d/A_b
$A_d =$	total road surface area (m^2) to be drained including any impermeable areas adjacent to the reservoir pavement
$A_b =$	base area of infiltration system beneath reservoir pavement
$i =$	rainfall intensity (m/hr)
$q =$	infiltration coefficient of the subgrade from percolation tests (m/h) - determined by following procedure in CIRIA R156 [Ref 9.I]
$D =$	rainfall duration (h)
$n =$	porosity of sub-base material

NOTE 1 The calculation in Table 4.6.1 is carried out for a range of storm durations (15 min, 30 min, 60 min, etc.) for the 1:10 year design storm return period to determine the maximum value of h_{max} .

NOTE 2 For piped outflows the calculation in Table 4.6.1 is simplified to: $h_{max} = Ri \frac{D}{n}$

- 4.7 When calculating the storage volumes with piped outflows, no allowance shall be made for any outflow during the storm.

- 4.7.1 Where it is demonstrated that a piped discharge system is able to fully drain the reservoir storage volume, an allowance for outfall discharges may be made in the calculation of required storage.

NOTE 1 For systems with a piped discharge CIRIA C582 [Ref 16.I] notes that there is insufficient information available to accurately model internal flow and storage properties within the subbase. This can lead to an overestimate of the required storage capacity.

NOTE 2 Practical experience suggests that discharge pipe systems can easily accommodate the required flow rate and that they need to be throttled to meet outflow discharge restrictions.

- 4.8 Water held in storage under the design storm shall empty from full capacity to 50% or less within 24 hours, but without exceeding the prescribed discharge limits (to an outfall).

NOTE The need for the system to empty to 50% or less within 24 hours is to ensure the system can accommodate subsequent storms.

- 4.9 Where infiltration forms the sole discharge (that is, there is no supplementary drainage), a factor of safety of 10 shall be included in the determination of the storage volume.
- NOTE 1** *The factor of safety is introduced by assuming a reduced infiltration rate (that is the measured subgrade infiltration rate used is divided by 10).*
- NOTE 2** *CIRIA R156 [Ref 9.I] allocates factors of safety based on the level of confidence in the adopted design parameters. These include uncertainties in the field testing for determining infiltration rate as measured using methods described in CIRIA R156 [Ref 9.I] and the potential for infiltration rate to decline with time.*
- NOTE 3** *The factor of safety allows for the consequences of failure, which is deemed to be significant in the case of road drainage.*
- NOTE 4** *The factor of safety can continue to be adopted until greater experience and feedback is gained with the design of these systems.*
- 4.10 Resistance to freezing shall be incorporated into the design thickness (and hence storage volume) of the subbase.
- 4.11 Following calculation of the design thickness and the application of the safety factor, the storage volume shall be increased by 30% to provide a resistance to freezing.
- NOTE** *Increasing the storage volume allows for any ice formed in cold conditions to expand into the free space without disturbing the reservoir pavement structure.*
- 4.11.1 Allowance for freezing may be varied according to site-specific requirements.

Discharge from reservoir layer to subgrade

- 4.12 Where discharge to subgrade is incorporated (reservoir pavement types I, II, IV, V), the infiltration capacity of the subgrade shall be determined.
- NOTE 1** *Infiltration of water into the subgrade depends on the properties of the soil. Permeability of the order of 5×10^{-6} m/s or greater allows water to seep into the soil.*
- NOTE 2** *For any permeability lower than 5×10^{-6} m/s, the discharge component from infiltration is likely to be insufficient and effective drainage requires the installation of under-drained and piped systems.*
- NOTE 3** *CIRIA C753 [Ref 24.N] identifies suitability of pavement types to subgrade infiltration types.*
- 4.13 For final design, in situ measurements of infiltration rate in accordance with CIRIA R156 [Ref 9.I] shall be undertaken at the proposed location.
- 4.13.1 For preliminary design, literature (such as CIRIA C753 [Ref 24.N]) values may be adopted.
- NOTE** *For preliminary design involving highly variable subgrade conditions, in situ measurement can be required.*

Outlets to piped drainage and outfalls natural water courses

- 4.14 Where the reservoir is discharged via pipes to an existing piped drainage system or piped to a natural water course, the actual outflow rate shall be controlled as follows:
- 1) to less than, or equal to, the original runoff rate for newly developed areas; or
 - 2) to less than the capacity of the downstream network.
- 4.14.1 Where the reservoir discharge is to a natural watercourse the outflow should be limited to greenfield runoff rates.
- 4.14.2 Other downstream discharge rates may be adopted by agreement with the relevant environmental protection agency (EPA).
- 4.15 To control the discharge rate a suitable throttle shall be provided, with an associated bypass or overflow.

NOTE *The use of robust and simple control devices is preferred, for example, throttle pipes.*

Design exceedance events

4.16 Additional overflows and outlets shall be provided for exceedance events.

NOTE 1 *Exceedance events (conditions such as drainage system failure and rainfall/runoff in excess of design flows) can cause backing up of water within the reservoir pavement.*

NOTE 2 *Without emergency outlets, excess water can compromise the integrity of the road surfacing or, at worse, the entire reservoir pavement.*

4.17 Water from emergency overflows and outlets shall be routed safely to avoid flooding the road and any impact upon the land of third parties adjacent to the road.

NOTE *Further advice on exceedance design, emergency overflows and outlets and safe water routing can be found in CIRIA C753 [Ref 24.N].*

Sediment deposition

4.18 Site selection, catchment and sediment load assessment, system design and inclusion of sediment management devices shall be undertaken to avoid clogging by sediments.

NOTE *The pores in a pervious surface can become clogged and/or sediment can be deposited within edge drains and channels.*

4.19 Where a significant sediment load is likely to be washed onto the road surfacing, the use of reservoir pavements shall be avoided.

NOTE *CD 523 [Ref 9.N] provides guidance on sediment load for a section of road that takes account of adjacent land use, geographical location, road size (by number of lanes and profile) and whether the road is level, in cutting or on embankment.*

4.20 As an intrinsic part of the design, edge drained injected systems shall include for the development of a site-specific and well managed maintenance regime with sustainable maintenance intervals.

NOTE *With sediment control and maintenance, edge drained injected systems can handle more significant sediment loads, but only if sediment can be trapped (and as importantly, removed) prior to injection of water into the subbase reservoir.*

4.21 Where verges drain toward the reservoir pavement, these areas shall be well vegetated or stabilised so that silt and sediment mobilisation is minimised.

NOTE *The preferred arrangement for verges that drain toward the reservoir pavement is for grassed verges, landscaped ground etc. to slope away from the reservoir pavement and for soils to be at least 50 mm below kerbs at the edge of the reservoir pavement CIRIA C753 [Ref 24.N].*

Alternative applications

Extended reservoir pavements

4.22 The use of extended reservoir pavements shall only be permitted where test data identifies that spare drainage storage and conveyance capacity is available in the reservoir drainage system.

NOTE *Extended reservoir pavements comprise systems that drain a larger area than that of the roadway immediately overlying the reservoir pavement.*

4.23 The additional drained area of an extended reservoir pavement (that is, beyond that lying immediately over the reservoir) shall avoid areas that could generate large amounts of sediment, for example runoff from embankments or verges.

4.24 Where extended systems discharge to a pervious road surfacing (reservoir pavement types I to III) the ratio of impervious to pervious surface shall be no greater than 2:1.

- 4.24.1 Where water is injected into the underlying subbase reservoir and where separate silt/sediment control is available, extended reservoir pavement systems may be more suitable for reservoir pavement types IV-VI.

5. Structural design principles

General

- 5.1 The standard structural designs adopted shall be for a flexible pavement that incorporates porous concrete as a subbase.

NOTE The standard structural designs provided are more appropriate for roads with moderately heavy traffic, were derived from CD 226 [Ref 3.N] and based on the analytical design method of TRL 615 [Ref 10.N].

- 5.2 For a given (proposed) design traffic, the thickness of the concrete base shall be dictated by the quality of the foundation and the design traffic.

NOTE The thickness of the asphalt road surfacing is solely dependent on the design traffic.

Standard designs

Subgrade

- 5.3 For subgrades intended to allow full and partial infiltration (reservoir pavements types I, II, IV,V), soaked California Bearing Ratio (CBR) tests (according to BS 1377-4 [Ref 16.N]) shall be carried out on soil representative of the in situ compacted condition of the subgrade.

NOTE 1 Current design practice uses the CBR of the underlying subgrade. For reservoir pavement design, the CBR of the subgrade is the value relating to the wetted condition.

NOTE 2 Unlike conventional pavement design where the subgrade is protected from ingress of water, full and partial infiltration reservoir pavement types deliberately allow water to come into contact with the subgrade.

- 5.4 Where full infiltration reservoir pavements are used the subgrade shall have a minimum permeability of 5×10^{-6} m/s.

NOTE Further guidance on the suitability of pavement types to subgrade infiltration capacity is provided in CIRIA C753 [Ref 24.N].

- 5.5 Where natural vertical drainage into the subgrade is unlikely or undesirable, (no infiltration reservoir pavement types III and VI) conventional (that is, non-soaked) CBR tests shall be carried out on soil representative of the in situ compacted condition of the subgrade.

NOTE 1 For no infiltration reservoir pavement types III and VI, an impermeable membrane is placed on the surface of the subgrade, preventing the infiltration of water into the subgrade. With partial and no infiltration reservoir pavement types II, III, V and VI, a positive drainage system is needed to assist in conveying water out of the subbase. The subgrade CBR design value can be higher than the value used for a subgrade intended to drain infiltrating water without positive drainage.

NOTE 2 The permeability of the subgrade affects the decision as to whether positive drainage is required at some level within the reservoir pavement because a highly impermeable soil is not able to absorb a significant percentage of the incident rainfall.

- 5.6 The subgrade CBR design value shall be the lower of the construction CBR and the long-term CBR.

- 5.6.1 Where wetting of the subgrade by infiltrated water occurs, the determination of both construction and long-term CBR provided in CD 225 [Ref 4.N] should be followed.

NOTE The long-term CBR value of a particular soil subgrade during the reservoir pavement's service life is dependent on whether, or not, the soil is regularly wetted by the infiltration of water from the subbase reservoir.

Geotextiles and membranes

- 5.7 Where infiltration into the subgrade is required (reservoir pavement types I, II, IV, V) geotextiles (permeable membranes) placed on the subgrade shall have a permeability that is greater than that of the underlying subgrade.

- NOTE 1** *Where the subgrade has a high silt and/or clay content and where traffic levels are significant, there is a risk of fines migrating between the subgrade and the porous subbase.*
- NOTE 2** *The risk of fines migrating between the subgrade and the porous subbase can be avoided by placing a permeable geotextile between these reservoir pavement layers.*
- NOTE 3** *Guidance on the use of geotextiles and membranes can be found in CIRIA C753 [Ref 24.N].*
- 5.8** When infiltration of water into the subgrade is not permissible (no infiltration reservoir pavement types III, VI) an impermeable membrane shall be placed over the subgrade and all joints suitably overlapped and welded.
- 5.9** Where an impermeable membrane is used for no infiltration reservoir pavement types III and VI, it shall be sufficiently robust to avoid tearing under the impact of sharp stones within the subbase, principally during compaction of the subbase layer.
- NOTE** *CIRIA C753 [Ref 24.N] gives guidance on the use and specification of membranes.*

Foundation and subbase design

- 5.10** The road foundation shall be designed to a chosen foundation class.
- NOTE 1** *The foundation class is identified following the selection of the type of reservoir pavement and whether the subgrade CBR strength is to be based on a wetted state or one protected from infiltrated water.*
- NOTE 2** *The road foundation (subgrade and subbase) is categorised in terms of foundation stiffness classes.*
- NOTE 3** *An unbound granular material provides a foundation class no better than class 2.*
- NOTE 4** *Guidance on foundation and class is given in CD 225 [Ref 4.N] with further explanation in TRL PPR 127 [Ref 19.N].*
- 5.11** The subbase shall be well compacted so that the high voids content is a result of the design grading and not under-compaction.
- NOTE 1** *The subbase is normally a structurally significant layer that provides a working platform on which materials can be transported, laid and compacted.*
- NOTE 2** *In a reservoir pavement, the subbase is used to temporarily store incident rainfall or runoff and needs a high void content.*
- NOTE 3** *In a conventional pavement, unbound granular Type 1 material is often used for the subbase. This is a continuously graded, dense material that has a low permeability when well compacted.*
- 5.11.1** The granular subbase should contain air voids so that water can pass freely through and be stored without saturating the subbase layer.
- NOTE** *The void content can be achieved by removing the fine fraction from the granular subbase (open graded) to produce a material with air voids content in the 30 to 40% range and by building the subbase sufficiently thick.*
- 5.12** The open-graded, unbound granular subbase of the reservoir layer shall be designed to ensure it provides a stable foundation to the overlying pavement.
- 5.12.1** The ratio of the maximum to minimum stone size should be greater than 3 in accordance with guidance in CERTU (Stormwater networks) [Ref 23.N].
- NOTE 1** *Cedergren [Ref 5.I] proposes that the 85 percentile, aggregate size is at least 4 times the 15 percentile size and that no more than 2% of the aggregate passes through a 2.54-mm sieve.*
- NOTE 2** *When large granular materials are used in the subbase, the surface is potentially not stable or smooth enough to permit construction of the overlying bound base layer.*
- 5.12.2** Where the surface is not stable or smooth enough to permit construction of the overlying bound base layer, a blinding layer of smaller sized aggregates should be raked-in and compacted.

5.12.3 The thickness of the subbase may be adjusted to accommodate a blinding layer.

Pervious asphalt and concrete layers

5.13 The road surfacing of reservoir pavements shall comprise either pervious asphalt for permeable road surfaces (reservoir pavement types I to III) or conventional impermeable asphalt for impervious road surface (reservoir pavement types IV to VI).

NOTE *The bound upper layers of a reservoir pavement comprises of a road surfacing, on an optional binder course, over a structural base.*

5.14 The lower bound layer (base) for a reservoir pavement shall be porous concrete.

5.14.1 Alternative designs with hydraulically bound materials may be adopted where these are demonstrated to meet the desired foundation class.

NOTE 1 *The need for the lower bound layers to be porous concrete, applies not only to reservoir pavements with pervious road surfacing but also for conventional impermeable road surfacing.*

NOTE 2 *For conventional impermeable road surfacing, porous concrete provides additional reserve water storage (over and above that provided in the subbase) for exceedance events.*

5.15 The air voids content of the pervious asphalt road surfacing and porous concrete base layer shall be at least 15%.

NOTE *The void content requirement is to ensure adequate permeability of these materials.*

Layer thickness design of the standard flexible pavement with porous concrete base

5.16 Design thickness for flexible pavements to carry between 10 and 80 msa₈₀ shall be in accordance with Table 5.16.

Table 5.16 Selected designs for a flexible pavement with porous concrete base under a dense (low permeability) asphalt road surfacing

Design parameters			Foundation class 2			
Aggregate	Coefficient of thermal expansion	Design traffic (million standard axles)	Layer thickness (mm) for:			
			Porous concrete of strength class			Asphalt
			C8/10	C12/15	C16/20	
Crushed rock	< 10x10 ⁻⁶	80 msa ₈₀	210	180	150	180
Gravel	≥ 10x10 ⁻⁶		250	210	180	180
Crushed rock	< 10x10 ⁻⁶	40 msa ₈₀	200	170	150	170
Gravel	≥ 10x10 ⁻⁶		240	200	170	170
Crushed rock	< 10x10 ⁻⁶	20 msa ₈₀	180	150	150	150
Gravel	≥ 10x10 ⁻⁶		215	180	150	150
Crushed rock	< 10x10 ⁻⁶	10 msa ₈₀	165	150	150	140
Gravel	≥ 10x10 ⁻⁶		200	165	150	140

NOTE *The designs given in Table 5.16 apply to those reservoir pavement designs with an impervious surface (reservoir pavement types IV to VI).*

- 5.17 When pervious asphalt replaces dense (low permeability) asphalt (in reservoir pavement types I to III) the thicknesses of the porous concrete base, in Table 5.16 shall be increased by between 5 mm for flexible pavements of design traffic 10 msa₈₀, and 10 mm for flexible pavements of design traffic 80 msa₈₀.
- 5.18 The maximum traffic loading for reservoir pavements shall be 80 msa₈₀.
- 5.18.1 Designs for levels of traffic loading not included in Table 5.16 may be derived using CD 226 [Ref 3.N].

Alternative designs

Introduction

- 5.19 Designs for reservoir pavements with other hydraulically bound materials as base, including asphalt, shall be based on the analytical design method in TRL 615 [Ref 10.N].
- NOTE** *Pervious asphalt base designs can incorporate pervious asphalt in the subbase only for water storage (with an impermeable asphalt road surfacing), or comprise pervious asphalt in both the subbase and the road surfacing TRL 615 [Ref 10.N].*
- 5.20 Designs that use an alternative to a porous concrete on an unbound granular subbase shall be supported and justified by laboratory testing and in situ trials.
- NOTE 1** *Guidance for reservoir pavement designs for other hydraulically bound lower base (subbase) materials and for flexible pavements with a pervious asphalt lower base (subbase) are also provided within this document.*
- NOTE 2** *The standard structural designs for a flexible pavement with a porous concrete base on an unbound granular subbase are derived from CD 226 [Ref 3.N]. Initially the foundation is designed for the CBR strength of the sub-grade.*

Subgrade

- 5.21 For all alternative design approaches, the design requirements for the subgrade shall be as described for the standard design.

Alternative subbase reservoir and foundation design

- 5.22 The adopted design methodology for reservoir pavements shall be that described in TRL 615 [Ref 10.N] for the design of flexible pavements with asphalt or hydraulically bound materials.
- NOTE 1** *The adopted design method was derived before the European terminology was derived. Appendix E provides a comparison of materials, classifications and performance between current European terminology and that used in TRL 615 [Ref 10.N].*
- NOTE 2** *The road foundation (subgrade and subbase) is categorised in terms of foundation stiffness classes.*
- NOTE 3** *Stiffness classes are defined in terms of the long-term, equivalent half-space stiffness of the composite foundation as follows:*
- 1) class 1 ≥ 50 MPa;
 - 2) class 2 ≥ 100 MPa;
 - 3) class 3 ≥ 200 MPa;
 - 4) class 4 ≥ 400 MPa.
- NOTE 4** *A class 2 foundation was designed to be equivalent to the previous standard foundation of 225 mm-thick layer of type 1 subbase on a subgrade with a CBR of 5%.*
- NOTE 5** *The class 1 foundation is applicable to construction on a capping layer. Class 3 and 4 foundations can involve bound subbases.*
- NOTE 6** *Design guidance for conventional pavement foundations is contained in CD 225 [Ref 4.N] and in TRL PPR 127 [Ref 19.N].*

5.22.1 For reservoir pavements that involve subgrade infiltration and unbound granular subbases, a class 1 or class 2 foundation should be used.

NOTE 1 A foundation that consists of a subbase with about 400 mm of unbound granular material on a subgrade with a CBR of 2.5% can produce a class 1 or class 2 foundation, dependent on the quality of the unbound granular material.

NOTE 2 Foundation of class 3 or class 4 can be attained by stabilising the subgrade.

NOTE 3 Although soil stabilisation can make the subgrade less moisture susceptible, it can also make it less permeable.

NOTE 4 The balance between adequate soil strength for structural performance and sufficient infiltration attenuation needs to be assessed as an integral element of the design.

NOTE 5 For a subbase with a lower foundation class, use of porous concrete as base can also increase the stiffness to foundation class 3 or class 4.

Pervious asphalt and concrete layers

5.23 When used as base, hydraulically bound materials used shall be in accordance with BS EN 13108-1 [Ref 1.N].

5.24 When used as base, the structural properties of hydraulically bound material at 360 days shall be adopted.

NOTE 1 This structural requirement for hydraulically bound material is in accordance with the adopted analytical design method of TRL 615 [Ref 10.N].

NOTE 2 For conventional cement-bound materials (CBMs) the 360 day compression strength of CBM is 25% higher than the 28 day strength (as used in earlier standards). For faster curing porous concrete this relationship might not apply and it can be assumed that no further strength gain occurs after 28 days.

NOTE 3 As shown in Appendix E, Table E2, pervious asphalt has approximately a half to a third of the stiffness of heavy duty macadam (HDM).

5.25 Porous concrete and all other hydraulically bound mixture (HBM) layers, which are expected to reach a compressive strength of 10 MPa at 7 days, shall have cracks induced in accordance with Clause 818 of MCHW Series 0800 [Ref 14.N].

5.25.1 Where induced cracks are required in an HBM, these should be aligned (maximum 100 mm tolerance) with any induced cracks in the underlying construction.

NOTE 1 The conditions for induced cracking apply until sufficient performance data is attained for a review of this requirement.

NOTE 2 The function of the depth of asphalt road surfacing in a flexible pavement with cement bound granular material (CBGM) base is primarily to delay the onset of reflection cracking.

NOTE 3 Delatte [Ref 17.I] identifies that as there is less shrinkage with porous concrete, it is not necessary to construct porous concrete road surfacing with construction joints. Consequently, transverse cracks might not develop so readily in these road surfacings.

Layer thickness design of flexible pavements with HBM or asphalt bases

5.26 The thickness of the asphalt shall be designed according to the method described in Chapter 4 of TRL 615 [Ref 10.N].

5.27 Laboratory determinations of the compressive and flexural strengths of the HBM base materials shall be undertaken for flexible reservoir pavements designs with CBGM bases and other HBMs.

5.28 The estimation of the dynamic modulus for CBGM bases and other HBM bases shall be undertaken using the equation 5.28.

Equation 5.28 Estimation of the dynamic modulus for CBGM bases and other HBM bases

$$E = \frac{\log(f_f) + 0.77}{0.00301}$$

where:

- f_f the flexural strength (MPa)
 E the dynamic modulus (GPa)

- NOTE 1 Further information on the derivation and use of Equation 5.28 and the mechanical properties of a range of materials are provided in Appendix E.*
- NOTE 2 The combination of stiffness and strength is crucial for design of a hydraulically bound base.*
- NOTE 3 Two different hydraulically bound materials can have the same base thicknesses for a given level of traffic, provided their flexural strengths compensate for any differences in their levels of stiffness.*

6. Design for construction and maintenance

Interface with conventional pavements

- 6.1 Where a reservoir pavement abuts a conventional pavement of traditional construction comprised of dense (low permeability) materials, the wetted subgrade of the reservoir pavement shall be isolated from the subgrade of the conventional pavement.

NOTE 1 An alternative to abutting reservoir and conventional pavements, but with increased landtake, is to separate these pavements types by a reserve whose width depends on whether, or not, a cut-off drain is used to reduce the extent of the wetted subgrade.

NOTE 2 Guidance on the potential extent of the wetted subgrade is given by Nakashima. (See Nakashima, S et al [Ref 19.I]).

- 6.1.1 The wetted subgrade may be isolated by a cut-off drain of depth appropriate to the expected extent of infiltration and/or by enclosing the reservoir using an impermeable membrane.

NOTE 1 Isolation of the wetted sub-grade of the reservoir pavement from the subgrade of the conventional pavement is not always necessary where a reservoir pavement abuts a conventional pavement, but where the subgrade is highly permeable, with a deep water table and strength that is not moisture susceptible.

NOTE 2 As the cut-off drain needs to have access points to inspect and clean pipework, this type of construction is expected to be suitable for short lengths of reservoir pavement, for example as occurs with laybys and emergency areas.

NOTE 3 Other possible solutions for isolating a reservoir pavement from a conventional pavement include reverse interlayer gradients compared to the reservoir pavement crossfall, substitution of dense (low permeability) with permeable materials and changes in layer thicknesses.

- 6.2 The reservoir pavement and drainage design shall not trap water within the conventional pavement.

6.2.1 Water infiltrating through conventional pavements should be drained at their low side by an edge of pavement drain in accordance with CD 524 [Ref 11.N].

6.2.2 Drainage from conventional pavements may be incorporated to discharge in an alternative manner, including into the reservoir pavement.

- 6.3 Where drainage from conventional pavements is received, the design storage and discharge capacity of the reservoir pavement shall allow for additional inflow.

Design for maintenance

- 6.4 The design of the reservoir pavement shall include necessary components for maintenance provision of the road surfacing when operational.

6.5 The design of the reservoir pavement shall include the means for inspection and maintenance with respect to the management and removal of sediment.

NOTE 1 Sediment management and removal can include provisions for settlement and storage (such as chambers).

NOTE 2 Highway runoff contains a significant amount of particulate material. Without periodic removal these materials can lead to the decline in performance and eventual failure of any design of drainage system. Reservoir pavements are particularly susceptible to derogation of performance caused by particulates.

- 6.6 During design, an initial management plan shall be developed for the entire drainage system.

6.6.1 This management plan should:

- 1) set out the objectives of the drainage systems (which can include, for example, flow and pollutant attenuation);

- 2) formulate an adaptable programme of maintenance to include cleaning or replacement of clogged materials;
- 3) establish procedures (including inspection) for observing and monitoring the behaviour of the drainage system (for example through permeability testing);
- 4) plan for regular reviews of the maintenance scheduling, which can lead to increased or decreased frequency of inspections, cleaning, etc; and,
- 5) prescribe the various maintenance operations required.

7. Normative references

The following documents, in whole or in part, are normative references for this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Ref 1.N	BSI. BS EN 13108-1, 'Bituminous mixtures – Material specifications. Asphaltic concrete.'
Ref 2.N	Highways England. CS 229, 'Data for pavement assessment'
Ref 3.N	Highways England. CD 226, 'Design for new pavement construction'
Ref 4.N	Highways England. CD 225, 'Design for new pavement foundations'
Ref 5.N	Highways England. CG 501, 'Design of highway drainage systems'
Ref 6.N	Highways England. CD 529, 'Design of outfall and culvert details'
Ref 7.N	National Highways. CD 530, 'Design of soakaways'
Ref 8.N	Highways England. CD 533, 'Determination of pipe and bedding combinations for drainage works'
Ref 9.N	National Highways. CD 523, 'Determination of pipe roughness and assessment of sediment deposition to aid pipeline design'
Ref 10.N	TRL. Nunn, M. TRL 615, 'Development of a more versatile approach to flexible and flexible-composite pavement design'
Ref 11.N	National Highways. CD 524, 'Edge of pavement details'
Ref 12.N	National Highways. CD 521, 'Hydraulic design of road edge surface water channels and outlets'
Ref 13.N	National Highways. GG 101, 'Introduction to the Design Manual for Roads and Bridges'
Ref 14.N	Highways England. MCHW Series 0800, 'Manual of Contract Documents For Highway Works. Volume 1 Specification for Highway Works. Series 800 Road Pavements — Unbound, Cement and Other Hydraulically Bound Mixtures'
Ref 15.N	Highways England. TAGG. MCHW 104 PAS, 'MCHW Series 100 Product Acceptance Schemes (PTS, HAPAS, CARES, BBA etc) [Clause 104.15-17]'
Ref 16.N	BSI. BS 1377-4, 'Methods of test for soils for civil engineering purposes. Compaction related tests'
Ref 17.N	The National Archives. Legislation.gov.uk. Reservoirs Act c.23, 'Reservoirs Act 1975 and various Reservoirs Act (Amendment) Regulations'
Ref 18.N	Highways England. LA 113, 'Road drainage and the water environment'
Ref 19.N	Transport Research Laboratory. Chaddock, B & Roberts, C. TRL PPR 127, 'Road foundation design for major UK highways'
Ref 20.N	Highways England. CS 228, 'Skidding resistance'
Ref 21.N	CIRIA. O'Brien AS, Hsu YS, Lile CR, and Pye SW. CIRIA C737, 'Structural and geotechnical design of modular geocellular drainage systems'
Ref 22.N	Highways England. CD 236, 'Surface course materials for construction'
Ref 23.N	Centre d'Etudes sur les Reseaux les Transport, l'Urbanisme et les constructions publiques. CERTU (Stormwater networks), 'Techniques alternatives aux reseau d'assainissement pluvial: Element cle pour leur mise en oeuvre'

Ref 24.N	CIRIA. Woods-Ballard,B, Wilson,S, Udale Clark,H, Illman,S, Scott,T, Ashley,R, Kellagher,R.. CIRIA C753, 'The SuDS Manual'
Ref 25.N	BSI. BS EN 14227-1, 'Unbound and hydraulically bound mixtures. Specifications. Cement bound granular mixtures'
Ref 26.N	National Highways. CD 532, 'Vegetated drainage systems for highway runoff'

8. Informative references

The following documents are informative references for this document and provide supporting information.

Ref 1.I	TRL. Chaddock B and Nunn M E (2011). TRL PPR 482, 'A pilot-scale trial of reservoir pavements for drainage attenuation '
Ref 2.I	Bulletin de Liaison des Laboratoires des Ponts et Chaussées, no 188 Nov/Dec 1993. Ranchet, J., Penaud, F., Le Grand, R., Constant, A., Obry, P. and Soudieu, B. LCPC 188, 'Comparison points of view'
Ref 3.I	Pratt, C.J. Pratt 1999, 'Developments in permeable pavement: Further observations on mineral oil bio-degradation. Proc. Standing Conf. on Stormwater Source Control, Vol XV11. ISBN 0 905949 80 3'
Ref 4.I	2000/60/EC, 'Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy'
Ref 5.I	John Wiley and Sons (1974). Cedergren HR. Cedergren, 'Drainage of highway and airfield pavements'
Ref 6.I	Baladés et al. Baladés et al, 'Evaluation des flux de pollution transitant dans un type de solution compensatoire. Conférence Novatech, Lyon. 189-190:66-75'
Ref 7.I	Highways England. CD 116, 'Geometric design of roundabouts'
Ref 8.I	CERTU (Centre d'Etudes sur les Réseaux les Transport, l'Urbanisme et les constructions publiques) (1999) . CERTU (Porous pavements), 'Guide Technique: Chaussées poreuses urbaines.'
Ref 9.I	CIRIA. CIRIA R156 , 'Infiltration Drainage Manual of Good Practice'
Ref 10.I	Journal of Irrigation Drainage 143(8). Knappenberger, T et al. (2017). Knappenberger, T et al, 'Monitoring porous asphalt stormwater infiltration and outflow'
Ref 11.I	Water Science and Technology 45:51-56. Newman et al . WST45, 'Oil bio-degradation in permeable pavements by microbial communities'
Ref 12.I	National Asphalt Pavement Association NAPA Information Series 131. www.hotmix.org. NAPA (2008). NAPA Information Series 131, 'Porous asphalt pavements for stormwater management (Revised November 2-008)'
Ref 13.I	The Science of the Total Environment. 156 :1402-1757. Hogland and Niemczynowicz. Hogland & Niemczynowicz, 'Porous Pavement in a Cold Climate'
Ref 14.I	Coventry University. Puehmeir, T. Puehmeir, 'Recent studies on oil degrading porous pavement structures. Proc. Standing Conf. on Stormwater Source Control, Vol XV111, ISBN 0 905949 80 3'
Ref 15.I	Water Science and Technology 39 :119-125. Legret et al. Legret et al, 'Simulation of heavy metal pollution from stormwater infiltration through a porous pavement with reservoir structure'
Ref 16.I	Construction Industries Research and Information Association, London. CIRIA (2002). CIRIA C582, 'Source Control Using Constructed Pervious Surfaces'
Ref 17.I	Washington, USA. Delatte, N. Delatte, 'Structural design of pervious concrete pavement. 86th Annual Meeting of TRB'
Ref 18.I	Croney, D. Croney 1997, 'The design and performance of road pavements '

Ref 19.I	International ISAP Symposium on Asphalt Pavements and Environment, 18th – 20th August 2008, Zurich, Switzerland. Nakashima, S, Tsatsumi, S and Oshita, T.. Nakashima, S et al, 'The effect of rainwater seepage on the mechanical properties of pavement subgrade'
Ref 20.I	Transport Research Laboratory . Powell, WD, Potter, JF, Mayhew, HC & Nunn, ME. TRL LR 1132, 'The structural design of bituminous roads'
Ref 21.I	MDPI. Razzaghmanesh,M. Beecham, S. Water 2018, 'Water 2018, 10, 337: A review of permeable pavement clogging investigations and recommended maintenance regimes'

Appendix A. Control of flooding and pollution

A1 General

Reservoir pavements capture and attenuate road runoff allowing slow release into the environment, thereby reducing flood risk. In addition, they may also retain pollutants washed from the road surfacing. Unlike other systems that provide similar benefits (such as ponds or vegetated treatment systems), they require little land-take and may be fully integrated into the curtilage of the road.

A2 Flow attenuation

As reservoir pavements provide storage capacity within a drainage network they may be used to attenuate the outward discharge to the receiving waterbodies. Spare storage capacity within a reservoir pavement, can be used on this basis, for example by diverting runoff into the subbase reservoir layer, either acting as an in-line balancing facility or as a "supplementary" soakaway. This configuration can work well with very porous, non-moisture susceptible subgrades.

Where the outward discharge is into a conventional conveyance system prior to discharge to an outfall, the outlet from the subbase reservoir layer may be throttled (through the use of small diameter pipes, orifice plates or other flow control systems) to reduce the rate of discharge. The combination of throttled discharge and subbase storage serve to control the rapid storm discharge and high peak hydrographs typical of runoff from paved road surfacing during high intensity storms.

Through designing the appropriate storage, it is possible to balance input from the design storm such that the outflow may be reduced (for a newly developed site) to a discharge rate equivalent to that of a greenfield runoff rate (typically 2-5 l/sec/Ha). This significantly reduces flood risk from road drainage outfalls.

Measures to control and contain the movement of sediment to the reservoir from the upstream drainage system need to be incorporated into these balancing/ attenuation systems.

A subsurface reservoir can be used in verges or in other off-line locations to provide flow and pollutant attenuation in an otherwise conventional drainage system. As verge locations would not be subject to the same structural loadings as trafficked conventional pavements, structural design requirements would be site specific.

Reservoir pavements incorporating geocellular tanks are particularly suited to these types of applications. Examples of such use are provided in CIRIA C753 [Ref 24.N], which provides additional guidance.

A3 Pollution containment and control

Collaborative research carried out for Highways England and the Environment Agency (see DMRB LA 113 [Ref 18.N]) has identified the key pollutants from road runoff as:

- 1) sediments (and associated bound pollutants);
- 2) metals (zinc, copper, cadmium); and,
- 3) hydrocarbons (oil and fuel) including polycyclic aromatic hydrocarbons (PAH).

Pollutants may also be associated with maintenance activities, such as pesticides and herbicides from landscape or verge maintenance. Guidance on the assessment and mitigation of these pollutant risks is given in LA 113 [Ref 18.N].

The interception of runoff by reservoir pavements may be expected to limit the direct discharge of pollutants into waterbodies.

There are no documented cases of the use of pervious road surfacing (and associated reservoir pavements) causing deterioration in the quality of receiving waterbodies (see CIRIA C582 [Ref 16.I]). All the evidence to date has demonstrated an improvement in water quality. Pollutants may be filtered from the percolating water. This may occur through entrapment (filtration), adsorption and biodegradation, or a combination of all three. Filtration can occur within the soil, the aggregate matrix

or on geotextile layers within the construction. Adsorption occurs when the pollutant attaches or binds to the surface of soil or aggregate particles. Microbial communities can become established that biodegrade organic pollutants such as oil or grease (see Pratt 1999 [Ref 3.I], and Puehmeir [Ref 14.I]). A number of research studies Baladés et al [Ref 6.I], Hogland & Niemczynowicz [Ref 13.I], Legret et al [Ref 15.I], WST45 [Ref 11.I], Pratt 1999 [Ref 3.I], LCPC 188 [Ref 2.I] have identified the benefits of pervious and reservoir pavements in attenuating pollutants in drained water. Reductions are recorded in, for example, suspended solids, oil, copper, lead, zinc and cadmium. Chemical oxygen demand (COD) was also reduced.

There is less direct evidence for the pollutant attenuation effects of edge-drained, injected type reservoir pavement systems (that is, reservoir pavement types IV- VI). Many of the attenuation processes described above, however, will still be active when water is injected into the subbase reservoir as opposed to percolating down from the surface. In addition, edge-drained, injected systems provide the opportunity to fit pollution containment within the edge drain system itself. This design might include, for example, sediment or hydrocarbon traps. With an appropriate maintenance regime, these traps will both address pollution issues and mitigate one of the more significant disadvantages of reservoir systems; their potential susceptibility to clogging by washed off sediments.

A4 Groundwater recharge

Where discharge to the ground is proposed, it is important to first undertake a risk assessment to evaluate both potential risks to groundwater (for examples shallow water tables, source protection zones, sensitive groundwater dependant ecosystems). Groundwater risk assessment advice is provided in LA 113 [Ref 18.N]. The hydraulic properties of the subgrade also need to be considered with respect to potential damage to road substrates. However, where infiltration to the ground is possible, there may be considerable environmental benefits through increased recharge to local aquifers. For roads over permeable soils, this effectively mimics the natural situation maintaining the groundwater balance.

Appendix B. Reservoir pavement design configurations

Figure B.1 Reservoir pavement type I

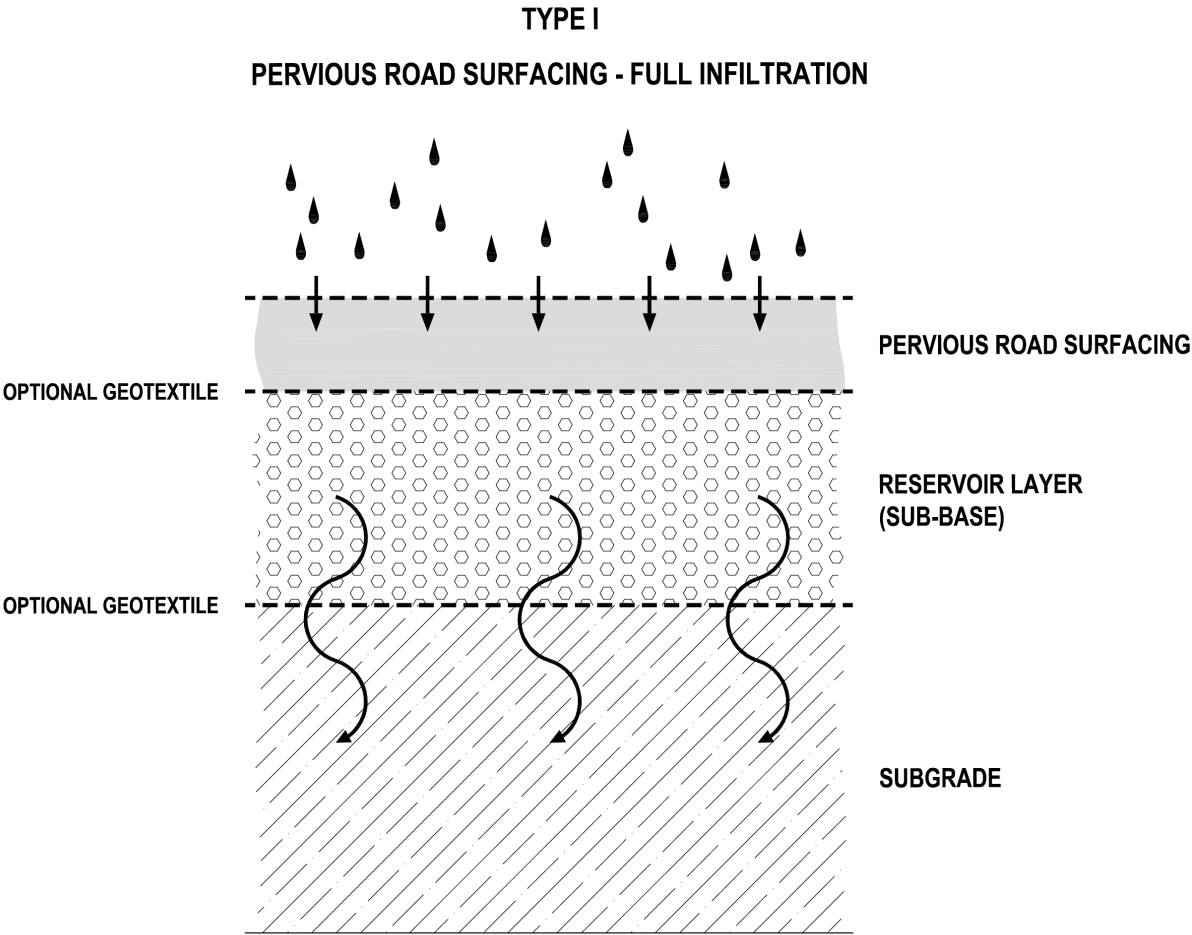


Figure B.2 Reservoir pavement type II

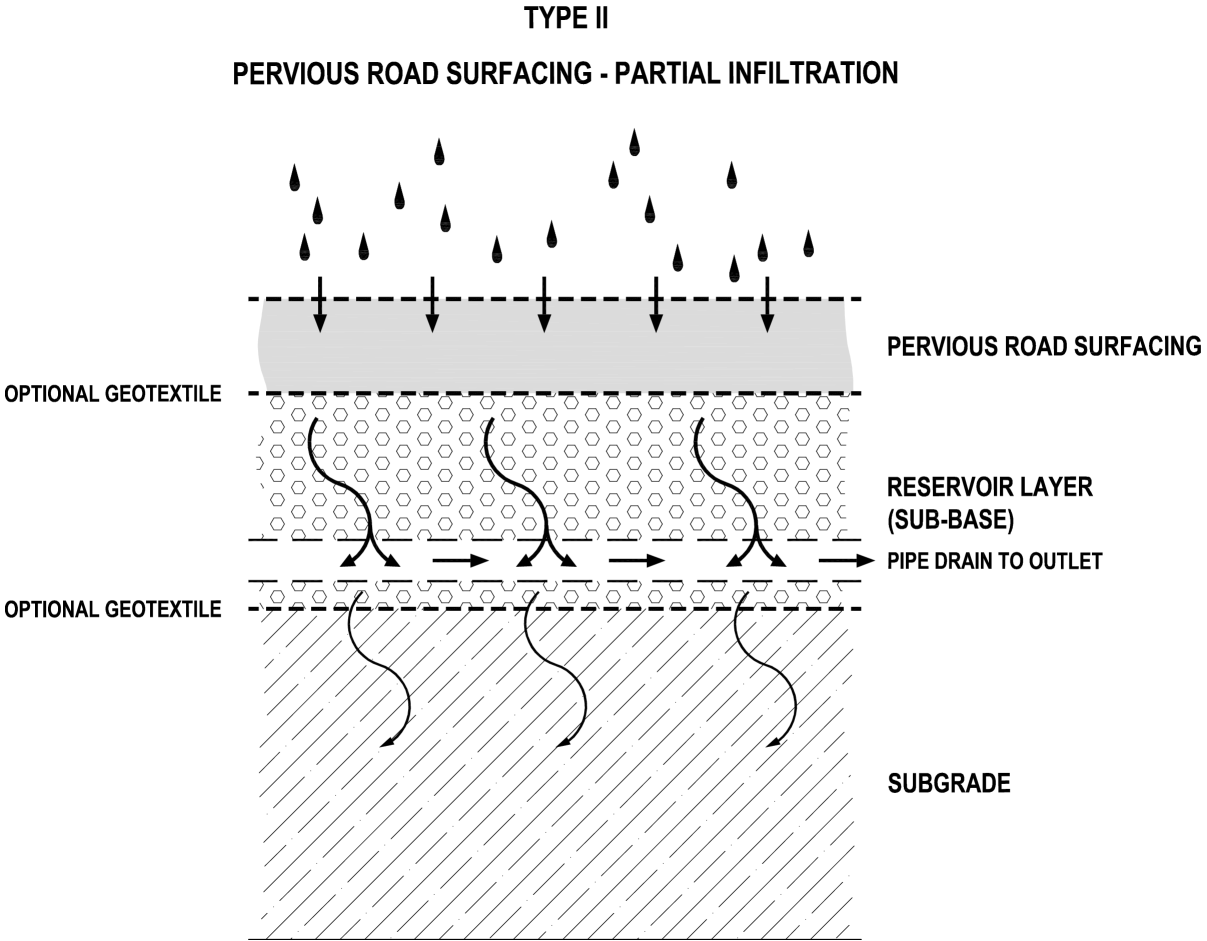


Figure B.3 Reservoir Pavement type III

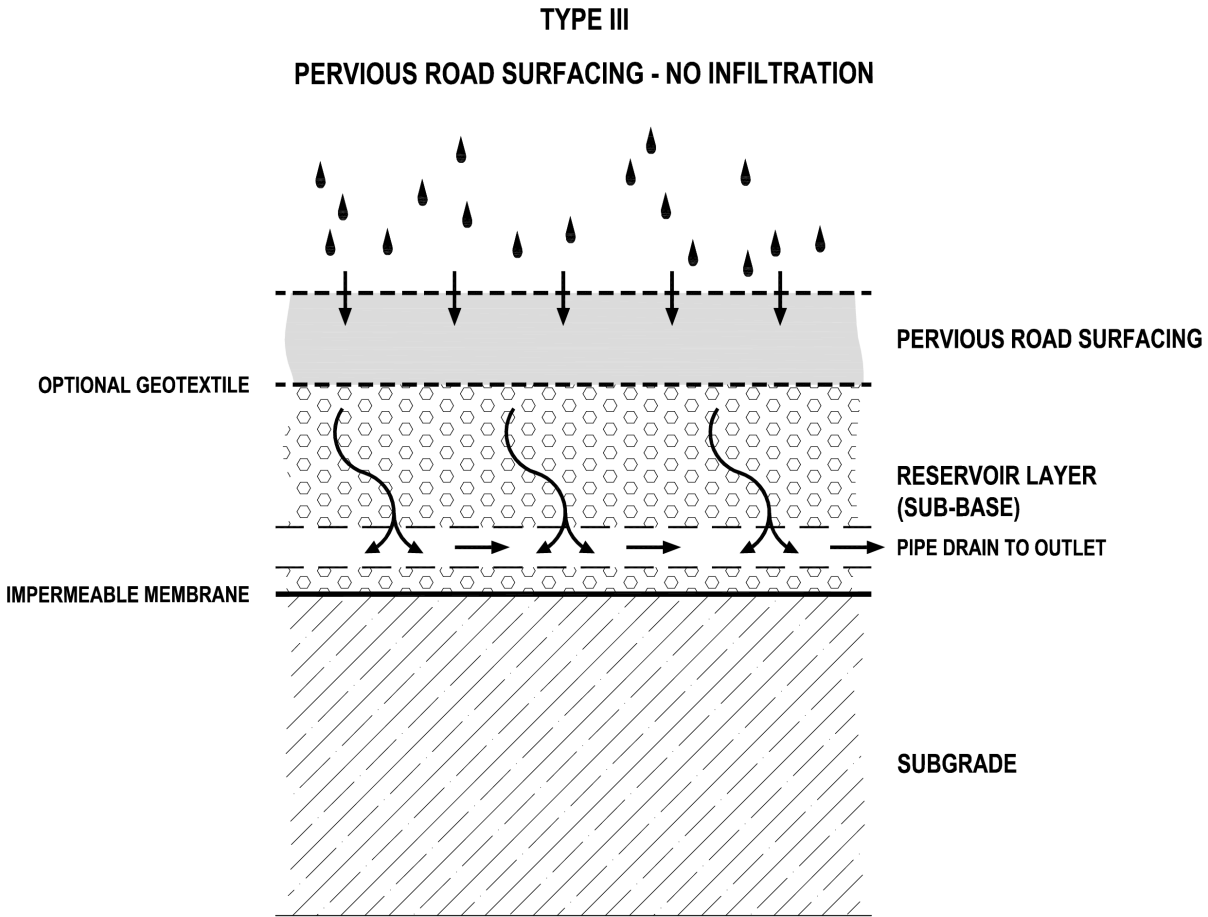


Figure B.4 Reservoir pavement type IV

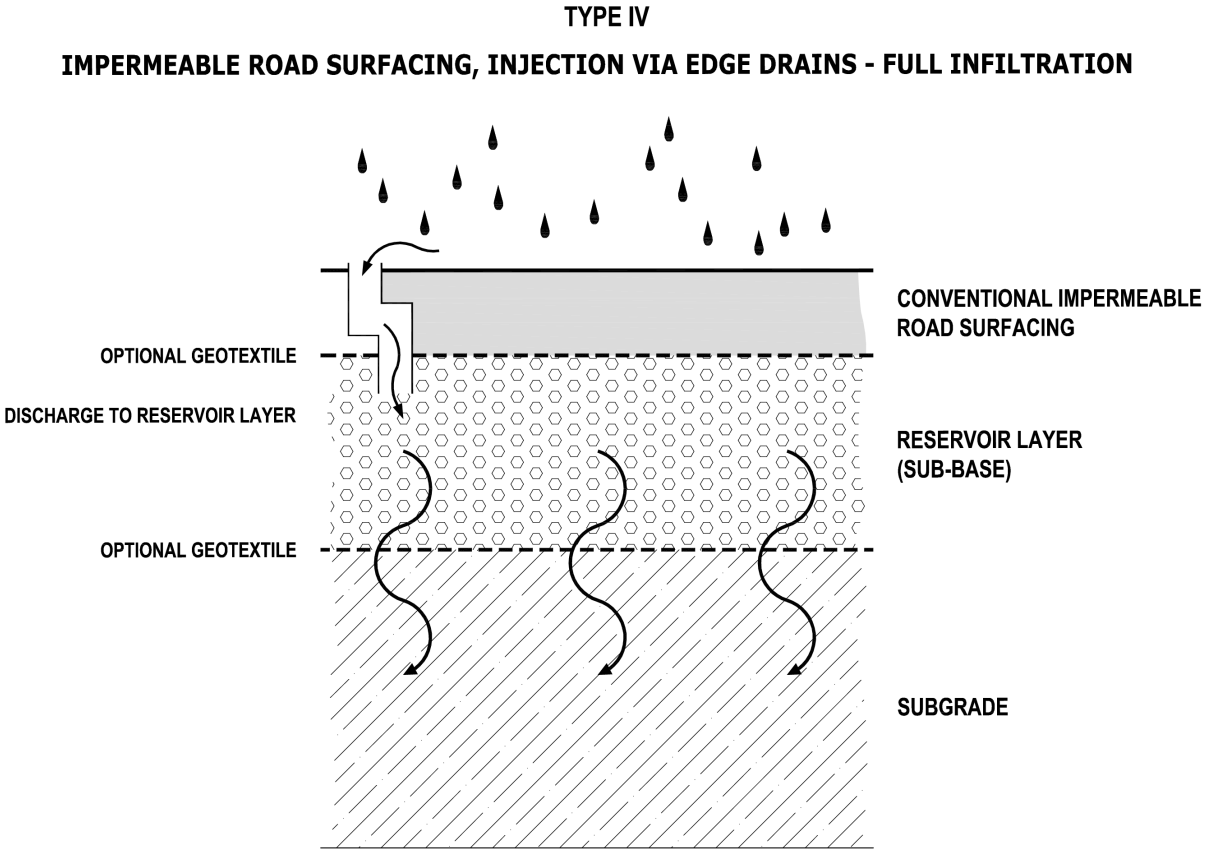


Figure B.5 Reservoir pavement type V

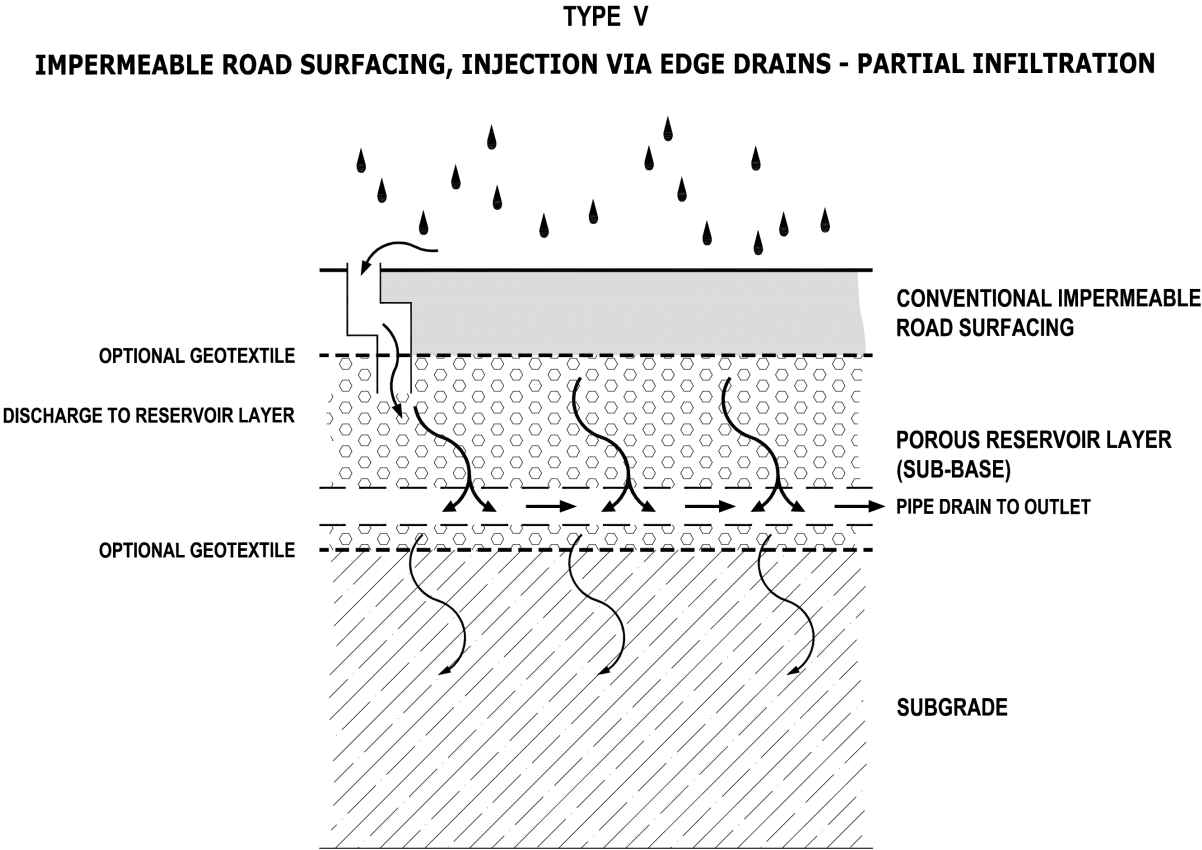
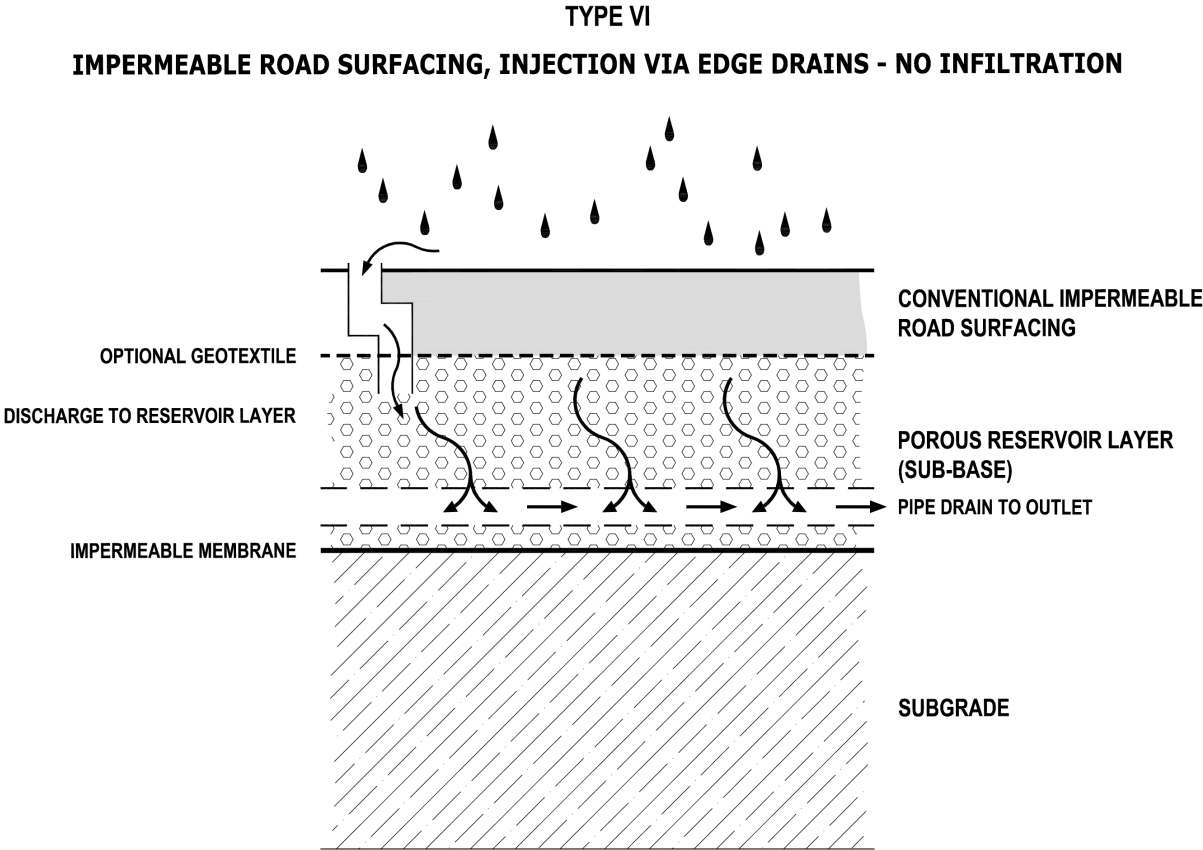


Figure B.6 Reservoir pavement type VI



Appendix C. Advantages and disadvantages of different design configurations

Table C.1 Advantages and disadvantages of different design configurations

Reservoir pavement type	Advantages	Disadvantages	Typical applications
Reservoir pavements with pervious road surfacing			
Type I	<ul style="list-style-type: none">1) simplest, cheapest design;2) self-contained (no outlet drainage other than emergency overflows for design exceedance);3) no land requirement adjacent carriageway;4) only emergency outfall (for design exceedance) required.	<ul style="list-style-type: none">1) road surfacing susceptible to blockage from silt and other road-borne materials;2) require regular inspection, intervention and maintenance to maintain pervious surfacing;3) less durable road surfacing than Types IV to VI;4) Deicing using rock salt to be avoided due to potential blocking of pervious surface;5) potential susceptibility to spillage entering directly into the reservoir;6) increased maintenance over conventional pavement and drainage systems.	<ul style="list-style-type: none">1) over permeable subgrade with non sensitive groundwater;2) in trafficked areas with low accretion of silt;3) non-trafficked areas such as laybys, footpaths and cycleways.
Type II	<ul style="list-style-type: none">1) surplus storage may be used as an in-line balancing facility;2) minimal additional landtake (for buried pipeworks and discharge).	<ul style="list-style-type: none">1) as Type I above;2) additional costs/ complexity from pipeworks and outlets;3) potential difficulties in maintenance of buried pipe systems;4) requires downstream drainage system.	<ul style="list-style-type: none">1) over poorly permeable subgrade;2) in trafficked areas with low accretion of silt;3) non-trafficked areas such as laybys, footpaths and cycleways.

Table C.1 Advantages and disadvantages of different design configurations (continued)

Reservoir pavement type	Advantages	Disadvantages	Typical applications
Type III	<ul style="list-style-type: none">1) as Type II above;2) may be used over moisture-susceptible or contaminated soils, and sensitive and shallow groundwater.	<ul style="list-style-type: none">1) as above;2) additional costs of membranes (if installed);3) effective sealing of membranes.	<ul style="list-style-type: none">1) over barely permeable subgrade;2) over sensitive groundwater areas;3) in areas of potential contaminant migration;4) over moisture-susceptible soils/subgrade (e.g. low strength, dissolution);5) shallow water tables (within 1 m of subbase);6) in trafficked areas with low accretion of silt;7) non-trafficked areas such as laybys, footpaths and cycleways.
Reservoir pavements with impervious road surfacing			
Type IV	<ul style="list-style-type: none">1) more durable, lower maintenance road surfacing (than Types I- III);2) allow capture of accidental spillage (such as by using decantation chamber in edge drains);3) self contained.	<ul style="list-style-type: none">1) increased complexity (design, construction) and costs over Type I due to additional edge drainage/ pipework);2) increased maintenance over conventional pavement and drainage systems.	<ul style="list-style-type: none">1) as Type I above
Type V	<ul style="list-style-type: none">1) more durable, lower maintenance road surfacing (than Types I-III);2) Allow capture of accidental spillage (such as by using decantation chamber in edge drains);3) may be used as an in-line balancing facility.	<ul style="list-style-type: none">1) as Type II with increased complexity and cost due to additional pipework	<ul style="list-style-type: none">1) as Type II above

Table C.1 Advantages and disadvantages of different design configurations (continued)

Reservoir pavement type	Advantages	Disadvantages	Typical applications
Type VI	1) as Type V above 2) may be used over moisture-susceptible or contaminated soils, and sensitive and shallow groundwater.	1) as Type III with increased complexity and cost including additional costs of membranes (if installed); 2) effective sealing of membranes	1) as Type III above

Appendix D. Worked example

D1 Background

A dual carriageway road is to be upgraded to include provision of a hard shoulder. As a result, the existing drainage (primarily in filter drains) will need replacement. For a 1-km section of the road widening, space constraints are such that there is insufficient room to provide a conventional drainage system.

An assessment carried out using LA 113 [Ref 18.N] demonstrated that there are not expected to be significant risks of spillage along this stretch of the road and that there are no significant risks to underlying groundwater.

An assessment carried out using CD 523 [Ref 9.N] identified that the generation of sediment and silt at the site could be managed with simple traps incorporated into the design. Note that the design detail of sediment management is not included in this example.

As the site does not overlay a sensitive groundwater body, it is intended that this 1-km stretch will be drained using a reservoir pavement with edge drainage "injected" (reservoir pavement type IV) into the subbase reservoir layer beneath the hard shoulder and then by infiltration into the underlying permeable subgrade.

The hydraulic design for the reservoir pavement includes the determination of the maximum depth of water that will occur in the subbase reservoir layer for a design storm of 1:10 years over a range of storm durations (15 mins to 24 hours). The depth of the reservoir will ensure the water held in storage under the design storm can empty from full capacity to 50% or less within 24 hours.

Following hydraulic design, the structural design of the subbase will be checked against the bearing capacity of the underlying subgrade. The ground is relatively flat with gradients of no more than 1% across the site. The underlying subgrade comprises well sorted sand and in situ infiltration tests have been carried out using the method described in CIRIA R156 [Ref 9.I] to establish the infiltration rate of the subgrade. The worked example in Table D1 is shown for determining subbase design thickness only.

Table D.1 The principle site features are as follows:

Length of road section	1000 m
Width of drained road section including hard shoulder	10.5 m
Drained road area (Ad)	10,500 m ²
Soil Infiltration rate (to subgrade)	4.5 x 10 ⁻⁵ m/s
Factor of safety (x 10) to be used for the soil infiltration to deal with the design exceedance, to allow for any errors in the field test results and to allow an element for blockage in the subbase reservoir layer	It is assumed in calculations that the soil infiltration rate is 4.5 x 10 ⁻⁶ m/s
CBR Value (sand; measured as "wetted" value)	5%
Porosity of the subbase material (n)	30%

The width of the reservoir is such that the ratio between drained area and the area of the reservoir pavement is greater than 2. Note, this recommendation applies primarily to those reservoir pavements employing a pervious surface (reservoir pavement types I-III) to reduce the potential impact of sediment from the carriageway. With reservoir pavement types IV, as applied here, sediment control may be applied by using sumped gullies or other in-line sediment control devices.

The design should include the preparation of maintenance regimes to ensure the reservoir itself remains free of sediment.

D2 Hydraulic design

In line with the guidance, the design follows a number of steps:

- 1) establish the design storm and establish rainfall (see CIRIA R156 [Ref 9.I]) intensities for the hydraulic region and from the drainage catchment to determine the runoff rate and volume. [Note that the critical storm duration for volume may differ from the critical storm duration for intensity];
- 2) following the procedure set out in CIRIA C582 [Ref 16.I] determine the maximum depth of water that will occur in the subbase for the design storms and check against the minimum recommended (350 mm) depth for the depth of the subbase;
- 3) check time of emptying to ensure 50% of the available storage is drained within 24 hours;
- 4) establish structural requirements of the subbase – adopt the greater thickness of hydraulic and structural requirements.

D2.1 Design storm

For the design storm of a 1:10 year return period, the rainfall intensity is determined by reference to the hydraulic region. In this example, the hydraulic region is considered with the values of the rainfall ratio (r) as 0.4, by reference to Figure 3.6 in CIRIA C582 [Ref 16.I].

Using the value of r , rainfall intensities for the 10-year storm are determined for the storm durations of 15 minutes to 24 hours, from Table 3.3 of CIRIA C582 [Ref 16.I], interpolating as required. The values for the rainfall intensities are presented in Table D.2 below.

Note that proprietary drainage software may also be used to generate design storm rainfall intensities for given hydraulic regions.

Table D.2 Rainfall Intensity for 10 year storm

Storm durations	Rainfall intensity (mm/h)	Rainfall intensity (m/h)
15 mins	62.33	0.0623
30 mins	39.87	0.0399
60 mins	24.8	0.0248
120 mins	14.95	0.0149
240 mins	8.85	0.0088
360 mins	6.48	0.0065
480 mins	5.4	0.0054
600 mins	4.32	0.0043
720 mins	4.02	0.0040
900 mins	3.56	0.0036
1080 mins	3.11	0.0031
1440 mins	2.20	0.0022

D2.2 Depth subbase (h_{max})

The worked calculations below are shown for the 15 minute duration, 1:10 year design storm. A simple spreadsheet calculation was used to determine results for all other storm durations. The results for these calculations are shown on Table D 2. The maximum depth of water (h_{max}) that will occur in the subbase (from CIRIA C582 [Ref 16.I]) is based on:

Table D.3 Depth subbase (hmax)

Hmax	$(R_i - q) \frac{D}{n}$
where	
R	ratio of the drained area to base area of pervious surface total-paved area (Ad)/ internal area of subbase (Ab) 10500/2500 = 4.2
i	rainfall Intensity (m/h) 0.062 m/h for 15 mins 10-year storm
q	infiltration rate (m/h) into subgrade/ subsoil 4.5 x 10 ⁻⁶ m/s (factor of safety 10 included) 0.00162 m/h
D	rainfall duration = 15 mins = 0.25 h
n	porosity of subbase material = 0.3

On this basis:

$$h_{\max} = ((4.2 \times 0.062) - 0.0162) \times 0.25 / 0.3 = 0.205 \text{ m} = 205 \text{ mm},$$

which is less than the recommended 350 mm minimum depth of the subbase.

Note: This calculation is that applied to the highlighted row in Table D3. Results for other storm durations are shown on Table D3, with the storm giving the highest values of hmax shown in bold.

D2.3 Time of emptying

Based on CIRIA R156 [Ref 9.I] - pp60 - plane infiltration system), the time taken for the system to half empty is given by:

Table D.4 Time if emptying

Te	$(h \times h_{\max}) / 2q$
where	
h	porosity of subbase material 0.3
hmax	depth of water within subbase 0.205 m (for 15-mins storm)
q	infiltration rate 0.0162 m/h

therefore:

$$T_e = (0.3 \times 0.205) / (2 \times 0.0162)$$

$$= 1.89 \text{ h}$$

These calculations are shown on Table D.4 for the range of storm intensities adopted, with the storm with the longest time to empty shown in bold.

Note that as above, the infiltration rate assumed in calculations is a factor of 10 less than that measured in infiltration testing to accommodate the recommended safety factor.

D2.4 Summary of hydraulic design considerations

The summary of the key data (hmax and time to 50% empty) for a range of storms to 24 hours duration are shown in Table D.5 below. Note: where figures are negative, the infiltration capacity is in excess of the volume generated by the storm (that is there is no accumulated storage within the subbase reservoir layer).

Table D.5 Summary of hmax and time to empty by 50%

Storm Durations	hmax (mm)	Half Drain Time (hours)
15 mins	204.7	1.89
30 mins	252.1	2.33
60 mins	293.2	2.71
120 mins	310.6	2.88
240 mins	279.6	2.59
360 mins	220.3	2.04
480 mins	172.8	1.60
600 mins	64.8	0.60
720 mins	26.9	0.25
900 mins	-61.8	-0.57
1080 mins	-188.6	-1.75
1440 mins	-556.8	-5.16

For the design storm the maximum depth of reservoir required is approximately 311 mm (for the 2-hour storm shown above). The system easily has the capacity to drain by 50% within a 24-hour period. Although the calculated value of hmax is 311 mm, the current recommendation of a minimum reservoir thickness of 350 mm is adopted.

D3 Structural design

To provide runoff attenuation capacity, the subbase is to be of an unbound granular material. On this basis the foundation class is considered to be no better than Foundation Class 2. Referring to CD 225 [Ref 4.N] a CBR value of 5% would result in a layer thickness of circa 220 mm for a foundation layer stiffness of 150 MPa.

This subbase layer thickness is less than the current minimum recommendation.

D4 Comments

In the example provided above, both hydraulic and structural design considerations suggest a subbase thickness less than the currently recommended minimum of 350 mm. A case could be made to reduce subbase thickness to the minimum required (310 mm) to meet hydraulic requirements, although using the minimum recommended depth provides for a little additional storage capacity. This thickness is still greater than that required by structural considerations.

Negative values for hmax on the table indicate the infiltration capacity of the subbase exceeds the rainfall intensity of the design storm.

For the initial hydraulic design calculations, it is assumed that a width of 2.5 m beneath the hard shoulder, for the full 1000-m road length, will provide the reservoir and that this will infiltrate into the underlying subgrade. Iterative calculations may be carried out to achieve a compromise between the width and depth of the subbase reservoir layer.

Figures D.1 and D.2 provide conceptual sketches of the installation of a reservoir pavement based on this worked example (plan and section respectively). Edge drainage and the means to "inject" water into the reservoir are not presently covered by this guidance. Methods will need to be adopted that are hydraulically proven and that also allow control of sediment to ensure this is not injected into the underlying subbase reservoir layer.

If moisture susceptible subgrades are encountered, a cut-off drain will be needed to isolate the conventional pavement foundation from the discharge from the reservoir pavement. These need to continue functioning throughout the life of the reservoir pavement.

Given sufficient hydraulic capacity, the reservoir may be discontinuous beneath the hard shoulder. In such cases, thicker reservoirs may be required to provide the necessary storage capacity.

The design should also accommodate an overflow to cater for exceedance events. Providing a greater subbase thickness could potentially give greater storage capacity for more extreme storms, however overflow is recommended for all installations.

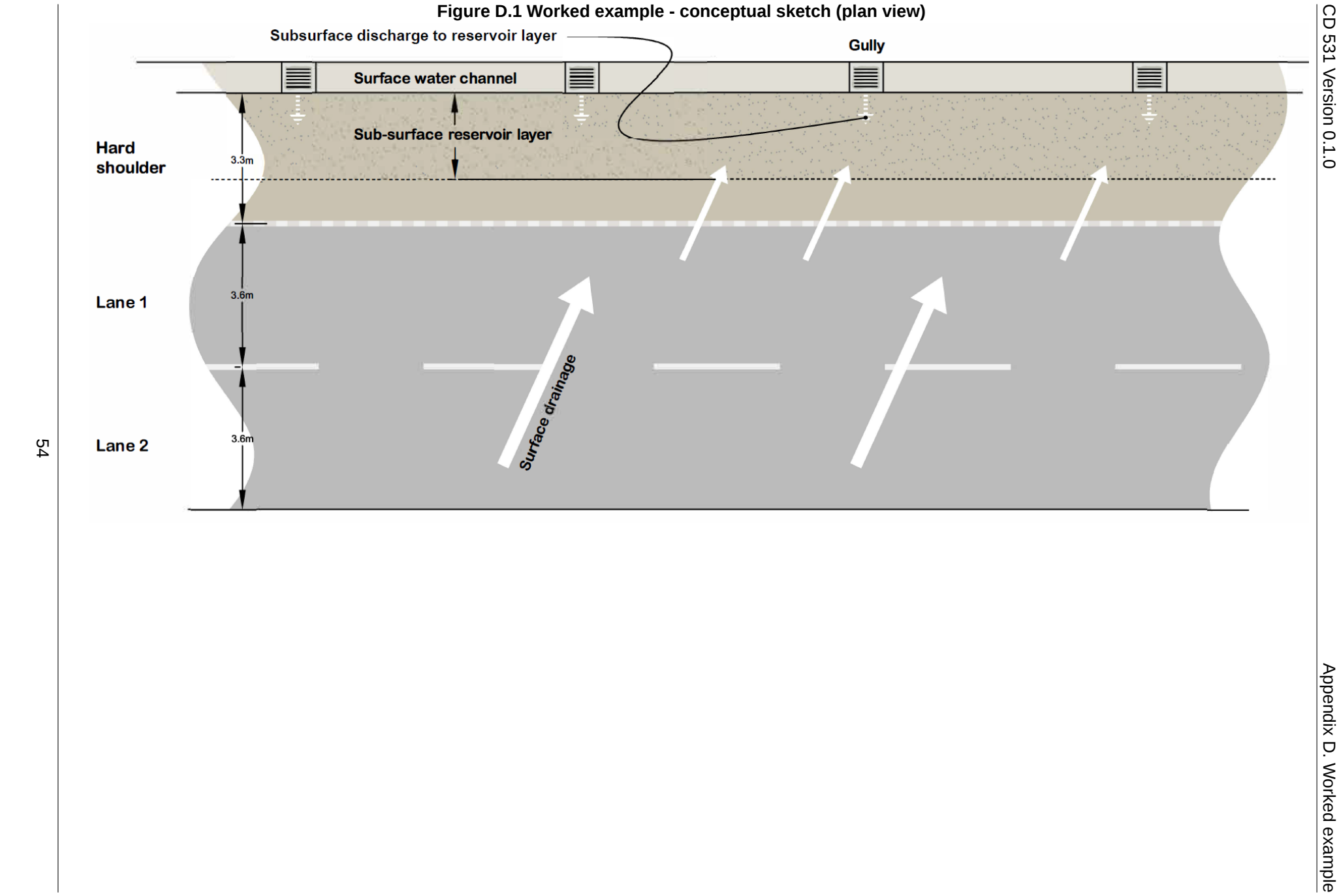
Road surfacing design will be dictated by traffic requirements, not covered in this example.

Table D.6 Depth of subbase calculations: determination of hmax – all storm durations

Storm Durations (mins)	Storm Durations (hours)	Avg Intensity (mm/h)	i Avg Intensity (m/h)	q Infiltration Rate (m/s)	Factored q	Infiltration Rate (m/h)	h max (m)	h max (mm)
15	0.25	62.33	0.062	0.000045	0.0000045	0.0162	0.205	204.7
30	0.5	39.87	0.040	0.000045	0.0000045	0.0162	0.252	252.1
60	1	24.8	0.025	0.000045	0.0000045	0.0162	0.293	293.2
120	2	14.95	0.015	0.000045	0.0000045	0.0162	0.311	310.6
240	4	8.85	0.009	0.000045	0.0000045	0.0162	0.280	279.6
360	6	6.48	0.006	0.000045	0.0000045	0.0162	0.220	220.3
480	8	5.4	0.005	0.000045	0.0000045	0.0162	0.173	172.8
600	10	4.32	0.004	0.000045	0.0000045	0.0162	0.065	64.8
720	12	4.02	0.004	0.000045	0.0000045	0.0162	0.027	26.9
900	15	3.56	0.004	0.000045	0.0000045	0.0162	-0.062	-61.8
1080	18	3.11	0.003	0.000045	0.0000045	0.0162	-0.189	-188.6
1440	24	2.2	0.002	0.000045	0.0000045	0.0162	-0.557	-556.8

Table D.7 Determination of time to empty to 50% storage volume

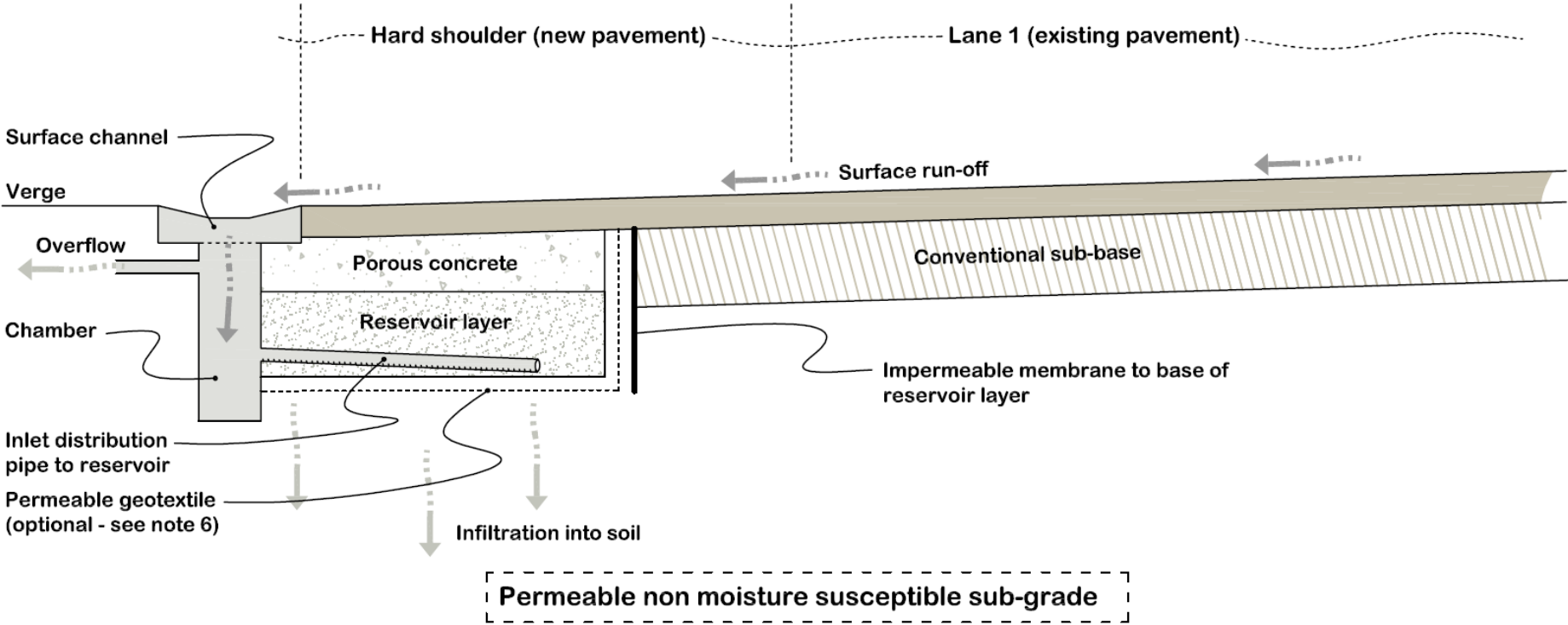
Rainfall (m)	Total Paved Area (m ²)	Internal Storage Area (m ²)	Volume of Rainfall (m ³)	Volume of Outflow (m ³)	Clearance Time (h)	Required Storage Volume (m ³)	Available Storage (m ³)
0.015583	10500	2500	163.6163	10.125	1.89	153.4913	262.5
0.019935	10500	2500	209.3175	20.25	2.33	189.0675	262.5
0.0248	10500	2500	260.4	40.5	2.71	219.9	262.5
0.0299	10500	2500	313.95	81	2.88	232.95	262.5
0.0354	10500	2500	371.7	162	2.59	209.7	262.5
0.03888	10500	2500	408.24	243	2.04	165.24	262.5
0.0432	10500	2500	453.6	324	1.60	129.6	262.5
0.0432	10500	2500	453.6	405	0.60	48.6	262.5
0.048206	10500	2500	506.16	486	0.25	20.16	262.5
0.053443	10500	2500	561.15	607.5	-0.57	-46.35	262.5
0.055954	10500	2500	587.52	729	-1.75	-141.48	262.5
0.0528	10500	2500	554.4	972	-5.16	-417.6	262.5



Notes:

Various edge drain types might be used, including surface water channels, kerb and gully and linear drainage channels; Combined channel and pipe systems may also be possible. Measures for entrapping sediment are to be included in the design of the edge drainage before water is introduced into the reservoir layer.

Figure D.2 Worked example - conceptual sketch (sectional view)



Notes:

- 1) existing foundation and pavement of dense materials.
- 2) new pavement depth to match existing pavement.
- 3) porous concrete provides additional storage; thickness in accordance with Table 5.16.
- 4) greater thickness in the reservoir layer may be used to decrease width.
- 5) example not applicable in low permeability and/or moisture susceptible sub-grades, or where shallow groundwater is encountered.
- 6) Permeable geotextile can be required to prevent contamination of reservoir layer by fines in the subgrade.

Appendix E. Pervious asphalt and concrete: terminology, classification and material properties

E1 Terminology and classification

The advice applied to alternative and standard designs is based on TRL 615 [Ref 10.N]. In that report, design stiffness values and terminology for material designations refer to the traditional UK national specifications used prior to 2004, applicable at the time that report was published. Since the methodology described in TRL 615 [Ref 10.N] was developed, the following changes have taken place:

- 1) harmonisation of European Standards in 2006 that required changes in material composition and designation; and,
- 2) revision in 2006 of DMRB HD 26 that redefined the standard UK conventional pavement materials.

In the European terminology now adopted BS EN 13108-1 [Ref 1.N] requires that asphalt mix designation consists of four sections:

- 1) mixture type;
- 2) upper aggregate sieve size in mm;
- 3) layer type; and,
- 4) binder grade.

For example, dense (low permeability) asphalt concrete with maximum aggregate size 20 mm for binder course with paving grade bitumen, grade 100/150 is designated as "AC 20 dense bin 100/150". This description would have been previously designated as "0/20 mm DBM 125 binder course" or "0/20 DBM 125", or similar.

As European specifications for hydraulically bound materials now apply, the use of the traditional material designations and terminology should be related to those materials under the European specification.

TRL 615 [Ref 10.N] provides designs for cement-bound material bases, CBM grades: CBM3, CBM4 and CBM5 based on the previous terminology. The use of these types of material are now covered by BS EN 14227-1 [Ref 25.N] and are referred to as Cement Bound Granular Material (CBGM).

Equivalence between these two systems of characterisation, shown in Table E.1 below is described in Appendix E of TRL 615 [Ref 10.N]. The European specifications make no distinction between the thermal properties of the aggregates used in CBGM.

These properties, however, remain an important part of the design process. Therefore, for a given strength class, the type of aggregate used (gravel – G and crushed rock – R) should still be declared for design as shown in Table E.1.

Table E.1 Design classifications

Traditional Material Class (after Nunn)	CBGM Strength Class (after BS EN 13108-1)
CMB3(G)	C8/10(G)
CBM3(R)	C8/10 (R)
CBM4(G)	C12/15(G)
CBM4(R)	C12/15(R)
CBM5(G)	C16/20(G)
CBM5(R)	C16/20(R)

E2 Material properties

Table E.2 provides a comparison of the stiffness values adopted prior to and following the release of CD 226 [Ref 3.N].

Table E.2 Comparison of the dynamic modulus of pervious and dense (low permeability) graded asphalt

Material	Dynamic modulus (GPa)
Standard values used in UK conventional pavement design prior to the 2006 edition of DMRB HD 26	
Dense bitumen macadam (DBM100)	3.1
Hot rolled asphalt (HRA50)	3.5
Dense bitumen macadam (DBM50)	4.7
Heavy duty macadam (HDM50)	6.2
Thin surface course system (TSCS)	2.0
Porous asphalt (PA)	2.0*
	* Value in common use
Standard values currently used in UK conventional pavement design following the 2006 edition of DMRB HD 26	
DBM125	2.5
HRA50	3.1
DBM50/HDM50	4.7
EME2	8.0

Guidance on the properties of grades of cement bound materials (CBMs) with gravel aggregate (G) and porous concrete is given in Table E.3 for an age of 28 days. Porous concrete can be seen to have a 28-day flexural strength between 1.0 to 3.8 MPa. These values are less than the range of 5 to 7 MPa for conventional pavement quality concrete but encompass the flexural strengths of CBM3G, 4G and 5G.

Table E.3 Mechanical properties of porous concrete and dense (low permeability) graded CBMs at 28 days

Material	Compressive Strength (MPa)	Flexural Strength (MPa)	Dynamic Modulus (GPa)
CBM3G	12.5	1.38	30.3
CBM4G	18.75	2.06	36.1
CBM5G	25	2.75	40.3
Porous concrete (range)	3.5 to 28*	1.0 – 3.8*	25 to 45**
Porous concrete (typical)	17.0*	2.5*	38**
* Values given by the American National Ready Mix Concrete Association			
** Determined using equation E 1 below. All other values are standard values used in UK conventional pavement design			

References for typical values of dynamic modulus of porous concrete are not found in the literature, hence it was assumed that the dynamic modulus of this material could be calculated from its flexural

strength. The relationship between elastic stiffness and flexural strength for concretes containing various aggregates are shown graphically by Croney 1997 [Ref 18.I].

TRL 615 [Ref 10.N] represented these relationships for traditional CBMs with gravel aggregate in the UK conventional pavement design method of TRL LR 1132 [Ref 20.I] by the following equation:

Equation E.1 Relationships for traditional CBMs with gravel aggregate in the UK

$$E = \frac{\log(f_f) + 0.77}{0.00301}$$

where:

- f_f the flexural strength (MPa)
- E the dynamic modulus (GPa)

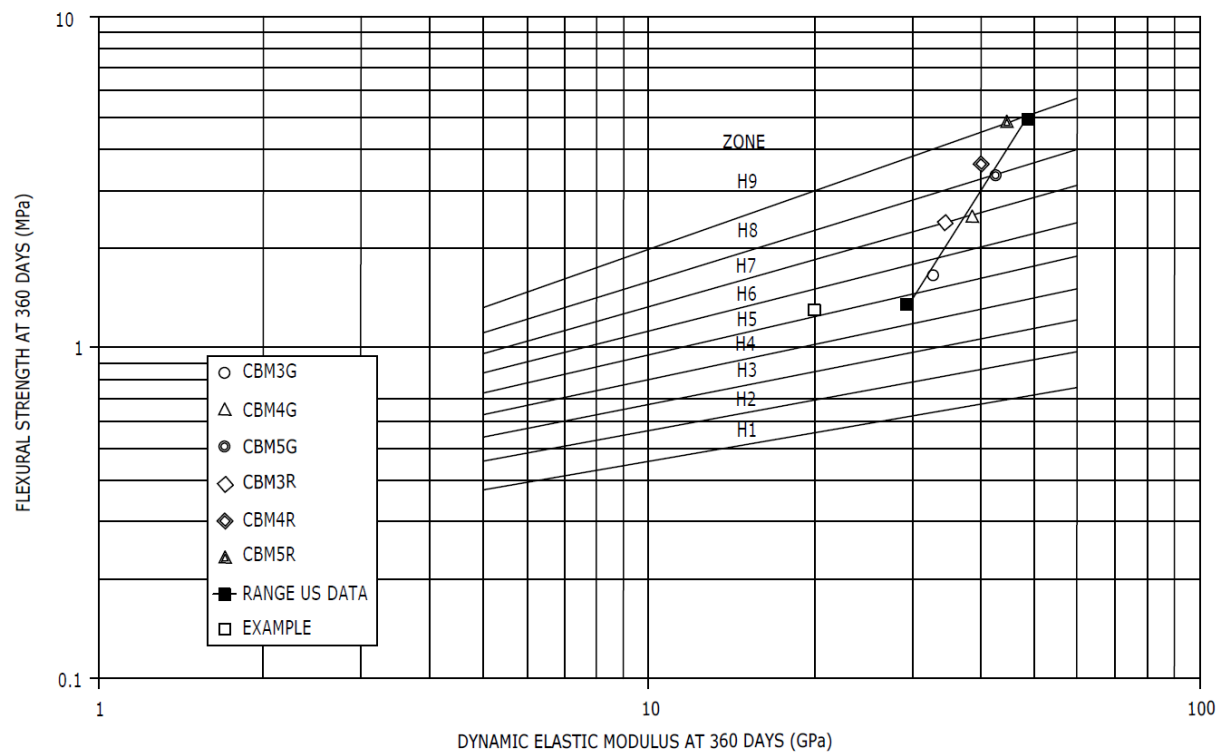
For porous concrete, the relationship between flexural strength and dynamic modulus may differ from that of traditional CBM materials and should be derived for more precise designs.

Table E.3 suggests that a porous concrete can be designed to at least achieve the properties of CBM3G and that it may be possible to achieve comparability with the higher strength grades. With hydraulically bound road base, it is desirable to have a high flexural strength and a relatively low modulus, as a material with a high modulus attracts stress.

The function of the depth of asphalt road surfacing in a flexible conventional pavement with CBGM base is primarily to delay the onset of reflection cracking and is dependent on the design traffic. As there is less shrinkage with porous concrete (see CIRIA R156 [Ref 9.I]), it is not necessary to construct porous concrete road surfacing with construction joints. Consequently, transverse cracks may not develop so readily in porous road surfacing.

Relationships between dynamic elastic modulus and flexural strength have been developed LA 113 [Ref 18.N] for equivalent performance and grouped into nine zones of hydraulically bound base (H1 to H9). These zones are shown in Figure E.1.

Figure E.1 Classes of hydraulically bound materials



The range of values for the flexural strength and estimated dynamic stiffness of porous concrete given in Table E.3, suggest that it could be characterised as a Zone H4 material for the weakest material up to Zone H8 material for the stronger end of the range. The mean values for porous concrete used in the USA (see the mid-point of the range shown in the chart and typical values from Table E.3) suggest that it is possibly a Zone H7 material.

With no measurements available for the dynamic modulus of porous concrete, it is suggested that porous concrete should be limited to a Zone H5 material for design purposes until further experience is gained. In a similar way, other HBMs can be conservatively assigned a strength/stiffness zone. The thicknesses of the HBM bases are then derived using the process described in Appendix C of TRL 615 [Ref 10.N]. Using the process, which is given in Figure C1 of that report, automatically accounts for the use of porous instead of dense (low permeability) asphalt. The assigned values are given in Chapter 3 of TRL 615 [Ref 10.N].

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Drainage
General Information

CG 501

Design of highway drainage systems

(formerly HD 33/16, TA 80/99)

Version 2.1.0

Summary

This document contains the over-arching requirements for drainage design on highways.

Feedback and Enquiries

Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated National Highways team. The email address for all enquiries and feedback is: Standards_Enquiries@highwaysengland.co.uk

This is a controlled document.

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Latest release notes

Document code	Version number	Date of publication of relevant change	Changes made to	Type of change
CG 501	2.1.0	August 2022	Core document	Incremental change to requirements
Mainly various corrections to Sections 3 (reflecting former HD 33/15 content; clauses 3.16 to 3.19), and 7 (clauses 7.5 to 7.7). Several editorial and drafting rules compliance corrections.				

Previous versions

Document code	Version number	Date of publication of relevant change	Changes made to	Type of change
CG 501	2.0.0	March 2020		
CG 501	1	December 2019		
CG 501	0	October 2019		

Foreword

Publishing information

This document is published by National Highways.

This document supersedes CG 501 revision 2.

Contractual and legal considerations

This document forms part of the works specification. It does not purport to include all the necessary provisions of a contract. Users are responsible for applying all appropriate documents applicable to their contract.

Introduction

Background

This document sets out requirements and provides recommendations on the design of drainage for the UK motorway and all-purpose trunk roads. It describes the various alternative drainage solutions that are available, including their potential to control pollution and flooding, as well as detailed design factors to be taken into account.

Road drainage can be broadly split into two categories: surface and sub-surface drainage. Generally speaking, road surfacing materials are effectively impermeable, and rainfall which does not permeate the carriageway surface is shed towards the edges of the pavement and into surface water drainage systems. Surface water can also infiltrate into road foundations, earthworks or structures through any surface which is not completely impermeable, and as such sub-surface drainage is utilised to allow such water to drain through underlying pavement layers and away from the formation.

The types of drainage discussed in this standard are one element of road drainage. Other elements include:

- 1) outfalls and culverts - see DMRB CD 529 [Ref 4.N];
- 2) soakaways - see CD 530 [Ref 2.I];
- 3) reservoir pavements - see CD 531 [Ref 8.I];
- 4) sumpless gullies - see CD 527 [Ref 9.I];
- 5) chamber tops and gully tops - see CD 534 [Ref 1.I];
- 6) certification of drainage design - see CG 502 [Ref 21.N].

Surface drainage is achieved through collection of surface water runoff from the pavement (and potentially adjacent land) through formal (such as through kerbs and gullies) or informal (over the edge) drainage, discharging into longitudinal surface channels or piped systems.

Sub-surface drainage is achieved by installation of longitudinal sub-surface drains situated in verges and/or central reserves at the low edges of road pavements. These drain the pavement layers and the pavement foundation (pavement and capping layers are contiguous with the side of the trench) and prevent ingress of water from verge areas adjacent to the pavement.

Drainage designs may utilise combined systems (where both surface water and subsurface water are collected in the same pipe) or separate systems (where subsurface water is collected in a separate drainage conduit from the one that is used for collection of surface water).

Assumptions made in the preparation of this document

The assumptions made in GG 101 [Ref 14.N] apply to this document.

Mutual Recognition

Where there is a requirement for compliance with any part of a "British Standard" or other technical specification, that requirement may be met by compliance with the Mutual Recognition clause in GG 101 [Ref 14.N].

Abbreviations and symbols

Abbreviations

Abbreviation	Definition
EQS	Environmental Quality Standard
FPL	Flow path length
GWQS	Groundwater Quality Standard
NG	Notes for Guidance (in MCHW)
PAHs	Polycyclic aromatic hydrocarbons
PCD	Pollution control device
PCS	Pollution control sign
SuDS	Sustainable drainage systems
VRS	Vehicle restraint system
WFD	Water Framework Directive

Symbols

Symbol	Definition
FL	flow control
F	fin drain
GSWC	grassed surface water channel
NF	narrow filter drain
O	other pollution control mechanisms
S	spillage control
SW	surface water channel
V	vegetated systems
X	removal of pollutants likely to occur but insufficient evidence available to quote indicative treatment efficiency

Terms and definitions

Term	Definition
Catchpit	small chamber that road runoff passes through, incorporating sediment collection sump
Combined kerb and drainage channel	kerb units with inlets to an enclosed internal drainage channel
Combined pipe and channel drain	open concrete channel with an integral enclosed drainage channel or pipe below it
Combined surface and sub-surface drain	system of filter drainage that comprises a perforated, porous or open-jointed carrier pipe, bedded in granular material, in a trench that is then backfilled with a granular filter material of Type A, B or C as defined in MCHW Series 0500 [Ref 15.N].
Crossfall	the slope on the road at right angles to the direction of travel
Crown line	the line on the road where the crossfall changes
Detention basin	landscaped depression that is normally dry except during and following rainfall events, designed to temporarily store water to attenuate flows and, where vegetated, provide treatment of pollution
Fin drain	a planar geocomposite arrangement designed to remove subsurface moisture from beneath the pavement NOTE: This can solely comprise a core surrounded by textile, or incorporate a pipe within the geotextile wrap.
First flush	the runoff from the first part of a rainfall event NOTE: This usually is the most polluted runoff, especially when there is intense rainfall after long dry periods during which pollutants can accumulate on the road.
Flood plain	any land with a 1 in 100 or greater annual probability of river flooding, or a 1 in 200 or greater annual probability of sea flooding
Flow path	the route taken by rainfall runoff from the point at which it falls on the carriageway surface to the carriageway edge
Flow path gradient	the overall net gradient produced from a combination of the longitudinal gradient and crossfall gradient (when changing from a superelevated carriageway to non-superelevated carriageway)
Grassed surface water channel	grassed triangular or trapezoidal surface water channel that is installed at the pavement edge to collect and convey rainfall runoff from the road surface

(continued)

Term	Definition
Groundwater	all water that is below the surface of the ground in the saturation zone (below the watertable) and in direct contact with the ground or subsoil
Handstop	flat plate, fitted to a pair of guide slots on a headwall or chamber wall, which can be raised and lowered manually (rather than screw thread as per penstocks)
Hard shoulder	a nearside lane adjacent to a carriageway, for emergency use
Hazardous substance	substances or groups of substances that are toxic, persistent and liable to bioaccumulate, and other substances or groups of substances that give rise to an equivalent level of concern NOTE: In accordance with the 2000/60/EC [Ref 3.I].
High watertable level	maximum permitted level of the groundwater table beneath the road sub-formation
Infiltration basin	dry basin designed to promote infiltration of surface water into the ground
Informal drain (over the edge)	an arrangement where surface water flows off the carriageway and across the verge to a drainage system, usually a ditch
Kerb and gully drainage	system of drainage whereby surface water is directed by edge of pavement kerbs into gullies that are connected to a longitudinal carrier drain or pipe set within the road verge
Linear drainage channel	closed profile hydraulic conduit with slots or holes located in the top
Narrow filter drain	edge-of-pavement subsurface drain that comprises filter material and a carrier pipe, which can be wrapped in a geotextile
Penstock	flat plate, fitted to a pair of guide slots on a headwall or chamber wall, which can be raised and lowered using a screw thread operated by a wheel, in order to control spillages
Pollution	direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land that can be harmful to human health or the quality of aquatic ecosystems (or terrestrial ecosystems directly depending on aquatic ecosystems) which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment. NOTE: In accordance with the 2000/60/EC [Ref 3.I].
Pervious asphalt	asphalt material used to make pavement layers pervious with open voids to allow water to pass through.

(continued)

Term	Definition
Reasonably practicable	<p>Something that is achievable without disproportionate level of complexity or having an impact on other design elements or construction, installation or maintenance of those elements.</p> <p>NOTE: Issues for consideration can include sewer capacity, maintenance responsibilities, capital and maintenance costs .</p>
Reservoir pavement	<p>pavement where rainfall percolates through the pervious road surfacing, or runoff is diverted via gullies, edge drains and pipes into a porous subbase material (reservoir)</p> <p>NOTE: Here, rain water accumulates before it slowly percolates into the soil subgrade or discharges through drains into the main surface water drainage system.</p>
Retention pond	<p>pond that generally retains some water at all times. Can have permeable base or banks. Primarily designed to attenuate flows by accepting large inflows, but discharging slowly. Can also treat water by allowing suspended solids to settle out.</p>
Roll-over lengths	<p>lengths of carriageway where the crossfall is varied for the provision/purpose of superelevation</p>
Sedimentation tank	<p>Contained structure that allows suspended particles to settle out of water as it flows slowly through the tank, providing a degree of purification</p> <p>NOTE: A layer of accumulated sludge collects at the base of the tank and needs periodic removal.</p>
Soakaway	<p>subsurface structure into which surface water is conveyed and which aids infiltration</p>
Source protection zone	<p>zones designated around public water supply abstractions and other sensitive receptors that show the risk of contamination from any activities that can cause pollution in the area</p>
Superelevated carriageway	<p>carriageway with a curved horizontal alignment where the crossfall slopes towards the inside of the bend</p>
Surface water body	<p>inland waters (except groundwater), transitional waters and coastal waters</p> <p>NOTE: In accordance with the 2000/60/EC [Ref 3.I].</p>
Surface water channel (including channel blocks)	<p>triangular, trapezoidal or rectangular cross-section channel, formed from asphalt or concrete, located near the edge of the carriageway, used to collect and convey surface water from the road</p>
Swale	<p>wide shallow grassed channel, normally located adjacent to a carriageway but often separated by a section of verge</p>

(continued)

Term	Definition
Wetland	a pond with a high proportion of shallow zones that promote the growth of bottom-rooted plants, and which can be used for treatment of pollution
Wide carriageway	Wide carriageways have layouts with dual, 4-lane carriageways. For 2- and 3-lane carriageways, junction areas and changes of superelevation are wide carriageways.

1. Scope

Aspects covered

- 1.1 The methods and design requirements in this document shall be applied where the design of new drainage is undertaken.

Implementation

- 1.2 This document shall be implemented forthwith on all schemes involving design of drainage on the Overseeing Organisations' motorway and all-purpose trunk roads according to the implementation requirements of GG 101 [Ref 14.N].

Use of GG 101

- 1.3 The requirements contained in GG 101 [Ref 14.N] shall be followed in respect of activities covered by this document.

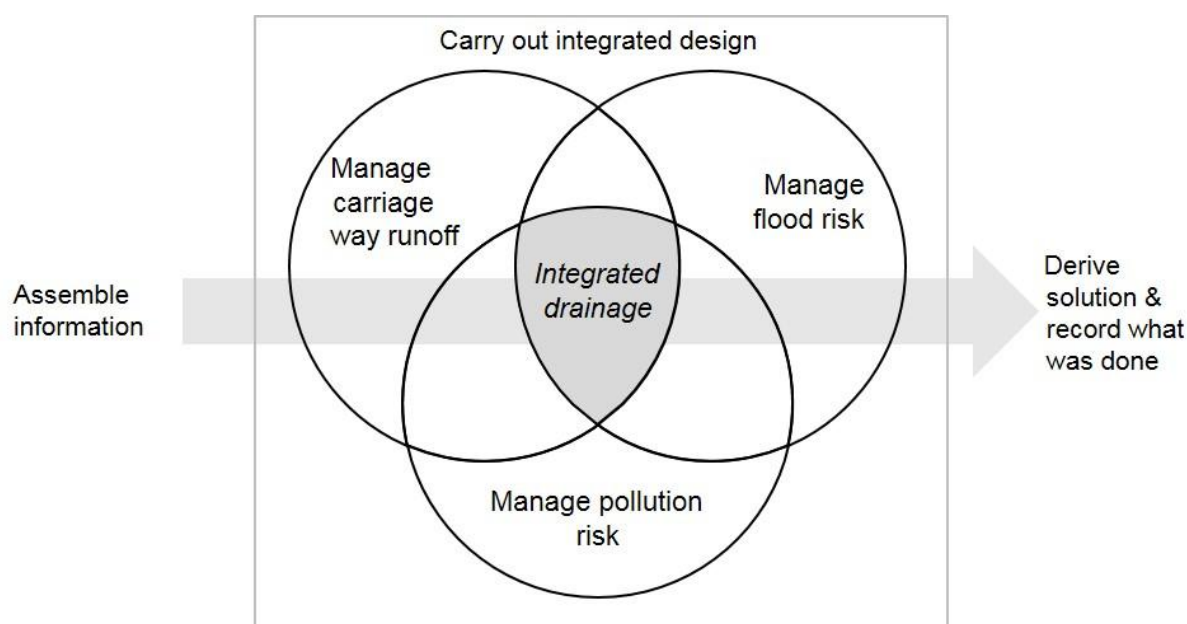
2. Design principles

Background

- 2.1 The design of surface and sub-surface drainage in UK motorway and all-purpose trunk roads shall:
- 1) remove surface water from the carriageway as quickly as possible to provide safety and minimum nuisance to the road users;
 - 2) maximise longevity of the pavement and its associated earthworks;
 - 3) minimise the impact of the runoff on the receiving environment in terms of flood risk and water quality; and,
 - 4) manage water flows from earthworks and structures associated with the roads.
- 2.2 Designs must be undertaken in accordance with the Construction (Design and Management) Regulations SI 2015/51 (CDM Regs) [Ref 11.N].
- 2.3 Drainage design shall be integrated such that drainage of the road, water quality and flood risk simultaneously meet the requirements given in the remainder of the Design Manual for Roads and Bridges (DMRB).

NOTE 1 The process of integrated drainage design is illustrated in Figure 2.3.N1.

Figure 2.3N1 Integrated design approach



NOTE 2 Requirements for the design of surface and sub-surface drainage are presented in:

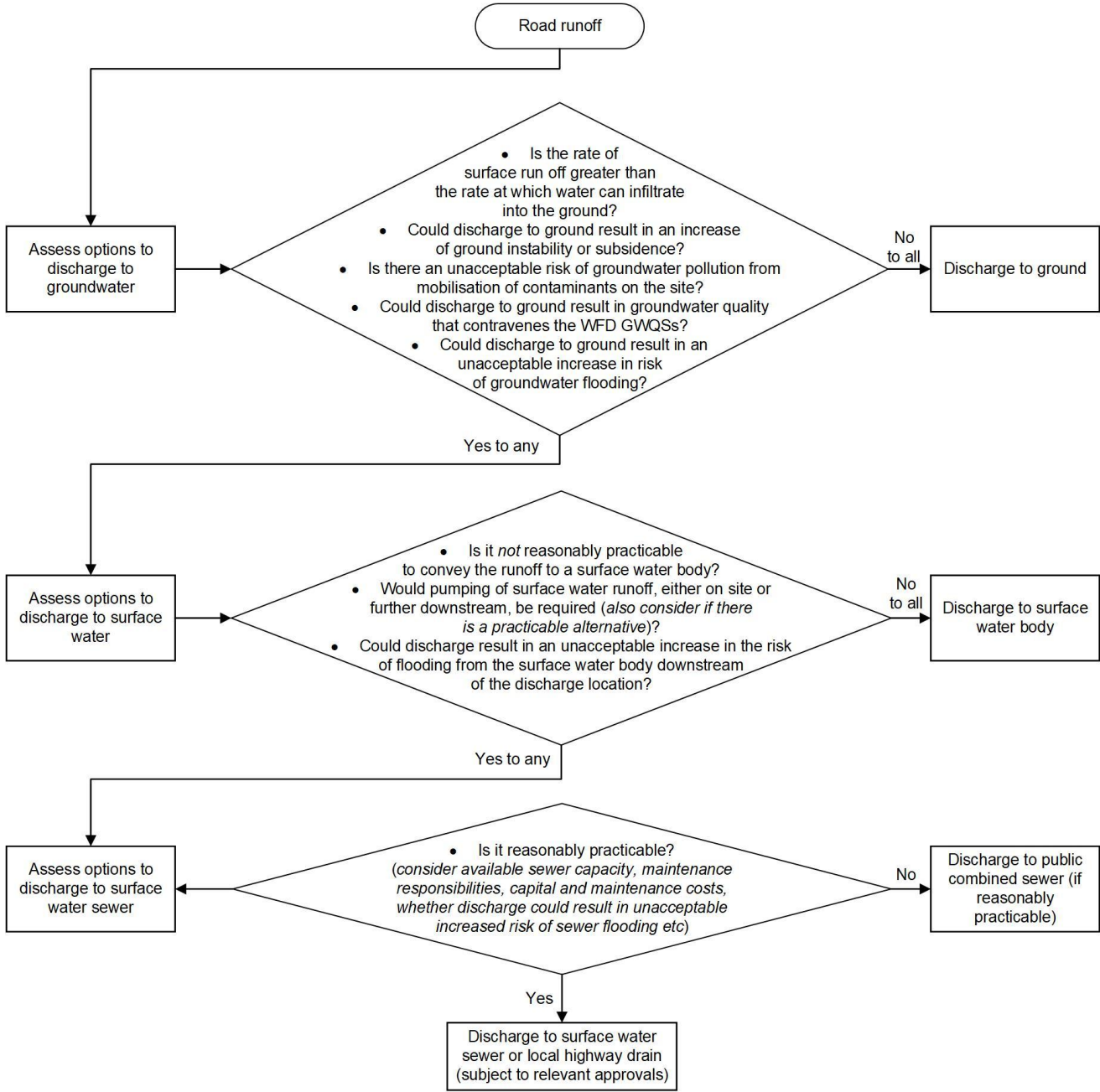
- 1) this document;
- 2) the reference documents listed in Table 3.4;
- 3) MCHW Series 0500 [Ref 15.N];
- 4) MCHW Series NG 0500 [Ref 7.I];
- 5) Section 1, Drainage of Volume 3 MCHW HCD Series F [Ref 17.N];
- 6) Section 1, Edge of Pavement Details of Volume 3 MCHW HCD Series B [Ref 16.N];
- 7) CD 523 [Ref 6.N] Determination of pipe roughness and assessment of sediment deposition to aid pipeline design;
- 8) CD 533 [Ref 5.N] Determination of pipe and bedding combinations for drainage works;

- 9) *CD 525 [Ref 3.N] Design of combined surface and sub-surface drains and management of stone scatter;*
- 10) *LA 113 [Ref 18.N] Road drainage and the water environment;*
- 11) *CD 521 [Ref 13.N] Hydraulic design of road edge surface water channels and outlets; and,*
- 12) *CD 524 [Ref 9.N] Edge of pavement details.*

Destinations for road runoff

- 2.4 Road drainage shall be discharged to the following destinations in order of preference:
 - 1) ground;
 - 2) surface water body;
 - 3) surface water sewer; and,
 - 4) combined sewer.
- 2.5 The decision process that shall be followed when determining the destination for road drainage is presented in Figure 2.5.

Figure 2.5 Destination of road runoff - decision flowchart



NOTE 1 *Groundwater quality standards can vary over time and between the various Overseeing Organisations.*

NOTE 2 *The acceptability of different risks varies according to geographic location, and is site specific.*

2.6 Road drainage shall only be discharged into lakes, ponds, canals or reservoirs where a site-specific risk assessment produced in compliance with LA 113 [Ref 18.N] demonstrates that this represents no or minimal risk to the lake, pond, canal or reservoir.

2.6.1 Discharge of road drainage to ground within a groundwater source protection zone 1 (SPZ 1) should be avoided. (See Environment Agency LIT 7660 [Ref 10.I]) .

NOTE *Guidance on discharge of road drainage to ground within a SPZ 1 is given within LA 113 [Ref 18.N].*

2.6.2 Discharge of road drainage to ground within a groundwater Source protection zone 2 (SPZ 2) should be avoided (see LIT 7660 [Ref 10.I]) though the acceptance of such is likely to require less justification than within a SPZ 1.

2.7 Discharge of road drainage shall not be to a foul sewer.

2.8 Where the rate of surface water runoff is greater than the rate at which water is able to infiltrate into the ground, discharge to the ground shall be utilised to drain water within the capacity of the ground conditions.

2.9 Discharge to the ground shall not create an unacceptable risk of groundwater flooding, ground instability or groundwater contamination.

2.10 Where the rate of surface water runoff is greater than the rate at which water is able to infiltrate into the ground, the excess runoff shall be drained to surface water or sewer options in accordance with Figure 2.5.

2.10.1 When using the decision flowchart in Figure 2.5 the potential to use mitigation measures (such as flow attenuation or SuDS) should be evaluated.

General requirements

2.11 A document describing the technical basis of the drainage design shall be prepared and submitted to the Overseeing Organisation in accordance with CG 502 [Ref 21.N].

NOTE *Factors associated with baseline environment are site-specific and include catchment size, drained areas, runoff destination, space, topography, groundwater, soil permeability, existing drainage and sensitive receptors.*

2.12 The use of the decision flowchart in Figure 2.5, together with the justification for the outcomes of it, shall be recorded in the document describing the technical basis of the drainage design.

2.12.1 The drainage design should be carried out early in the design process for a project.

2.13 All drainage designs shall incorporate safety measures as required by CD 521 [Ref 13.N], CD 524 [Ref 9.N], CD 525 [Ref 3.N] and CD 532 [Ref 24.N].

NOTE *CD 532 [Ref 24.N] includes details of safety risk assessments and mitigation measures for open bodies of water.*

2.14 Assessment of effects of road drainage on the water environment shall be carried out in accordance with LA 113 [Ref 18.N].

2.15 All documentation shall be managed in accordance with CD 535 [Ref 7.N].

3. Road drainage design selection

General

- 3.1 Detailed design of carriageway drainage shall identify the range of options and recommend the most suitable option based on site-specific constraints.

NOTE Table 3.4 presents guidance on the suitability of different types of road drainage in different scenarios and references the documents that contain detailed design advice and standards.

- 3.2 The design process shall determine:
- 1) the appropriate destination of road runoff (see Figure 2.5);
 - 2) the design storms to be used in the design of the drainage elements within the catchment under consideration;
 - 3) the flows from the design storms at each drainage element within the catchment, incorporating the necessary allowances for climate change;
 - 4) the hydraulic adequacy of each drainage element within the catchment;
 - 5) where necessary, the structural loadings upon drainage conduits, and verification that each conduit can withstand the loading placed upon it;
 - 6) the appropriate location and levels of associated outfalls and/or soakaways; and,
 - 7) where necessary, the incorporation of pollution and flood risk control measures.
- 3.3 Where excavation is required, the design of drainage systems shall include management of the excavated material to minimise waste and minimise risk to human health or the environment.
- 3.4 Justification shall be given for the system selected for drainage, based upon the requirements stated within this document.

Table 3.4 Surface, combined and sub-surface drainage types

Drainage collector detail		Urban applications	Rural applications	Scenarios not suitable for	Reference documents for detailed design requirements
Surface drainage	Combined pipe and channel drain	1) not generally applicable.	1) high- speed roads; 2) embankments where verge space is limited.	1) areas subject to equestrian use; 2) in front of a vehicle restraint system (VRS) if the flow depth is greater than 150 mm; 3) within the working width behind a VRS if the flow depth is greater than 200 mm.	CD 521 [Ref 13.N] CD 524 [Ref 9.N]
	Combined kerb and drainage channel	1) areas of congested public utility services; 2) shallow outlets; 3) flat long gradients; 4) roundabouts.	1) flat long gradients where footways are within highway verge; 2) roundabouts.	1) junction or stretch of road where maintenance would require road closure or complex traffic management requirements; 2) areas with leaf litter or where overhanging/dense vegetation is present.	CD 524 [Ref 9.N] CD 127 [Ref 1.N]

Table 3.4 Surface, combined and sub-surface drainage types (continued)

Drainage collector detail		Urban applications	Rural applications	Scenarios not suitable for	Reference documents for detailed design requirements
Surface drainage	Grassed surface water channels/swales	1) not generally applicable.	1) in verges for grassed surface-water channels; 2) on gently sloping embankments for swales; 3) on areas where there is over-the-edge drainage.	1) on central reserve if located at the pavement edge; 2) where the height of an embankment exceeds the width of a proposed channel (due to the risk of percolation destabilising the embankment slope); 3) within a groundwater SPZ (unless unacceptable risk of groundwater pollution); 4) in front of a VRS if the flow depth is greater than 200 mm; 5) within the working width behind VRS if the flow depth is greater than 200 mm.	CD 521 [Ref 13.N]
	Informal drainage (over the edge)	1) not generally applicable.	1) in verges; 2) embankments (but only where there is an open ditch or watercourse at the base of the embankment).	1) locations where footways or segregated cycleways abut carriageways; 2) on structures; 3) embankments constructed of clayey or silty soil or of depth greater than 1.0 m and slope steeper than 1:3 (33%).	CD 521 [Ref 13.N] CD 524 [Ref 9.N]

Table 3.4 Surface, combined and sub-surface drainage types (continued)

Drainage collector detail		Urban applications	Rural applications	Scenarios not suitable for	Reference documents for detailed design requirements
Surface drainage	Kerbs and gullies	1) general usage; 2) embankments.	1) footways within highway verge, such as in laybys; 2) roundabouts.	1) not recommended for rural roads unless footways are located within the verge, safety barriers or parapets are required, or continual surface and sub-surface drains are present; 2) where they can pose a hazard to pedestrian, cycle or equestrian crossings.	CD 127 [Ref 1.N] CD 524 [Ref 9.N] CD 526 [Ref 20.N]
	Linear drainage channels	1) car park areas; 2) adjacent to vertical concrete barriers; 3) nosings of interchanges.	1) nosings of interchanges.	1) in front of a VRS (when located in the verge or central reserve); 2) locations where frequent maintenance interventions are required; 3) areas subject to pedestrian and cyclist use (risk associated with slotted drains only); 4) areas with leaf litter or where overhanging/ dense vegetation is present; 5) areas subject to high sediment input.	CD 524 [Ref 9.N]

Table 3.4 Surface, combined and sub-surface drainage types (continued)

Drainage collector detail		Urban applications	Rural applications	Scenarios not suitable for	Reference documents for detailed design requirements
Surface drainage	Surface water channels (including channel blocks)	1) not generally applicable.	1) high-speed roads; 2) embankments; 3) cuttings.	1) edge drains contiguous with hard shoulders, hardstrips or carriageways (channel blocks); 2) areas subject to equestrian use; 3) in front of a VRS if the flow depth is greater than 150 mm; 4) within the working width behind VRS if the flow depth is greater than 200 mm.	CD 521 [Ref 13.N] CD 524 [Ref 9.N]
Com-bined	Combined surface and sub-surface drains	1) not generally applicable.	1) along edge of cuttings or within central reserve where groundwater levels have the potential to interfere with operation of a surface water drainage system or there is limited verge width; 2) roads with long lengths of zero longitudinal gradient.	1) central reserves in order to reduce health and safety risks during maintenance; 2) in narrow verges subject to use by equestrians.	CD 524 [Ref 9.N] CD 533 [Ref 5.N] CD 525 [Ref 3.N]

Table 3.4 Surface, combined and sub-surface drainage types (continued)

Drainage collector detail		Urban applications	Rural applications	Scenarios not suitable for	Reference documents for detailed design requirements
Sub-surface drainage	Fin drain	1) not generally applicable.	1) edge of pavement where groundwater ingress is not expected to be large.	1) roads comprising rigid or flexible carriageways with over the edge drainage; 2) roads with free draining subgrade; 3) areas where significant groundwater ingress is expected.	CD 524 [Ref 9.N]
	Narrow filter drain	1) not generally applicable.			CD 524 [Ref 9.N]

- NOTE 1** *Additional details on the advantages and disadvantages of these drainage types are presented in Appendix A. Tables 3.5.1 and 3.5.2 provide details of edge of pavement and central reserve drainage design options.*
- NOTE 2** *The general principle of highway drainage is that surface water and sub-surface water are kept separate as far as practically possible until the sub-surface water discharges to a chamber that connects to the carrier pipe. This is in order to prevent large amounts of water being introduced to the road pavement foundation, however the use of combined drainage is preferable in certain circumstances (see Combined drainage (below) and Table 3.4).*
- 3.5** Edge of pavement drains shall be included on all roads except the following, in accordance with CD 524 [Ref 9.N]:
- 1) roads with combined surface and sub-surface drains;
 - 2) roads comprising rigid or flexible carriageways with over-the-edge drainage; and,
 - 3) roads with free draining subgrade.
- 3.5.1** The decision processes presented in Table 3.5.1 may be used to determine the most appropriate edge of pavement drainage design.

Table 3.5.1 Recommended design selections for verge-side edge drainage

Kerbs (with gullies) necessary because of: a) footway within highway verge; b) urban conditions; or, c) other site-specific considerations?								
	Yes - kerbs (with gullies) required			No - kerbs (with gullies) not required				
Location	Road in cutting		Road on embankment	Road in cutting		Road on embankment		
Constraints	Groundwater problems	No groundwater problems	-	Groundwater problems	No groundwater problems	No verge restrictions	Verge restrictions	Low embankment of granular material
Primary design solution	Combined surface and sub-surface drain	NF drain with long, sealed, carrier drain	NF or F drains with separate gully connections	Combined surface and sub-surface drain	SW channel with F or NF drain	SW channel with F or NF drain	SW channel with F or NF drain	Informal over-the- edge drain
Alternative design solution	GSWC	GSWC	-	GSWC	GSWC	-	-	GSWC

NOTE *NF – narrow filter drain; F – fin drain; SW – surface water channel; GSWC - grassed surface water channel*

3.5.2 The decision processes presented in Table 3.5.2 may be used to determine the most appropriate central reserve drainage design.

Table 3.5.2 Recommended design selections for central reserve drainage

Location	Balanced carriageway		Superelevated carriageway	
	Paved	Unpaved	Paved	Unpaved
Central reserve				
Design solution	F or NF drain		SW channel and F or NF drain	
Alternative design solution	-	-	-	Combined surface and sub-surface drain

NOTE *NF – narrow filter drain; F – fin drain; SW – surface water channel.*

3.6 Where a pavement overlay is being installed over an existing pavement, the design of the overlay shall not compromise operation of existing pavement edge drainage.

3.7 The levels of gully grating and filter media on kerb and gully drains or combined surface and sub-surface drains shall be raised to match the new pavement level.

3.7.1 The edge of the overlay may be shaped to tie in with the top of surface water channels if it can be achieved without compromising the structural integrity of the pavement.

3.7.2 As an alternative to shaping the edge of the overlay, the existing drainage channel may be broken out and replaced at a higher level.

Surface water drainage design

3.8 Where surface water edge of pavement drainage is used it shall be designed in accordance with the requirements of these documents: CD 521 [Ref 13.N], CD 524 [Ref 9.N], CD 525 [Ref 3.N] and LA 113 [Ref 18.N].

Kerb and gully drainage

3.9 Kerb and gully drainage systems located within the nosing sections of junction merge and diverge tapers shall be designed to withstand trafficking of the hard shoulder.

NOTE *Locations such as the nosing sections of junction merge and diverge tapers commonly have low points in cross-section due to the direction of crossfalls.*

3.10 Where kerb and gully drainage is designed in combination with fin drains, it shall not have an adverse effect on fin drain operation.

NOTE 1 *Functioning of kerb and gully systems is dependent upon the build-up of a flow of water in front of the kerb.*

NOTE 2 *Flows of water against the kerb face generally increase in the direction of longitudinal gradient until the flow is intercepted by a road gully.*

NOTE 3 *Build-up of widths of water flow, which have the potential to intrude into the hard shoulder, hardstrip or carriageway of the highway present a hazard to vehicles.*

3.11 Gully spacing shall be designed in accordance with CD 526 [Ref 20.N].

NOTE *Details of acceptable flow widths are presented in CD 526 [Ref 20.N].*

3.11.1 For low embankments with toe ditches, gullies may discharge directly to the toe ditches via discrete outlets.

Combined drainage

- 3.12 Where combined surface and sub-surface drainage is used it shall be designed in accordance with the requirements of this document and CD 525 [Ref 3.N].

NOTE The requirements and advice on pipe and bedding combinations in combined surface and sub-surface drains is presented in CD 533 [Ref 5.N].

- 3.13 Surface treatment or stabilisation of combined surface and sub-surface drains shall be included in the design at locations where the risk of stone scatter occurring is greatest (refer to CD 525 [Ref 3.N]).

NOTE Potential risks associated with combined surface and sub-surface drains include surface failure of embankments and pavement failures.

- 3.13.1 To minimise surface water input at trench base level, the design of combined drainage for cuttings may include pipes with sealed joints and with perforations or slots laid uppermost.

- 3.13.2 Lining of trench bottoms with impermeable membranes up to pipe soffit level may be used to prevent infiltration of water from the drainage system into surrounding dry sub-soil or from polluting an underlying aquifer.

- 3.13.3 Separate design estimates for groundwater flow may not be needed when designing combined surface and sub-surface drainage for a cutting.

Sub-surface drainage design

- 3.14 Where sub-surface drainage is used it shall be designed in accordance with CD 524 [Ref 9.N].

- 3.15 The design of sub-surface drainage shall include shaping of the formation and sub-formation such that sub-surface water drains to longitudinal sub-surface drains.

- 3.16 Sub-surface water shall not be retained within the subbase or capping layer.

- 3.17 The minimum depth of installation of fin and narrow filter drains shall be as shown in Volume 3 MCHW HCD Series F [Ref 17.N] relative to formation level, or sub-formation level (as defined in Volume 1 MCHW Series 0500 [Ref 15.N]).

- 3.18 Where there is no capping layer, fin and narrow filter drains shall be laid to the lower of either formation or sub-formation level (as defined in Volume 1 MCHW Series 0500 [Ref 15.N]).

- 3.19 Drains shall maintain the water table level at least 300 mm below the road sub-formation level.

NOTE 1 High groundwater levels have the potential to interfere with the operation of surface water drainage systems.

NOTE 2 In situations where large volumes of groundwater are anticipated, filter drains can provide a better solution than fin or narrow filter drains.

- 3.20 The design of sub-surface drainage shall not contain any low spots where water can accumulate.

- 3.20.1 Use of 100 mm-diameter pipes within narrow filter drains, rather than pipes of smaller diameter, may reduce future maintenance costs.

- 3.21 The subbase shall be drained unless the underlying materials (capping or subgrade) are more permeable than the subbase, and the water table is never within 300 mm of the underside of the foundation (in accordance with CD 225 [Ref 2.N]).

Embankments and cuttings

- 3.22 Subsurface drainage in cuttings shall lower groundwater to a depth such that it does not have the potential to interfere with the operation of a surface water drainage system (in accordance with CD 525 [Ref 3.N]).

- 3.22.1 Circumstances in which subsurface drainage may be omitted are described in CD 524 [Ref 9.N].

Groundwater

3.23 Subsurface drainage shall function regardless of variations in groundwater level.

NOTE 1 Water moves partly by gravity and partly by capillary action, and these movements are susceptible to control by subsoil drainage.

NOTE 2 Groundwater is subject to seasonal variations consequential to rainfall conditions, geology and soil permeability.

3.23.1 Ground investigations undertaken to inform a drainage design should provide groundwater level data representative of worst case conditions.

4. Climate change

Climate change allowances

- 4.1

All scheme designs shall incorporate assessment of and mitigation against the potential impacts of climate change.
- 4.2

Drainage designs shall be developed on the basis that all new road drainage has a minimum design lifetime of 60 years, unless otherwise instructed by the Overseeing Organisation.
- 4.3

All scheme designs shall include the latest climate change allowances in accordance with relevant national policy.
- 4.4

For the design of carriageway drainage, calculation of a 20 % uplift in peak rainfall intensity together with a sensitivity test to 40 % uplift in peak rainfall intensity shall be undertaken and documented within the report describing the technical basis of the drainage design.
- NOTE

The difference between the 20 % and 40 % scenarios enables understanding of the range of impact between climate change risk scenarios.
- 4.5

The 20 % increase in peak rainfall intensity shall be the minimum increase accommodated by the carriageway drainage design.
- 4.6

Use of an increase in peak rainfall intensity of greater than 20 % in carriageway drainage design shall be subject to approval by the Overseeing Organisation.
- 4.7

Justification for the value of peak rainfall intensity chosen for the carriageway drainage design shall be given within the report describing the technical basis of the drainage design.
- 4.8

All scheme designs shall include assessment and minimisation of flood risk in compliance with the requirements set out in LA 113 [Ref 18.N].
- NOTE

This document, CG 501, addresses how the effects of climate change are dealt with as part of drainage design only.
- 4.9

In schemes that use existing outfalls current discharge rates shall not be exceeded.
- 4.10

All pavement edge drainage for collection of surface runoff plus the carrier pipes/conduits that convey that runoff shall be designed based on the rainfall experienced by the catchment in which the road is located.

5. Storm flows and flood risk

5.1 For road runoff within drainage systems the following overall design criteria shall apply:

- 1) 1 in 1 year – no surcharge of the drainage system; and,
- 2) 1 in 5 years – no flooding from the drainage system.

NOTE *This requirement applies to all types of road drainage.*

5.2 The requirements for various types of drainage, relating to 1-in-1 and 1-in-5 year storm events, as outlined in Table 5.2, shall be adhered to.

Table 5.2 Storm event requirements

Location/ drainage type	1-in-1 year storm requirements	1-in-5 year storm requirements
Carrier drains	Drain to accommodate flows in bore without surcharge over the crown of the pipe	Flows not to cause chamber surcharge levels to rise above the soffit of the chamber cover
Combined surface and subsurface drains	Drain to accommodate flows in bore without surcharge	Flows not to cause chamber surcharge levels to rise above the formation level, or subformation level where a capping layer is present
Surface water channels	Flows to be contained within the channel. no surcharge to take place	Surcharge not to encroach into the running lane
Verges	Surcharges for storms up to 1-in-5 year return period limited to a width of 1.5 m in the case of hard shoulder and 1.0 m in the case of hardstrip	
Central reserve	Surcharges for storms up to 1-in-5 year return period not to encroach the carriageway. Flooding within non-pavement width of the central reserve permissible providing there is safeguard against flows from the surcharged channel overtopping the central reserve and flowing into the opposing carriageway	

NOTE *For combined surface and sub-surface drains, 1-in-5 year storm requirements are based on the assumption that pipes are sealed and that flow between pipes and filter material does not take place.*

5.3 All drainage systems shall be designed so that highway surface water flooding does not extend beyond the highway boundary up to the 1-in-100 year rainfall event, including an allowance for climate change.

5.3.1 The risks associated with events that exceed the capacity of the drainage system should be evaluated and documented within the report describing the technical basis of the drainage design.

5.3.2 The design of the site and the drainage system should cope with events that exceed the design capacity of the system, so that excess water can be safely stored on or conveyed from the site without adverse impacts.

NOTE *The level of events that need assessment depends upon site-specific conditions and the consequences of such an event occurring. For further advice see CIRIA C753 [Ref 11.I] and CIRIA C688 [Ref 5.I].*

5.3.3 Analytical tools (for example software) utilised to calculate runoff flows from roads should model particular storm intensities and permit analysis of the system under surcharged conditions.

5.4 The assessment of flood risk both to a project and resulting from a scheme shall be undertaken in accordance with LA 113 [Ref 18.N].

6. Drainage from adjacent land

Drainage from adjacent land

- 6.1 Assessment of existing land drainage and runoff from catchments adjacent to the road pavement shall be included in the design of highway drainage in accordance with CD 522 [Ref 8.N].

NOTE *Runoff can be derived from land both within the overall highways boundary or external to it.*

New and existing connections

- 6.2 In order to ensure the integrity of road drainage systems, no new runoff that arises due to any change of use of land within the surface water catchment of the road shall be accepted into the drainage systems of motorways and all-purpose trunk roads.
- 6.3 No new connections from drainage systems of third party developments shall be permitted to enter the drainage systems of motorways and all-purpose trunk roads (see DfT Circular 02/2013 [Ref 22.N]).
- 6.3.1 Where there is an existing connection of external drainage to the road drainage, either historical or by agreement, the right of connection may be permitted by the Overseeing Organisation to continue provided that the input from the contributing catchment to the connection remains unaltered (see DfT Circular 02/2013 [Ref 22.N]).
- 6.3.2 Existing surface water flows from local authority side roads may continue where there is no alternative outfall, subject to agreement by the Overseeing Organisation.

Management of land drainage

- 6.4 Where it is not possible to avoid surface water and subsurface water from adjoining land flowing towards a road, that land drainage shall be managed in accordance with CD 522 [Ref 8.N].
- 6.4.1 Selection of the most appropriate edge of pavement drainage design may be undertaken using the decision process presented in Table 3.4.
- 6.4.2 During the choice of drainage system the potential for contaminated ground or groundwater to exist at or adjacent to the road should be assessed.

NOTE *Installation of drainage early in the construction process allows management of land drainage during construction.*

- 6.5 The potential effect of proposed drainage ditches on embankment or cutting slope stability shall be subject to geotechnical assessment.
- 6.5.1 In rural areas, ditches may be used to provide a more effective and efficient option than formal drains.

NOTE 1 *Offsetting of toe ditches from the base of slopes can aid maintenance of slope stability.*

NOTE 2 *Assessment of slope stability early in the design process can assist in identification of land acquisition requirements for the project.*

NOTE 3 *Offsetting of toe ditches could also have implications for the:*

- 1) choice of drainage solution;
- 2) management of adjacent land; and,
- 3) landscape design.

- 6.6 Where a road crosses an existing watercourse or ditch, the drainage design shall fulfil the requirements of LA 113 [Ref 18.N], CD 522 [Ref 8.N] and CD 529 [Ref 4.N].

7. Road geometry

- 7.1 The design of road geometry shall enable the drainage of surface water runoff for any given length of carriageway.
- 7.2 The design of road geometry shall allow the discharge of subgrade drainage at levels above the design flood level for any given length of carriageway.
- 7.2.1 A coordinated analysis of the horizontal and vertical alignments with reference to surface water drainage should be carried out before alignments are fixed.
- NOTE** *The need to provide appropriate drainage can be a factor in the design height of embankments and design depth of cuttings.*
- 7.3 The construction tolerances permissible for road levels shall be assessed when producing a road surface design that can shed water as effectively as possible.

Drainage of superelevated carriageways

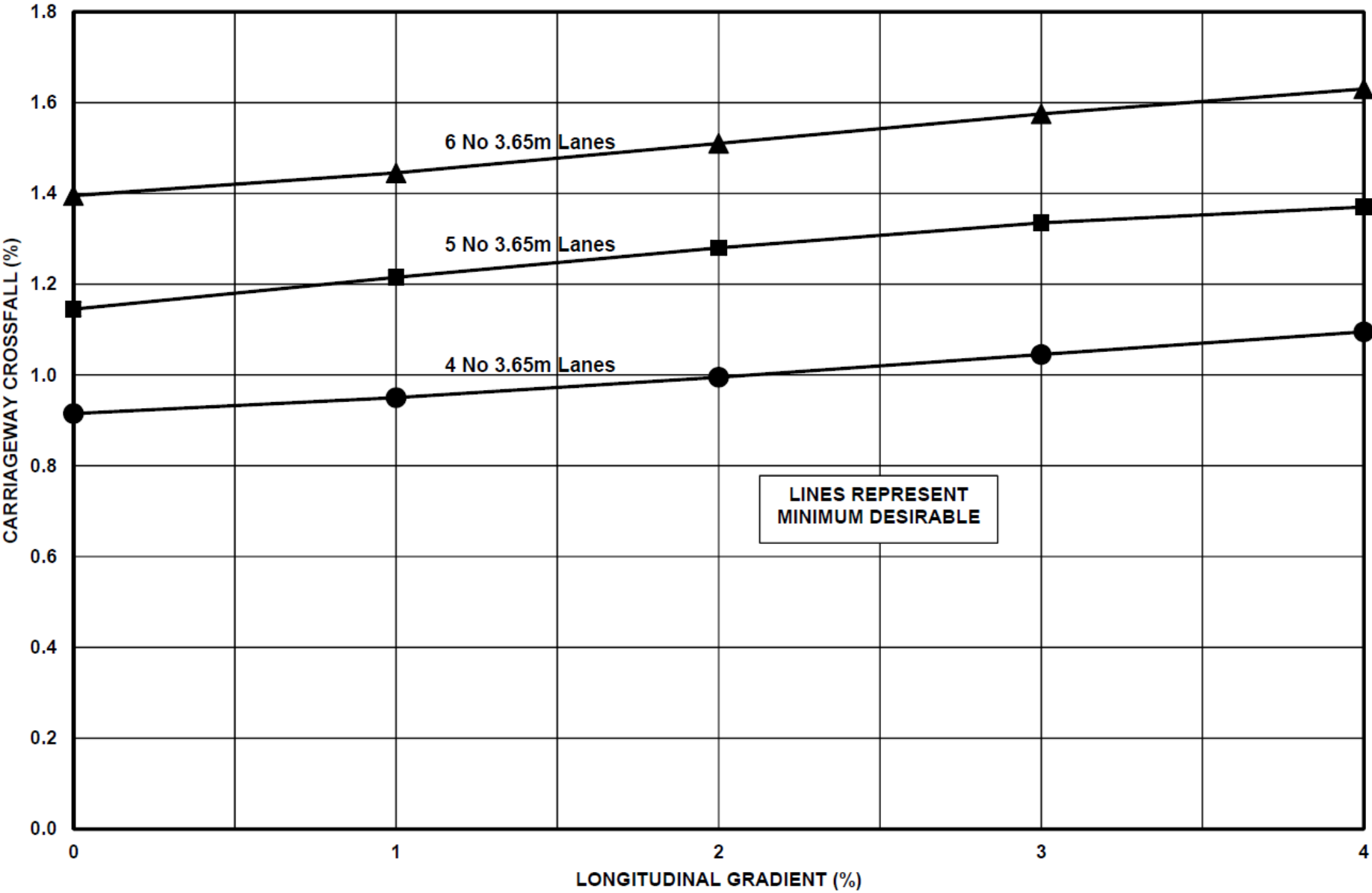
- 7.4 Superelevated carriageways shall be designed to adequately drain water from the carriageway.
- 7.4.1 A flow path gradient of at least 0.5 % may be used to facilitate drainage from superelevated carriageways (see CD 109 [Ref 12.N]).
- NOTE 1** *Where superelevation is applied or removed, the crossfall of a carriageway can be insufficient for drainage purposes without assistance from the longitudinal gradient of the road.*
- NOTE 2** *The flow path gradient of superelevated carriageways includes the effects of the application of superelevation acting against the gradient where superelevation is applied to a downhill gradient or removed on an uphill gradient.*
- 7.4.2 The superelevation area may be moved to a different location by revision of the horizontal alignment, increasing the variation in grade of the edge profile or applying a rolling crown (CD 109 [Ref 12.N]).
- NOTE** *Further advice on shedding of water from superelevated carriageways is provided in CD 109 [Ref 12.N] and CD 116 [Ref 6.I].*

Drainage of wide carriageways

Drainage flow paths

- 7.5 Wide carriageways shall be designed in accordance with the drainage design principles set out in Section 2.
- NOTE** *The requirements for drainage of carriageways and adjacent paved areas in storm events are given in Table 5.2.*
- 7.5.1 For lengths of carriageway with consistent geometry, the combinations of longitudinal gradient and crossfall that fall below the curves given in Figure 7.5.1 should be avoided.

Figure 7.5.1 Effect of geometric design on drainage



7.5.2 For lengths of carriageway with varying width and geometry, contoured plans of the carriageway surface should be generated in order to calculate local flow path lengths and gradients.

NOTE The flow path length is calculated from the edge of the paved area being assessed.

7.5.3 Flow path lengths and gradients may be checked by referring to Figures 7.5.3N2a and 7.5.3N2b.

NOTE 1 Flow path lengths can increase rapidly at low crossfalls.

NOTE 2 Roll-over lengths between superelevation areas are where low crossfalls occur and flow path lengths can be long.

Figure 7.5.3N2a Flow path lengths (4 no. 3.65 m lanes)

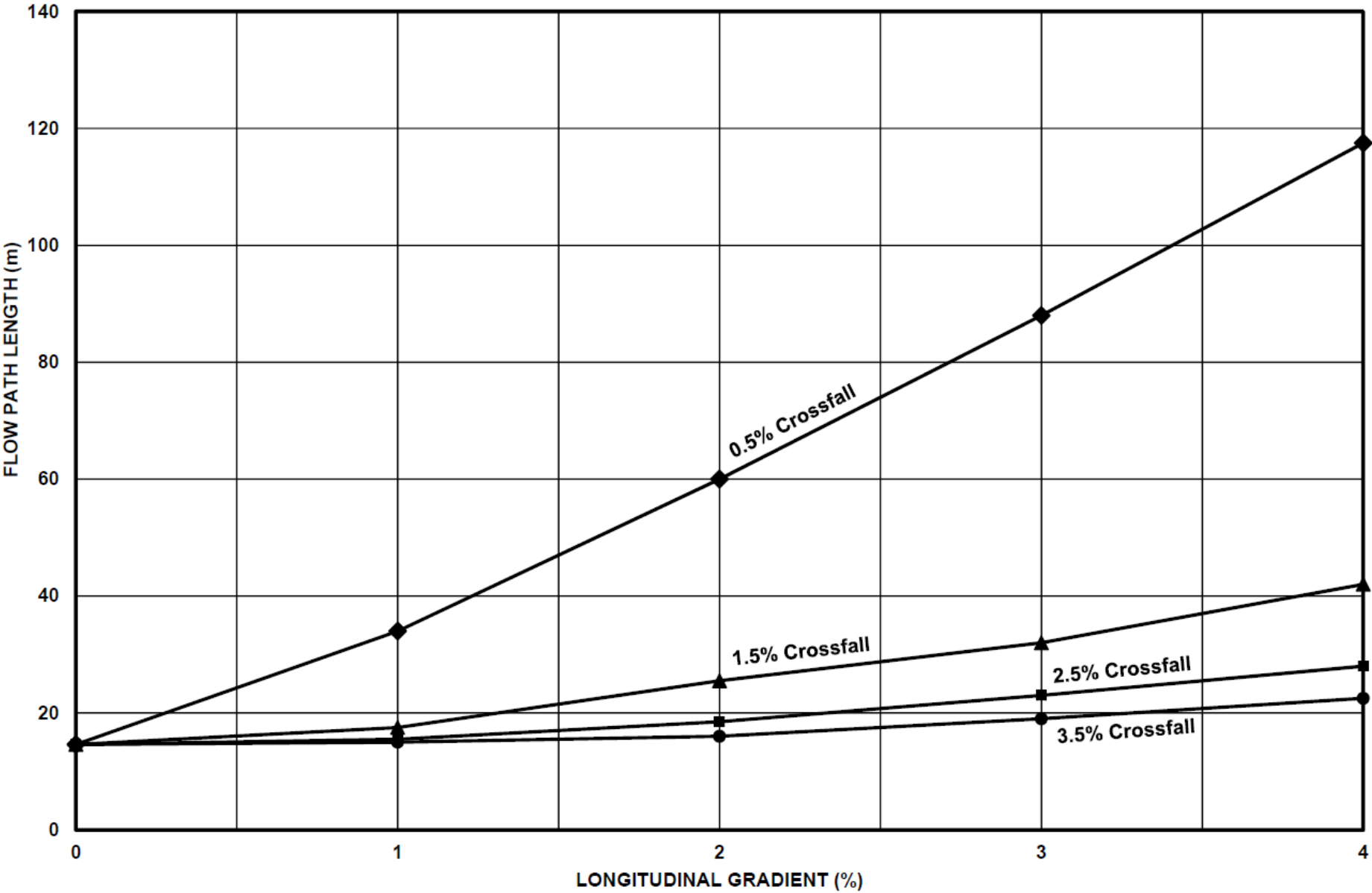
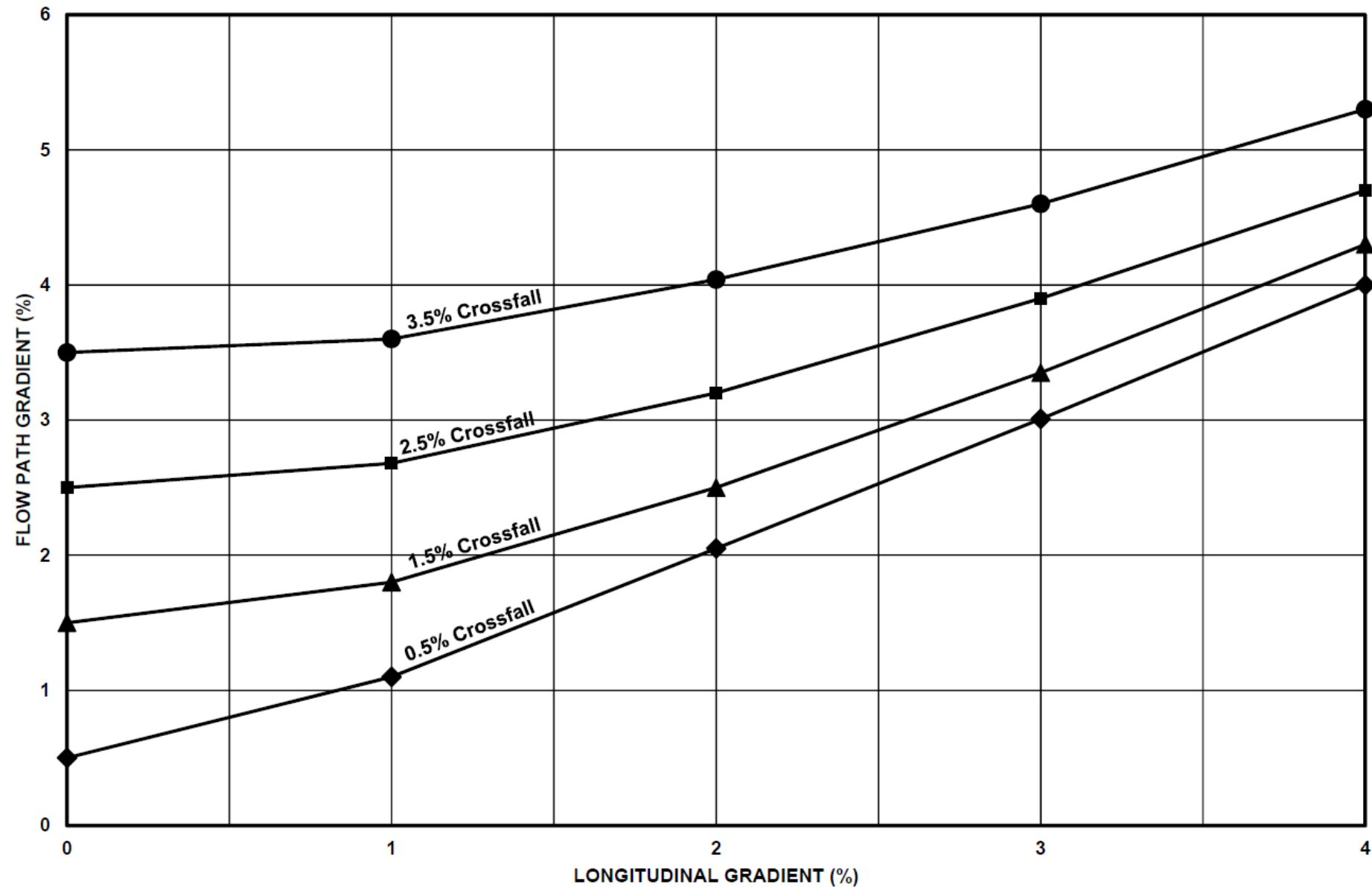
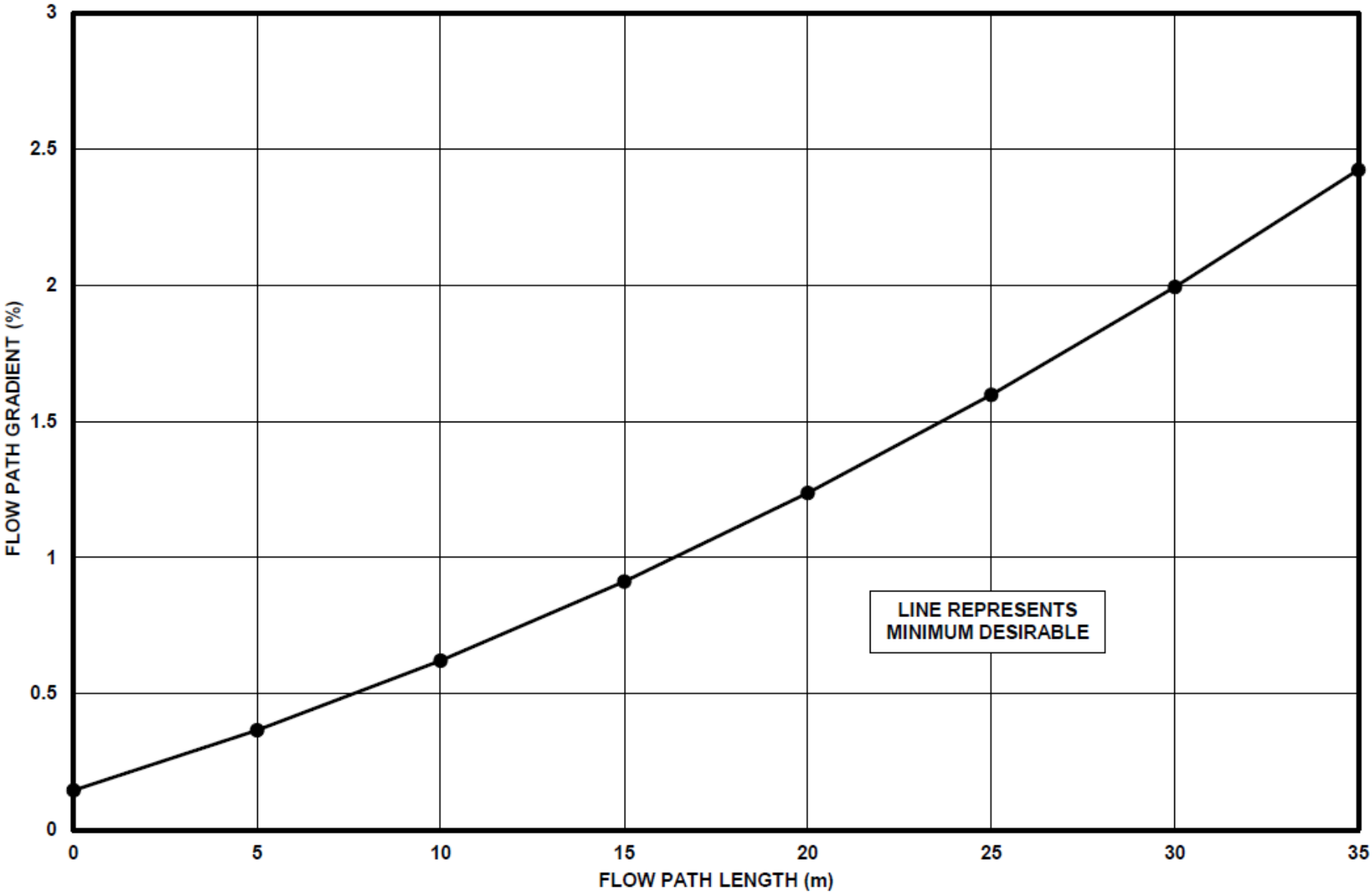


Figure 7.5.3N2b Flow path gradients



- 7.5.4 For lengths of carriageway with areas of varying width and geometry the combinations of localised flow path lengths and gradients shown below the curve on Figure 7.5.4 should be avoided.

Figure 7.5.4 Effect of flow path length and flow path geometry on drainage



Effect of carriageway edge markings

- 7.6 Continuous carriageway edge markings shall not exceed a thickness of 3 mm at the drainage exits to superelevation roll-over areas with sections having a crossfall less than 0.67 % (1 in 150).
- NOTE 1 Carriageway surface drainage has the potential to be affected by continuous edge markings, particularly where raised rib markings are used.*
- NOTE 2 A continuous carriageway edge marking thickness of less than 3 mm allows water to drain over the line during storms.*
- 7.7 Where the longitudinal gradient on any section of road is less than 0.67 % (1 in 150) drainage gaps shall be provided in carriageway edge markings in accordance with TSM Chapter 5 [Ref 23.N].
- 7.8 Where renewal of markings is being undertaken, existing lines shall be removed at the drainage exit to a superelevation roll-over area, where the longitudinal gradient is less than 0.67 % (1 in 150).

Crossfalls

- 7.9 Crossfalls shall be incorporated into the design to adequately drain water from the carriageway.
- 7.9.1 Where carriageway crown lines are used, crossfalls should be reduced from the standard 2.5 % (1 in 40) to 2 % (1 in 50) for one lane width either side of the crown, to limit the change of angle to 4 % (1 in 25).
- NOTE 1 In DMRB CD 109 [Ref 12.N] guidance is given on how to assess both the drainage and appearance of the road when applying superelevation.*
- NOTE 2 Crown lines are more easily introduced between hard shoulders and superelevated carriageways, and at merges and diverges where lane gains and lane drops occur.*
- NOTE 3 Rolling crowns (crowns that run diagonally) can be applied where surface drainage cannot otherwise be achieved.*
- 7.9.2 Carriageway crossfalls may be increased from the standard 2.5 % (1 in 40) to 2.85 % (1 in 35) on lengths of carriageway that are straight or have radii well in excess of those requiring elimination of adverse camber.
- NOTE Applying an increased crossfall on the additional nearside lanes of a widened carriageway does not significantly reduce the depth of water at the edge of the carriageway but can increase the capacity of the road edge channel where kerbs are used.*

8. Pollution and flow control design

Principles of pollution and flow control

8.1 Assessment of effects of road drainage on the water environment shall be carried out in accordance with LA 113 [Ref 18.N].

8.2 LA 113 [Ref 18.N] shall be used to identify the need for pollution and flow control measures within a drainage design.

8.3 Pollution control measures shall be designed in compliance with LA 113 [Ref 18.N].

NOTE A number of the pollution control measures discussed within this document also provide a degree of flow control.

8.3.1 Pollution control measures should be designed to treat the 'first flush'.

NOTE Discharges from short intense storms with long antecedent dry periods pose a higher pollution threat than discharges from longer rainfall events, which provide higher dilution.

8.3.2 A degree of bypass may be acceptable for the larger storm events, where runoff volumes can be higher and therefore there can be a greater degree of dilution.

NOTE 1 Further information on design of pollution control measures in drainage is published in CIRIA C753 [Ref 11.I] and the DMRB documents referenced in Table 8.3.2N

Table 8.3.2N1 Pollution and flow control measures options

Name of measure	Category of measure				Design standard reference documents	Indicative treatment efficiencies			Optimum spillage risk reduction factor R _F
	Vegetated systems	Spillage control	Flow control	Other pollution control mechanisms		Suspended solids (% removal)	Dissolved copper (% removal)	Dissolved zinc (% removal)	
Baffles		Yes	Yes			0	0	0	
Combined kerb and drainage channel			Yes			0	0	0	
Combined kerb and gully		Yes		Sediment removal		See Note 7			
Combined surface and sub-surface drains/filter drain		Yes	Yes	Pollutant removal	CD 525 [Ref 3.N]	60	0	45	0.6
Ditch (vegetated)	Yes	Yes - lined	Yes - lined/unlined	Sediment/pollutant removal (unlined)	CD 532 [Ref 24.N](vegetated)	25	15	15	0.7
Dry/detention basin	Yes		Yes	Pollutant removal	CD 532 [Ref 24.N]	50	0	0	0.6
Infiltration basin/soakaway	Yes		Yes	Pollutant removal	CD 532 [Ref 24.N] CD 530 [Ref 2.I]	Infiltration of water facilitates the removal of dissolved metals and solids.			0.6 (infiltration basin)
Notched weir		Yes	Yes			0	0	0	0.6
Penstock/valve		Yes	Yes			0	0	0	0.4
Piped systems			Yes			0	0	0	
Ponds	Yes		Yes	Pollutant removal	CD 532 [Ref 24.N]	60	40	30	0.5
Reservoir pavement/pervious asphalt			Yes	Sediment removal	CD 531 [Ref 8.I]	50	0	0	
Sedimentation tank		Yes		Sediment removal		40	0	0	

Table 8.3.2N1 Pollution and flow control measures options (continued)

Name of measure	Category of measure				Design standard reference documents	Indicative treatment efficiencies			Optimum spillage risk reduction factor R _F
	Vegetated systems	Spillage control	Flow control	Other pollution control mechanisms		Suspended solids (% removal)	Dissolved copper (% removal)	Dissolved zinc (% removal)	
Sediment trap (catchpit)				Sediment removal		See Note 7			0.6
Surface water channel		Yes			CD 521 [Ref 13.N]	See Note 7			
Swale/grassed channel	Yes	Yes	Yes	Pollutant removal	CD 532 [Ref 24.N] CD 521 [Ref 13.N]	80	50	50	0.6
Vortex chamber			Yes			0	0	0	
Vortex grit separator		Yes		Sediment/ pollutant removal	CD 528 [Ref 12.I]	40	0	15	
Wetland (surface flow)	Yes		Yes	Pollutant removal	CD 532 [Ref 24.N]	60	30	50	0.5

- NOTE 2** Table 8.3.2N1 presents potential treatment efficiencies for the various pollution control measure types for different contaminants.
- NOTE 3** Types of treatment other than those listed in Table 8.3.2N1 are available.
- NOTE 4** While Table 8.3.2N1 gives a singular treatment efficiency value for each type of treatment system it is a simplified representation of values reported in literature. Individual treatment systems of the same type will perform differently due to variables including:
- 1) variation in influent quality;
 - 2) climate and season – particularly affecting the performance of vegetated treatment systems;
 - 3) hydraulic loading – treatment systems perform differently depending on the frequency, duration, run-off rate and volume of each rainfall event;
 - 4) variation in design of the treatment system, e.g. residence time, dimensions, plant species used; and,
 - 5) frequency and extent of maintenance.
- NOTE 5** While Table 8.3.2N1 gives a simplified representation of the treatment performance, it is not a substitute for informed and site-specific selection of treatment systems.
- NOTE 6** The spillage risk reduction factors in Table 8.3.2N1 represent what is considered achievable. Actual risk reduction factors are site-specific and potentially higher (representing a lower risk reduction) depending on factors such as size of treatment system and retention time.
- NOTE 7** Removal of pollutants likely to occur but insufficient evidence available to quote indicative treatment efficiency.
- 8.4** Where the design of pollution control measures includes infiltration into ground, the risk to groundwater shall be assessed and mitigation measures, where that assessment identifies the need, implemented in accordance with LA 113 [Ref 18.N].
- 8.5** The design of pollution control measures shall include safe means of access for operation (where relevant), emergency response and maintenance.
- 8.5.1** Pollution control measures should be located above the level of the flood plain wherever possible.
- NOTE** Storm water inundation can compromise the operation of pollution control devices.

Selection of pollution and flow control measures

- 8.6** The selection and design of pollution and flow control measures shall follow the process presented below:
- 1) complete assessment in accordance with LA 113 [Ref 18.N];
 - 2) if mitigation is required, identify viable options/combinations of measures, taking account of:
 - a) road drainage hierarchy in this document;
 - b) site constraints;
 - c) storm flow and flood risk requirements;
 - d) climate change allowances; and,
 - e) road geometry.
 - 3) review short list of options against construction and maintenance requirements;
 - 4) confirm measures fulfil mitigation requirements identified from LA 113 [Ref 18.N] assessment;
 - 5) obtain approval for mitigation measures from Overseeing Organisation or relevant statutory consultation body; and,
 - 6) incorporate mitigation measures into overall drainage design.
- 8.6.1** Pollution control measures may be used to intercept pollution close to its source, treat it, manage sediment mobilisation or reduce the risks from spillages.

- NOTE 1

The selection and design of systems depends on the pollution load, the risk of spillage or flood. and the site conditions, particularly if protected habitats, species or sites can be affected.
- NOTE 2

Guidance on the design of pipelines for reduced sediment deposition is contained in CD 523 [Ref 6.N].
- NOTE 3

Measures to control flooding generally include limiting (attenuating) peak outflows and providing an appropriate volume of water storage in the system to accommodate large or critical storm events.
- 8.6.2

Drainage designs for roads may include the following general categories of pollution control measures:
1) vegetated systems;
2) spillage control;
3) flow control; and,
4) other pollution control mechanisms such as removal/separation of sediments or oils.
- 8.6.3

Where site conditions allow the use of vegetated systems their use should be prioritised over other forms of treatment.
- NOTE

Further detail on the design of vegetated systems can be found in CD 532 [Ref 24.N].
- 8.6.4

Where verge space restricts the use of vegetated systems, the use of conventional drainage systems, either independently or in combination with vegetated systems should be reviewed.
- NOTE 1

The advantages and disadvantages of a selection of pollution control measures are presented in Appendix B.
- NOTE 2

A high proportion of highway pollutants are found to be adsorbed to the fine silt fraction of the suspended solids. By collecting, filtering and treating the fine sediment that is subsequently removed, the system deals with a significant part of the runoff pollution.
- 8.7

Oil separators shall not be used.
- 8.7.1

Existing oil separators should be replaced by an alternative solution for mitigating the potential impacts of road runoff.
- NOTE 1

Oil separators are designed to mitigate oils and cannot be relied upon to treat suspended solids or dissolved metals.
- NOTE 2

Oil separators require regular maintenance to function effectively.

Signage of pollution control devices

- 8.8

Signs marking the location of pollution control devices are labelled as PCD (pollution control device) and shall be designed in accordance with BS EN 12899-1 2007 [Ref 10.N].
- 8.9

The faces of pollution control signs (PCS) used shall be one of the options shown in Figure 8.9 and meet the requirements shown in Table 8.9.

Figure 8.9 Pollution control sign design options

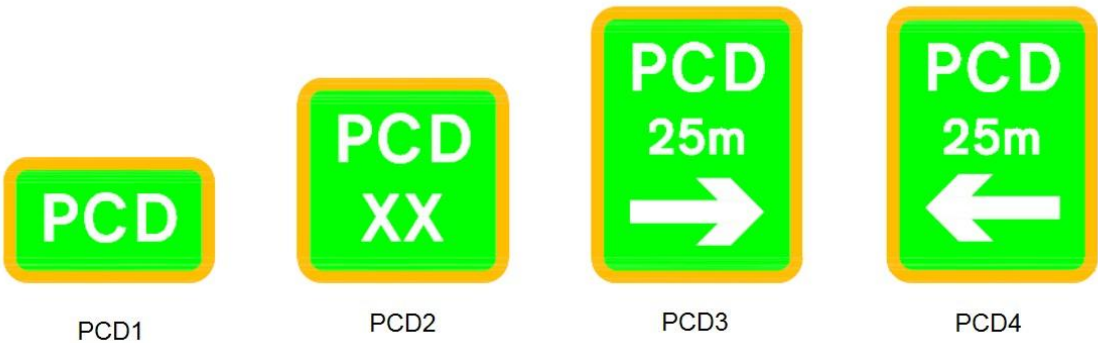


Table 8.9 Required attributes of pollution control signs

Attribute	PCD1	PCD2	PCD3	PCD4
Legend	white	white	white	white
Background	light green	light green	light green	light green
Border	yellow	yellow	yellow	yellow
Font	transport medium	transport medium	transport medium	transport medium
Material	class 1	class 1	class 1	class 1
X-height (mm)	50	50	50	50
Width (mm)	320	320	320	320
Height (mm)	190	310	410	410
Area (m ²)	0.06	0.1	0.13	0.13

NOTE 1 *Class 1 - material that is retroreflective Class 1 material in accordance with BS EN 1463-1 [Ref 19.N].*

NOTE 2 *Illumination of pollution control signs is not required.*

8.10 The location of PCSs other than at the edge of the carriageway shall not be permitted without approval of the Overseeing Organisation.

8.11 PCSs shall be visible from the running lanes of the carriageway.

8.11.1 The location of PCSs should be at least 600 mm from the edge of a single carriageway and 1500 mm from the edge of high-speed dual carriageway or motorway.

8.11.2 The mounting height of PCSs should be at least 900 mm above the highest point of the carriageway immediately adjacent to the sign.

8.11.3 The mounting height of PCSs may be increased up to 1500 mm where excessive spray is likely to occur around the sign.

8.11.4 PCSs should specify the distance and direction to the device.

9. Normative references

The following documents, in whole or in part, are normative references for this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Ref.	Document
Ref 1.N	Highways England. CD 127, 'Cross-sections and headrooms'
Ref 2.N	Highways England. CD 225, 'Design for new pavement foundations'
Ref 3.N	Highways England. CD 525, 'Design of combined surface and sub-surface drains and management of stone scatter'
Ref 4.N	National Highways. CD 529, 'Design of outfall and culvert details'
Ref 5.N	National Highways. CD 533, 'Determination of pipe and bedding combinations for drainage works'
Ref 6.N	National Highways. CD 523, 'Determination of pipe roughness and assessment of sediment deposition to aid pipeline design'
Ref 7.N	National Highways. CD 535, 'Drainage asset data and risk management'
Ref 8.N	Highways England. CD 522, 'Drainage of runoff from natural catchments'
Ref 9.N	National Highways. CD 524, 'Edge of pavement details'
Ref 10.N	BSI. BS EN 12899-1, 'Fixed, vertical road traffic signs. Fixed signs (Designated Standard - CPR)', 2007
Ref 11.N	The National Archives. legislation.gov.uk. SI 2015/51 (CDM Regs), 'HEALTH AND SAFETY - The Construction (Design and Management) Regulations 2015'
Ref 12.N	Highways England. CD 109, 'Highway link design'
Ref 13.N	National Highways. CD 521, 'Hydraulic design of road edge surface water channels and outlets'
Ref 14.N	National Highways. GG 101, 'Introduction to the Design Manual for Roads and Bridges'
Ref 15.N	Highways England. MCHW Series 0500, 'Manual of Contract Documents for Highway Works, Volume 1 Specification for Highway Works. Series 500 Drainage and service ducts.'
Ref 16.N	Highways England. MCHW HCD Series B, 'MCHW Volume 3: HCD Section 1 Series B - Edge of Pavement Details'
Ref 17.N	Highways England. MCHW HCD Series F, 'MCHW Volume 3: HCD Section 1 Series F - Drainage'
Ref 18.N	Highways England. LA 113, 'Road drainage and the water environment'
Ref 19.N	BSI. BS EN 1463-1, 'Road marking materials – Retroreflecting road studs – Initial performance Requirements (Designated Standard - CPR)'
Ref 20.N	Highways England. CD 526, 'Spacing of road gullies'
Ref 21.N	Highways England. CG 502, 'The certification of drainage design'
Ref 22.N	The National Archives. Department for Transport and Highways Agency. DfT Circular 02/2013, 'The strategic road network and the delivery of sustainable development'
Ref 23.N	TSO. TSM Chapter 5, 'Traffic Signs Manual Chapter 5 - Road Markings'

Ref 24.N	National Highways. CD 532, 'Vegetated drainage systems for highway runoff'
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10. Informative references

The following documents are informative references for this document and provide supporting information.

Ref.	Document
Ref 1.I	Highways England. CD 534, 'Chamber tops and gully tops for road drainage and services'
Ref 2.I	National Highways. CD 530, 'Design of soakaways'
Ref 3.I	2000/60/EC, 'Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy'
Ref 4.I	SI 2016/1154, 'Environmental Permitting (England and Wales) Regulations 2016 (SI 2016 No. 1154)'
Ref 5.I	Construction Industry Research and Information Association. McBain W., Wilkes D. and Retter M.. CIRIA C688, 'Flood Resilience and Resistance for Critical Infrastructure'
Ref 6.I	Highways England. CD 116, 'Geometric design of roundabouts'
Ref 7.I	Highways England. MCHW Series NG 0500, 'Manual of Contract Documents for Highway Works, Volume 2 Notes for Guidance on the Specification for Highway Works. Series 500 - Drainage and Service Ducts'
Ref 8.I	National Highways. CD 531, 'Reservoir pavements for drainage attenuation'
Ref 9.I	Highways England. CD 527, 'Sumpless gullies'
Ref 10.I	The Environment Agency. Environment Agency and DEFRA. LIT 7660, 'The Environment Agency's approach to groundwater protection'
Ref 11.I	CIRIA. Woods-Ballard,B, Wilson,S, Udale Clark,H, Illman,S, Scott,T, Ashley,R, Kellagher,R.. CIRIA C753, 'The SuDS Manual'
Ref 12.I	Highways England. CD 528, 'Vortex separators for use with road drainage systems'

Appendix A. Drainage option advantages and disadvantages

Table A.1 lists the types of drainage discussed in this document, and details potential advantages and disadvantages of each drainage type.

Table A.1 Advantages and disadvantages of drainage options

Drainage collector detail		Advantages	Disadvantages
Surface drainage	Combined pipe and channel drains	<ul style="list-style-type: none">1) provide extra flow capacity than for a channel of the same width, reducing the number of outlets from the system and reducing, or even eliminating, the need for a separate carrier pipe;2) where space is limited (for example, in road widening schemes) they allow a narrower channel to be built than would otherwise be possible;3) suited to in situ construction in concrete using slip forming techniques;4) they can remove the need for a separate carrier drain in the verge and can enable flow to be carried longer distances between outlets.	<ul style="list-style-type: none">1) pipes follows the gradient of the road and consequently can be quite flat allowing build-up of sediment;2) slots (where present) can become blocked with sediment restricting inflow;3) slots (where present) reduce the efficiency of any jetting to clear sediment.
	Combined kerb and drainage system	<ul style="list-style-type: none">1) their use at roundabouts removes the need for any 'false' crowning of road-edge channels;2) they may be economic in rock cuttings, as a cheaper option compared to carrier drain installation;3) useful on roads with relatively flat gradients (see DMRB CD 525 [Ref 3.N]);4) useful in urban areas where there is a high incidence of utility services because they do not need as great a depth of excavation as piped system (see CD 524 [Ref 9.N]).	<ul style="list-style-type: none">1) prone to the build-up of sediment and debris which can impede flow into and within the system (see CD 524 [Ref 9.N]);2) less robust than solid kerbs of equivalent dimensions (see CD 524 [Ref 9.N]);3) require linear maintenance procedures taking longer and requiring additional traffic management and lane closure than the point maintenance of gully sucking;4) at roundabouts their maintenance requires complex lane closure with traffic management.

Table A.1 Advantages and disadvantages of drainage options (continued)

Drainage collector detail		Advantages	Disadvantages
Surface drainage	Grassed surface water channels	<ul style="list-style-type: none">1) ability to treat pollution (see CD 521 [Ref 13.N]);2) peak discharge flow rate to a receiving watercourse will be less from the grassed channel, (see CD 521 [Ref 13.N]).	<ul style="list-style-type: none">1) prone to rutting resulting from vehicular over running;2) require regular maintenance (grass cutting), which involves potential risk to operatives.
	Informal drainage (over the edge)	<ul style="list-style-type: none">1) cost effective and easily maintained solution in rural settings	<ul style="list-style-type: none">1) can cause soil erosion, topsoil slippage, softening of the side slopes and embankment instability (see CD 524 [Ref 9.N]);2) uncontrolled growth on verges can inhibit free drainage;3) inappropriate for usage in locations where footways or segregated cycleways abut carriageways;4) only suitable for embankments < 1 m high (see CD 524 [Ref 9.N]).
	Kerbs and gullies	<ul style="list-style-type: none">1) a longitudinal gradient to carry road surface runoff to outlet is not dependent upon the longitudinal gradient of the road itself and can be formed instead within a longitudinal carrier pipe;2) different types of gully are available that provide for varying degrees of entrapment of detritus;3) kerbs provide some structural support during pavement laying and protect footpaths and verges from vehicular overrun.	<ul style="list-style-type: none">1) gullies can become blocked due to lack of maintenance;2) side-entry gullies are inefficient;3) the permitted width of channel flow may significantly reduce the spacing between gullies when used on high speed roads.

Table A.1 Advantages and disadvantages of drainage options (continued)

Drainage collector detail		Advantages	Disadvantages
Surface drainage	Linear drainage channels	1) may be used in both verges and central reserves on motorways; (see CD 524 [Ref 9.N]).	1) linear drainage channels built on relatively flat gradients are prone to the build-up of sediment and debris (see CD 524 [Ref 9.N]).
	Surface water channels	1) relatively easy maintenance; 2) long lengths can be constructed quickly and fairly inexpensively; 3) it may be possible to locate channel outlets at appreciable spacings, and possibly coincident with watercourses; 4) the risk to vehicles and occupants impinging on surface water channels is lower than for other types of surface drainage; 5) suited to in-situ construction in concrete using slip forming techniques (not blocks).	1) carriageways with flat longitudinal gradients may necessitate discharge of channels fairly frequently into outlets or parallel longitudinal carrier pipes in order to minimise the size of the channels; 2) presence of features such as safety fences, services, lighting columns and signs may restrict ability to use; 3) ability to install long channel lengths may be prevented by discontinuities in the verge/central reserve such as piers, abutments, slip roads, junctions, laybys, central reserve crossover points, emergency crossing points or changes in superelevation.

Table A.1 Advantages and disadvantages of drainage options (continued)

Drainage collector detail		Advantages	Disadvantages
Surface drainage	Surface water channels with channel blocks	<div>1) It may be possible to locate channel outlets at appreciable spacings and possibly coincident with watercourses;</div> <div>2) suited to use on steep embankments (Types D, E and F) (see CD 524 [Ref 9.N]);</div> <div>3) suitable where positive drainage is desirable for dealing with small volumes of flow that would not justify use of the larger surface water channel. (Types A and B) (see CD 524 [Ref 9.N]).</div>	<div>1) effectiveness of drainage channel blocks is reduced by settlement of adjacent unpaved surfaces;</div> <div>2) drainage channel blocks are prone to the build-up of sediment and debris in flat areas;</div> <div>3) presence of drainage channel blocks may reduce ability to undertake mechanical grass cutting;</div> <div>4) should be avoided in verges subject to frequent usage by equestrians or other vulnerable users;</div> <div>5) presence of features such as safety fences, services, lighting columns and signs may restrict ability to use;</div> <div>6) ability to install long channel lengths may be prevented by discontinuities in the verge/central reserve such as piers, abutments, slip roads, junctions, laybys, central reserve crossover points, emergency crossing points or changes in superelevation.</div>

Table A.1 Advantages and disadvantages of drainage options (continued)

Drainage collector detail		Advantages	Disadvantages
Combined surface and subsurface drainage	Combined surface and subsurface drains (filter drains)	<div>1) can be installed early in the construction phase and be used to manage drainage during construction (with appropriate maintenance);</div> <div>2) they remove groundwater to a greater depth beneath pavement level than fin or narrow filter drains;</div> <div>3) easier to construct than a solution with both surface and sub-surface drainage constructed separately;</div> <div>4) easier inspection and maintenance than fin or narrow filter drains;</div> <div>5) allow collection of water from drainage systems installed separately in the side-slopes of cuttings;</div> <div>6) enable rapid removal of runoff from the road and verge surface (see CD 524 [Ref 9.N]);</div> <div>7) can manage a wide range of flows (see CD 524 [Ref 9.N]);</div> <div>8) particularly suited to dealing with subsurface water flows, which can vary as the water table fluctuates (see CD 524 [Ref 9.N]);</div> <div>9) generally have an exceptionally large groundwater capacity which can extend as a cut-off below the capping layer (see CD 524 [Ref 9.N]);</div> <div>10) removes sediment and attached pollutants providing a degree of water quality treatment.</div>	<div>1) surface failure of embankments and pavement failures;</div> <div>2) risk of stone scatter where subject to vehicular over run.</div>

Table A.1 Advantages and disadvantages of drainage options (continued)

Drainage collector detail		Advantages	Disadvantages
Sub-surface drainage	Fin drain	1) can be installed at the edge of the unbound pavement construction allowing a range of edge collection systems to be constructed above.	1) can be unsuitable for dealing with high groundwater flows or where a longitudinal carrier drain is necessary to transport surface-water runoff from the carriageways (see CD 524 [Ref 9.N]); 2) ground stability issues are possible during excavation of and working within the narrow trenches needed for Types 5, 6 and 7 (see MCHW HCD Series F [Ref 17.N]).
	Narrow filter drain	1) can be installed at the edge of the unbound pavement construction allowing a range of edge collection systems to be constructed above.	1) can be unsuitable for dealing with high groundwater flows or where a longitudinal carrier drain is necessary to transport surface-water runoff from the carriageways (see CD 524 [Ref 9.N]).

Appendix B. Pollution control components

Table B.1 Advantages and disadvantages of pollution control components

Drainage component	Advantages	Disadvantages	Design notes
Combined kerb and drainage channels	<div>1) they can attenuate flow due to the high storage capacity of their design;</div> <div>2) their use can reduce the size of attenuation storage or retention ponds where utilised in combination with each other.</div>	<div>1) sediment drop out can occur at inlets resulting in road-edge debris requiring additional road sweeping maintenance;</div> <div>2) standard jetting operations result in large loss of water from the kerb units. This may increase time on site and vehicle movements as well as resulting in debris spreading across the carriageway and thus additional road sweeping maintenance.</div>	<div>1) Check catchment sediment load and gradients of drainage to confirm they have suitable load carrying capacity.</div>
Combined surface and subsurface drains	<div>1) They can provide spillage containment if adequate downstream control, such as a penstock or handstop, is provided;</div> <div>2) The filter media can adsorb suspended solid pollutants and heavy hydrocarbons, reducing downstream pollution risk from routine runoff;</div> <div>3) Inclusion of an over-sized carrier drain can provide flow control.</div>	<div>1) Where routine runoff causes a build-up of pollutant in the filter media, maintenance requirements may be increased (see CD 525 [Ref 3.N]);</div> <div>2) Maintenance or replacement of filter media may be needed if contaminated by a serious accidental spillage;</div> <div>3) Risk of stone scatter where subject to vehicular over run.</div>	

Table B.1 Advantages and disadvantages of pollution control components (continued)

Drainage component	Advantages	Disadvantages	Design notes
Ditches	<div>1) Unlined ditches can allow infiltration of runoff through soil and vegetation, particularly where residence times are long.</div> <div>2) Lined ditches can act as containment basins if located between the road drain and receiving watercourses.</div>	<div>1) Scientifically robust information on their treatment performance is limited.</div> <div>2) Ditches with concrete or similar facing do not have the same treatment potential as unlined ditches, but can be adapted to contain spillages.</div> <div>3) Where unlined ditches are located above permeable strata, there is a risk that highway runoff will infiltrate and potentially contaminate any underlying aquifer.</div> <div>4) Unlined ditches encourage vegetation growth that can hamper access and operational ability as well as giving an increased maintenance requirement.</div>	<div>1) The direct input of a pollutant to groundwater without percolation through soil or subsoil is an offence under Section 12(1) of the Environmental Permitting Regulations SI 2016/1154 [Ref 4.I];</div> <div>2) Ditches with shallow side slopes have similar properties to swales.</div> <div>3) Where lined ditches are used as containment basins they should have a minimum of 25 m³ capacity and have a downstream control that can be shut or blocked in the event of accidental spillage of pollutants on the road.</div>
Informal drainage (over the edge)	<div>1) It can provide, in some circumstances, a degree of pollution control as highway runoff is allowed to filter through vegetation on the slope.</div> <div>2) Pollution control is possible with informal drainage, using a downstream control.</div>	<div>1) Where informal drainage is used above permeable strata, there is a risk that highway runoff will infiltrate and potentially contaminate any underlying aquifer.</div>	<div>1) Toe ditches associated with informal drainage can be lined to prevent percolation through the soil or subsoil.</div>

Table B.1 Advantages and disadvantages of pollution control components (continued)

Drainage component	Advantages	Disadvantages	Design notes
Kerbs and gullies	<ul style="list-style-type: none">1) ability to capture potentially contaminated sediments during normal rainfall events prior to discharge into a receiving watercourse;2) provide initial stage of interception of spillages.	<ul style="list-style-type: none">1) less effective at trapping finer grained sediment than coarser grained sediment;2) high inflow rates can cause resuspension of sediments and mixing of oils with the water in the gully pot;3) contaminated water can discharge from the gully pot into the receiving drainage network or watercourse.	<ul style="list-style-type: none">1) resuspension or mixing of oils can be avoided by ensuring that the gradient of the pipe leading to the gully is as shallow as possible whilst still providing adequate hydraulic performance;2) sumptless gullies should be considered where this is not possible.
Penstocks and handstops	<ul style="list-style-type: none">1) They can provide spillage containment if they are closed in time.	<ul style="list-style-type: none">1) Failure to open penstock after a spillage incident (or closure of penstock due to vandalism or equipment failure etc) could result in flooding or scouring following breach of the headwall or ditch.2) regular maintenance needed;3) handstops not appropriate for larger systems.	<ul style="list-style-type: none">1) The size of handstops should be such that the plate can be lifted manually.
Piped systems	<ul style="list-style-type: none">1) They can provide spillage containment if adequate downstream control such as penstock or handstop is provided.		

Table B.1 Advantages and disadvantages of pollution control components (continued)

Drainage component	Advantages	Disadvantages	Design notes
Reservoir pavements	<div>1) They can allow full infiltration of surface water into the subgrade or partial infiltration combined with capture for controlled release elsewhere;</div> <div>2) can provide economical drainage solution.</div>	<div>1) only permitted in locations outside the main trafficked lanes (see CD 531 [Ref 8.1]).</div>	<div>1) Use in main trafficked lanes requires departure from standard.</div>
Sedimentation tanks		<div>1) They are not reliable for the removal of dissolved copper and zinc.</div>	<div>1) Efficiency of sediment removal depends on factors such as inflow velocity, separator size, retention time, maintenance frequency and settlement time of individual particles.</div> <div>2) not be relied upon to remove dissolved copper and zinc.</div>
Surface water channels		<div>1) Where channels are not self-cleansing, deposition of gross pollutants and sediments is likely to occur;</div> <div>2) Ponding of water behind such deposited material can cause safety threat to road users.</div>	<div>1) To avoid sediment build up, designs to ensure that surface water channels are self-cleansing and sediments deposited in a downstream system;</div> <div>2) channels designed so that emergency response kits can be used in them and can act as a pollution control measure for spillages.</div>
Surface water channels with channel blocks			

Table B.1 Advantages and disadvantages of pollution control components (continued)

Drainage component	Advantages	Disadvantages	Design notes
Weirs and baffles	<div>1) They can act as both pollution and flood control devices.</div> <div>2) Baffles can be placed in both open channels and ditches.</div>		<div>1) Where weirs are used for spillage control, they should be designed with a notch or orifice that can readily be blocked by a sandbag in an emergency;</div> <div>2) Where baffles are used for spillage control, they should be designed so that they can readily be blocked in an emergency.</div> <div>3) Where baffles are used for spillage control, the design should include at least 25 m³ of containment.</div>

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