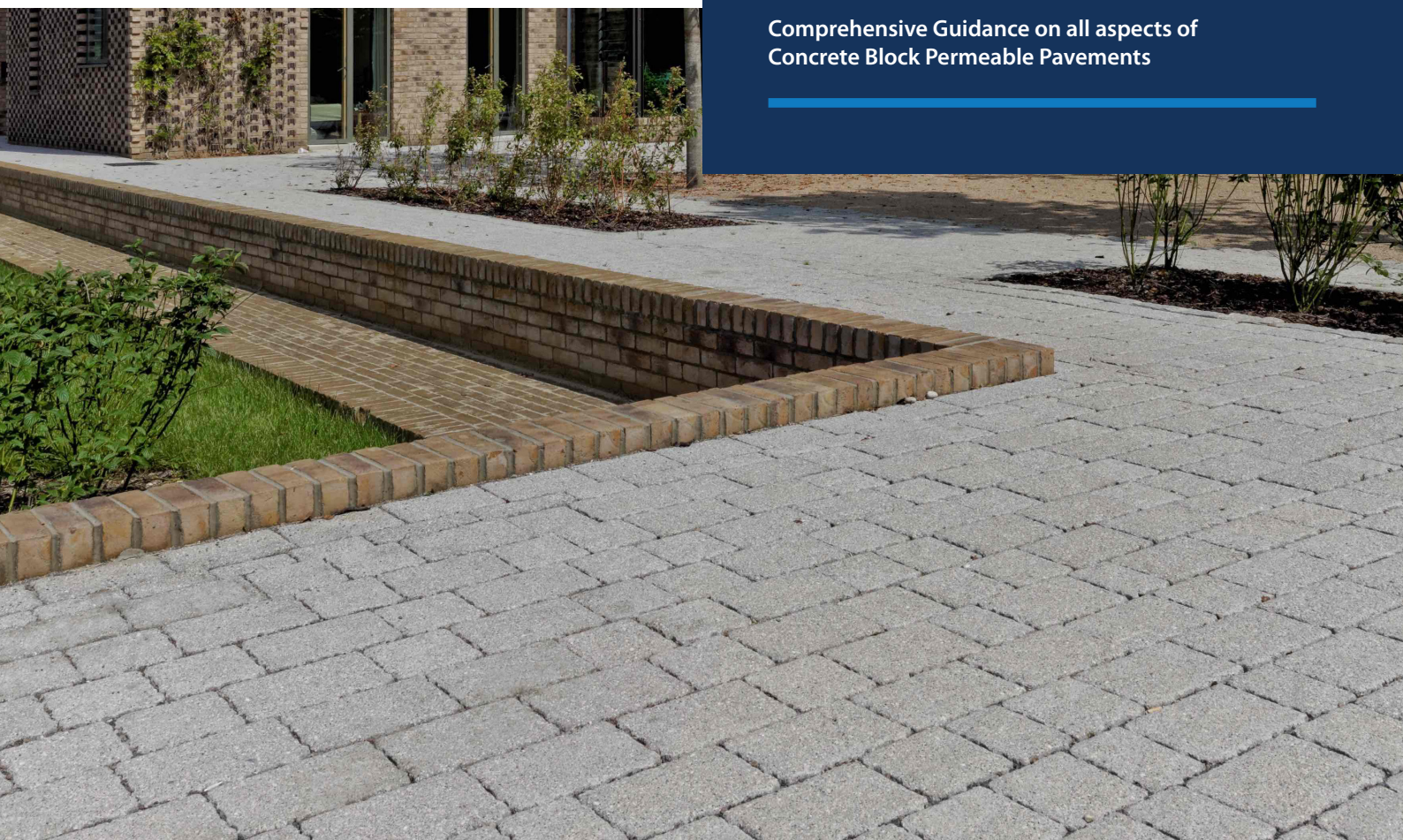


August 2026

# The Permeable Paving Manual

Comprehensive Guidance on all aspects of  
Concrete Block Permeable Pavements



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# Preface

First published in 2003, Interpave's *Guide to the design construction and maintenance of concrete block permeable pavements* has provided the definitive source of information on CBPP through seven editions. Interpave is now part of MPA Precast and this latest iteration of the guide – *The Permeable Paving Manual* – has been expanded to cover the latest developments and diverse opportunities available with CBPP today, reflecting decades of experience, research and innovation.

## About the Manual

The Manual is intended for planning, highways, flood risk and other authorities, as well as architects, urban designers, landscape architects, civil engineers and developers. It aims to assist them in the design, construction, approval and maintenance of CBPP on developments, notably as an essential, multifunctional SuDS technique.

It covers all aspects and stages relevant to the various professions constituting the project design team, from master-planning through to engineering design and construction, and finally maintenance. Its primary aims are to ensure that CBPP delivers predictable, robust solutions and to minimise costs, maintenance and adoption issues. It encourages the use of pavement construction materials that are widely available.

Early sections of the Manual provide a basic understanding of CBPP and SuDS, essential for effective use of technical guidance later. A Glossary (Section 17) provides definitions of terminology related to permeable paving. Separate, straightforward design and construction guidance for CBPP on private driveways, patios and other lightly trafficked domestic paving can be found in MPA Precast's *Paving for Rain*.

Where materials, design or installation references in British Standards or other referenced publications are updated after publication, advice from the supplier or the Mineral Products Association should be sought to confirm any updated specification requirements.

## Relationship With Other Guidance

The Manual provides the detailed information on CBPP necessary to meet requirements of the *National Standards for SuDS:2025*, the *Manual for Streets* and the *National Planning Policy Framework* (which calls for SuDS on developments). The Manual aligns with the recommendations of various other authoritative publications including *The SuDS Manual* (CIRIA, 2015) and *BS 7533-103:2026 Design and installation of modular permeable pavements*. International experience has also been considered, including *Permeable Interlocking Concrete Pavements* (Interlocking Concrete Pavement Institute, USA).



# 1. Introduction

**Concrete block permeable paving (CBPP) is a fully-engineered and predictable alternative to conventional sealed paving, integrating surface water drainage with modular paving for a wide range of applications. Replicating rainwater management in nature, CBPP collects, treats, stores and conveys runoff to provide a controlled flow of clean water at the head of sustainable drainage systems (SuDS) ‘management trains’.**

The need to respond to climate change continues to grow in urgency. It demands a far wider application of permeable surfaces – whether for new-build, renewal or replacement – reversing the sealing-up of urban areas and moving towards a ‘sponge city’ paradigm. This approach is recognised by requirements for SuDS on new developments, action on surface water flooding from existing impermeable surfaces and enforcement of planning rules for ‘unplanned paving’.

With more than 30 years’ use on a wide range of project typologies, from footways to lower-speed adopted roads and even container terminals, CBPP has proven to be a robust, resilient and adaptable technology. This long experience also gives a greater understanding of the capabilities of CBPP, revealing that it performs far better than originally anticipated and with important potential for even more applications and innovations.

The realisation that CBPP is unique in acting as a permeable ‘source control’ – intercepting traffic pollutants at the head of the ‘management train’ – reinforces its essential role in SuDS. In addition, CBPP works in synergy with street trees and green infrastructure, providing irrigation and essential oxygen/CO<sub>2</sub> exchange without root disruption to the surface. The controlled flow of clean water from CBPP can also benefit habitat creation as part of ‘Biodiversity Net Gain’ programmes. These benefits are all available with CBPP, without additional land-take.



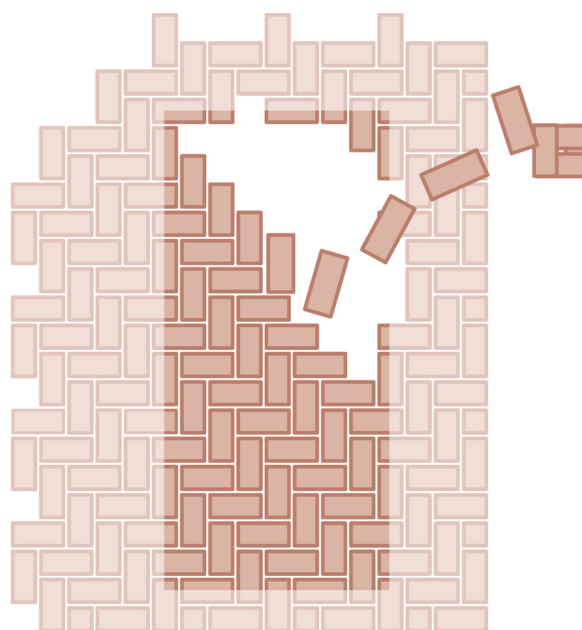


## 2. Permeable Pavement Principles

The use of segmental paving laid to create a hard surface for roads can be traced back over 6,000 years and modular concrete block paving continues this tradition today in modern forms. CBPP is fundamentally different to 'conventional' impermeable block paving, although they share the same block manufacturing technology and modular characteristics.

Essentially, concrete paving blocks from MPA Precast manufacturers are engineered products, manufactured under automated factory conditions using high strength, semi-dry concrete in a vibration/compression process. This ensures precise dimensional control and consistent performance characteristics making them slip/skid resistant, safe, strong, durable, reusable and sustainable.

For CBPP, these high-strength, interlocking units are installed with hard angular grit (not sand, as used for impermeable block paving), filling joints and as a laying course, enabling miniscule movement between blocks as a 'flexible pavement'. This 'surface zone' of blocks and laying course is supported by various permeable structural layers below to form the pavement construction, with interlock between the blocks contributing to the structural performance of the pavement. Similarly, horizontal interlock through tessellated block shapes and/or laying patterns (such as herringbone) resists traffic braking and turning forces.



### Modern Methods of Paving

Adopting the principles of 'modern methods of construction', including mechanised installation, concrete block paving delivers fast, low-cost installation using weather-independent, 'dry' construction methods. Whether for construction or low-impact sub-surface access and reinstatement, there are no curing, hot-work or noxious fume problems and only small plant and equipment is needed, with noise and disturbance minimised.

A wide choice of block shapes, styles (including small-element flags), colours, textures (including natural aggregates) and finishes add a richness, diversity, visual interest and human scale to the urban realm. With an extremely long lifespan, blocks can be taken up and re-used without processing for low-intervention repairs, changing demands and layouts, or completely new schemes – saving carbon, meeting 'circular' economy' criteria and adding to sustainability credentials.

## Concrete Block Permeable Paving

CBPP enhances concrete block paving technology providing an inherently permeable surface and multi-functional SuDS technique. It simply combines self-drained, safe and attractive surfaces for a wide range of applications with attenuation, storage, pollution treatment and conveyance of rainwater runoff.

The difference between CBPP and conventional concrete block paving is angular grit (2/6.3mm) – never sand – used to fill enlarged joints usually generated by integral spacer nibs and as a laying course. This permeable ‘surface zone’ is the key to CBPP performance with the natural filtering of runoff water through the grit. It is supported by various layers below: generally, coarse-graded aggregate (typically 4/20mm) with voids (typically 30%), enabling water attenuation and storage, as well as structural support.

Alternative structural layers can be used to create opportunities for street trees and green infrastructure, provide additional water storage, accommodate statutory services or meet other requirements. They include: structural soils, tree pits, geocellular systems and impermeable sub-bases. Also, retrofit permeable surface zone overlays, utilising existing road-bases (and their embodied carbon), offer particularly effective street renewal and regeneration solutions.

Figure 1: CBPP working in synergy with street trees.

## Permeable, Pervious or Porous?

*The SuDS Manual* identifies concrete block permeable paving as the most commonly used of ‘Pervious Pavement’ SuDS typologies. Pervious Pavements are essentially sub-divided into ‘Porous’ (infiltrating water across the whole surface via pores in the material) and ‘Permeable’ (infiltrating water through joints between impermeable units). Confusion between typologies has resulted in misleading myths. CBPP does **not**: clog, have low strength or poor durability, require frequent maintenance or suitability only for light-duty applications.

CBPP is unlike – and not to be confused with – porous materials and other forms of pervious pavements, which cannot deliver its long-term performance and multifunctional benefits.





## 2.1 How CBPP Works

In conventional pavements, rainwater simply runs across the surface to gulleys that collect and direct it into pipes, removing it as quickly as possible. This means that water and the pollutants contained in it are rapidly conveyed into overloaded drains, streams and rivers, leading to floods in extreme conditions and loss of public amenity and biodiversity.

In contrast to conventional sealed pavements, CBPP temporarily stores water within it during rainfall, releasing it gradually over time. It also cleans the water and addresses flooding, pollution and water quality issues, unlike attenuation tanks which only deal with flooding (volume). It serves a dual purpose, acting as the drainage system as well as a hard surface supporting traffic loads. It also provides a 'controlled flow of clean water' for amenity and biodiversity benefits. In fact, CBPP goes further in satisfying a diversity of requirements and providing multifunctional SuDS in line with the Code of Practice BS 8582 (BSI, 2013a).

CBPP allows water to pass through the surface – between the paving units (Figure 2) – and the permeable laying course, into the underlying permeable construction where it is stored and, dependent on the system type, released slowly into the ground, to the next SuDS management stage or to a drainage system. At the same time, many pollutants are substantially removed from the water and treated within the CBPP itself, before water infiltrates to the subgrade or passes into the next stage of the management train.

CBPP is used at the head of the management train for surface water collection as a 'source control'. It provides a controlled source of clean water for downstream, open SuDS features as an integral and multifunctional part of landscape design. Unlike conventional road constructions, the CBPP materials are specifically designed to accommodate water.

The multifunctionality of CBPP makes it very efficient in terms of space. A study by H. R. Wallingford (Kellagher and Laughlan 2003) confirmed that CBPP is one of the most space-efficient SuDS components available, as they do not require any additional land take (Figure 3), unlike other SuDS methods, particularly attenuation tanks.



Figure 2: Principles of CBPP. As water passes through the pavement silt and other pollutants are also removed, which reduces downstream pollution.



Figure 3: CBPP in a high density development.

## 2.2 Surface Management of Rainwater

CBPP behaves differently to normal hard surfaces when it rains.

On conventional hard surfaces, the rain first wets the surface then, as the rainfall increases, water may pond in surface depressions until these have filled. The surface water then moves towards drainage points or discharges into watercourses, conveying surface pollution directly to pipe inlets. This moving water becomes the surface water runoff, whilst the water remaining in puddles will evaporate. The amount of time taken for the water to move from the farthest point where rain hits the ground to entering the drainage system is known as the 'time of entry'.

In the case of traditional impermeable surfaces the distance from the farthest point to a gully inlet may be some 20 to 30m. In contrast, with CBPP, the initial 5mm of rain is absorbed by the pavement surface and any excess then flows into the joints or voids between adjacent blocks (typically a maximum of 100mm). As this time is so short, standing water on the pavement and surface ponding are virtually eliminated. This is clearly demonstrated in practice when comparing CBPP and impermeable surfaces under similar conditions (Figure 4). Importantly, this also means that localized clogging of the surface has little impact because water simply finds an alternative way into the CBPP nearby.

Unlike conventional, impermeable pavements, CBPP can be laid level with no fall, while still retaining excellent surface drainage, up to a maximum surface gradient of about 5% (1 in 20). For steeper gradients, consideration of the management of the water passing through the sub-base is required (see section 4.4). Retrofitting CBPP on steep gradients and crossfalls should be avoided. This is because water flows onto the permeable surface quickly concentrating at the kerb edge causing clogging and overland flow rather than infiltrating into the surface.



Figure 4: a demonstration of 'ponding' on impermeable asphalt paving, absent from adjacent CBPP under the same rain conditions.

## 2.3 Benefits of Concrete Block Permeable Pavements

The main benefits of CBPP can be summarised as follows:

- providing a structural pavement while allowing rainwater to infiltrate into the pavement construction for temporary storage
- playing an important part in removing a wide range of pollutants from water passing through the construction profile
- allowing treated water to infiltrate to the ground, be re-used or released to the next part of the SuDS management train, directly to a water-course or other drainage arrangement
- suitable for a wide variety of residential, commercial and industrial applications
- optimising land use by combining two functions in one: structural paving combined with attenuation of rainfall
- handling rainwater from roof drainage and impervious pavements as well as the CBPP itself
- requiring no more maintenance than conventional road surfaces and less prone to catastrophic failure due to blockage than gullies and pipes
- avoiding blockages and winter icing failures experienced with gulleys and pipes, while eliminating puddles and potholes



## 3. Types of System

**The key to CBPP is its permeable surface zone of high-strength concrete blocks with angular aggregate (2/6.3mm) used to fill enlarged joints and as a laying course.**

It allows water to pass between the blocks intercepting silt and filtering out and treating pollution while preventing ingress of debris, retained on the surface where it can easily be removed. This unique permeable surface works in conjunction with various construction profiles and differentiates the technology from other types of pervious paving.

In most CBPP constructed to date, water passes from the surface zone into voids (approx. 30% by volume) within an underlying coarse grade aggregate (CGA) permeable sub-base. Here it is stored and released slowly, using the following alternative three Systems (drawings are indicative only). It is important to determine the appropriate System for specific applications and conditions (see Section 7 – System Selection).

In many situations (apart from System A) it is beneficial to use straightforward, shallow flow controls – generally in chambers accessible for observation and adjustment if needed – with a calculated orifice accurately limiting outlet flows from CBPP compartments. This allows straightforward compliance to be demonstrated as part of the SuDS design approval process.

### 3.1 System A – Total Infiltration

System A can be used in situations where it is possible and allowable to discharge all the collected water into the subgrade. This system (Figure 5) allows all water falling onto the pavement to infiltrate down through the joints or voids between the concrete blocks, passing through the constructed layers below and eventually into the subgrade. Some retention of the water may occur temporarily in the underlying permeable construction allowing for initial storage before it eventually passes through.

System A is sometimes known as 'Zero Discharge', as no water from the CBPP is discharged into the next stage of the management train or the sewer system, eliminating the need for pipes and gulleys.

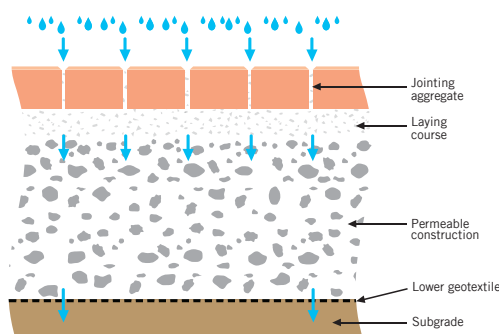


Figure 5: System A - total infiltration

## 3.2 System B – Partial Infiltration

System B can be used in situations where the existing subgrade may only be capable of absorbing water slowly and additional rainfall events may overwhelm the storage capacity and/or where interception is required. In System B (Figure 6) perforated outlet pipes within the CBPP collect the excess water and drain it to another part of the SuDS management train or drainage system (such as sewers or watercourses). Alternatives to pipes include fin-drains, proprietary CBPP drainage systems or geocomposite blankets at the bottom of the pavement or placed vertically around the edges to collect the water.

For smaller storm events, typically the water entering the pavement can infiltrate into the existing ground. However, for more extreme events, (> 1 in 10 year) the water that cannot infiltrate discharges to an outfall to either surface water or sewer, with a maximum allowable discharge rate that is agreed with the environmental regulators.

This is one way of achieving the requirement for reducing the volume and frequency of runoff by interception and will most likely remove the need for any other long-term storage. The pipes ensure that water does not sit on the surface of the subgrade for long periods and the risk of soil softening is negligible. Importantly, the outlet pipes are connected to a chamber with a flow control device to restrict flow so that water is temporarily stored within the pavement and discharge slowed.

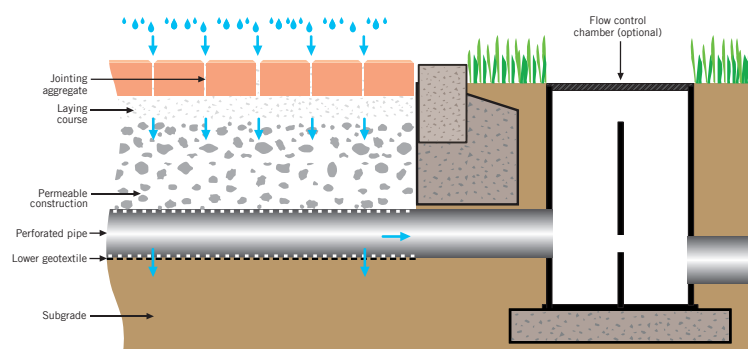


Figure 6: System B - partial infiltration

## 3.3 System C – No Infiltration

This system is designed on the basis that all the water that enters the pavement is discharged via outlet pipes. There is no infiltration assumed in the design. The system is used where infiltration rates are very low. Normally a geomembrane liner should not be used to tank the system because even minor losses into the ground are beneficial in reducing the volume of water leaving the system.

In some cases where water needs to be prevented from entering the ground a geomembrane may be used below the bottom of the sub-base and up the sides to provide a tank to hold water. Such cases include:

- where the ground is contaminated and the infiltrating water will mobilise pollutants and cause harm to a receptor
- inside water supply borehole source protection zones where the pollutants from surface water runoff or in the ground below may pose a risk to water quality. Note that it is not likely for the former to be the case in residential settings
- where the pavement structural design is not based on saturated CBR values and thus the formation could be weakened (normally CBPP is designed based on saturated CBR values which will not be reduced by the presence of water)
- where there are potential geotechnical hazards.

A geomembrane liner may also be provided where the permeable paving is storing water for re-use.

Water is collected (using techniques discussed in 12.5) and is discharged via pipes at suitable locations to transmit the water to another part of the SuDS management train or drainage system (such as sewers or watercourses). Importantly, the outlet pipes are connected to a chamber with a flow control device to restrict flow so that water is temporarily stored within the pavement and discharge slowed.

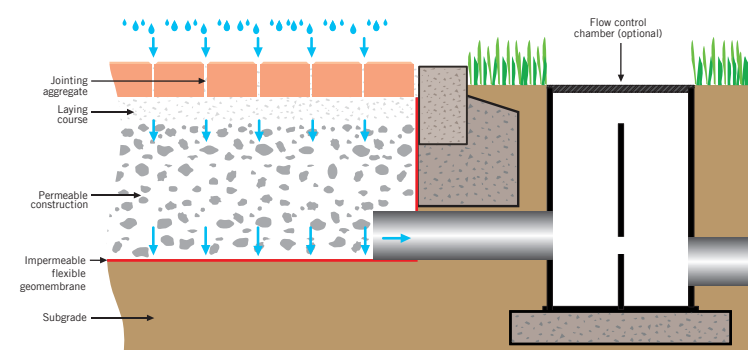


Figure 7: System C - Impermeable flexible geomembrane on geotextile

## Other CBPP Profiles

Alternative structural layers (as follows) can be used to cater for trees and green infrastructure, provide additional storage, accommodate statutory services or meet other requirements. The ability of CBPP to remove silt is particularly important to protect many of these alternative structural layer systems from clogging.

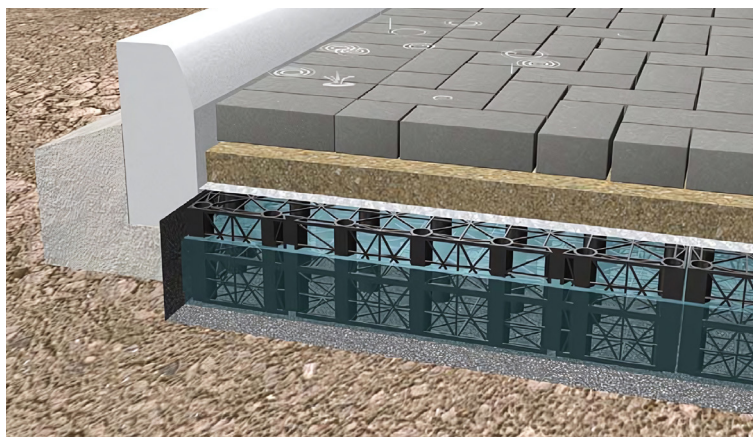


## 3.4 Sub-Base Replacement Systems

Proprietary permeable sub-base replacement systems usually consist of plastic units forming a cellular raft to replace the CGA sub-base, designed to support anticipated traffic loadings. With over 90% void volume, they can provide additional water storage or reduce pavement thickness, or accommodate tree soils. They are also useful to form inlets and outlets from the permeable constructions.

Particular care is needed with design of these systems, especially in handling the high loads encountered and to ensure adequate water treatment. Advice should be sought from the suppliers/manufacturers or found in the SuDS Manual (CIRIA, 2015).

Figure 8: CBPP with geocellular sub-base replacement system below



## 3.5 Permeable Paving Overlays

CBPP can be used as a permeable surface in various situations, such as on roofs, balconies and podium decks, effectively as a 'blue roof' system (that should follow guidance in CIRIA Report C817D).

It can also be used at ground level as an overlay comprising only the paving units and laying course, with a thin drainage medium below, installed over an existing road construction. As low-intervention renewal and improvement works, utilising existing impermeable road-bases (and their embodied carbon), this approach delivers low-cost retrofit SuDS. However, the treatment process and volume management is reduced with the absence of a permeable sub-base. This can be provided by discharge to a secondary SuDS component (e.g. the SuDS basin shown in Figure 9).

Discharging near the surface, the overlay CBPP collects, cleans and stores up to 20mm of everyday rainfall, representing up to 95% of rainfall events and the 'first flush' of silt and pollution from the surface. Discharge may be into other shallow SuDS features, such as rain-gardens, or to existing road gulleys below the pavement surface. The latter may be particularly useful when traditional stepped kerb streets are transformed into shared-surface areas.

The structural design of the CBPP overlay should take account of the condition of the existing road surface. If it is in poor condition, the water could soak into cracks and reduce the strength of the underlying pavement. The existing surface should be sealed.

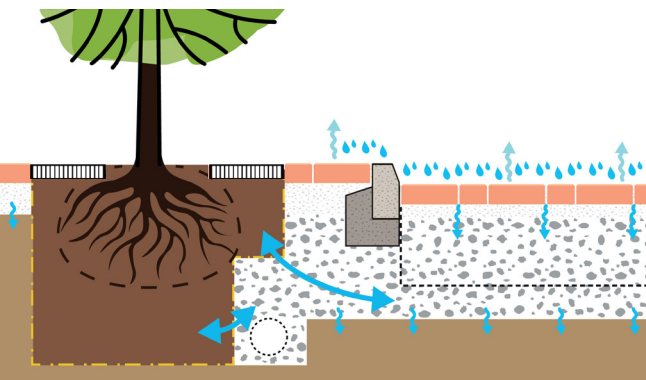
CBPP should not be retrofitted into existing roads where there are significant cross falls and/or long falls on the surface that channel water into the gutter of the road. It should also not take water from upstream areas that is discharged onto the CBPP by channelised flow in the gutter.

Where retrofitted it is not necessary to provide a geomembrane liner to prevent water ingress to adjacent impermeable construction. The sub-base is dry for the majority of the time and during the majority of rainfall events. The water depths are also normally not sufficient to cause sideways flow and, if anything, the permeable sub-base will act as a drain for water that is trapped in the adjacent sub-base, making it more durable.



Figure 9: CBPP retrofitted over an existing road structure collects water and discharges it through slot drains into adjacent SuDS basins

## 3.6 Tree Pits

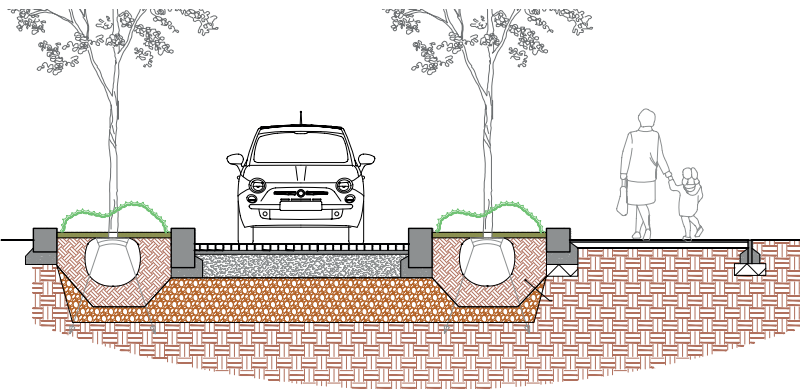


CBPP can be used over and around standard tree pits, enabling irrigation and simple gas (oxygen/carbon dioxide) exchange essential to tree roots, without additional reservoirs or pipes. It also avoids root disruption common with other paving and can be used close to trees. The current Code of Practice for accessibility in the external environment, BS 8300-1:2018, recommends permeable paving rather than large tree grilles for pedestrian safety. The CBPP should be terminated away from the tree trunk allowing sufficient space for future growth.

The tree pit and surrounding rooting environment can be considered as both 'source control' and 'sub-catchment'. Tree pits can be interlinked before discharging relatively clean water to the management train or piped drainage system.

Figure 10: CBPP working in synergy with street trees

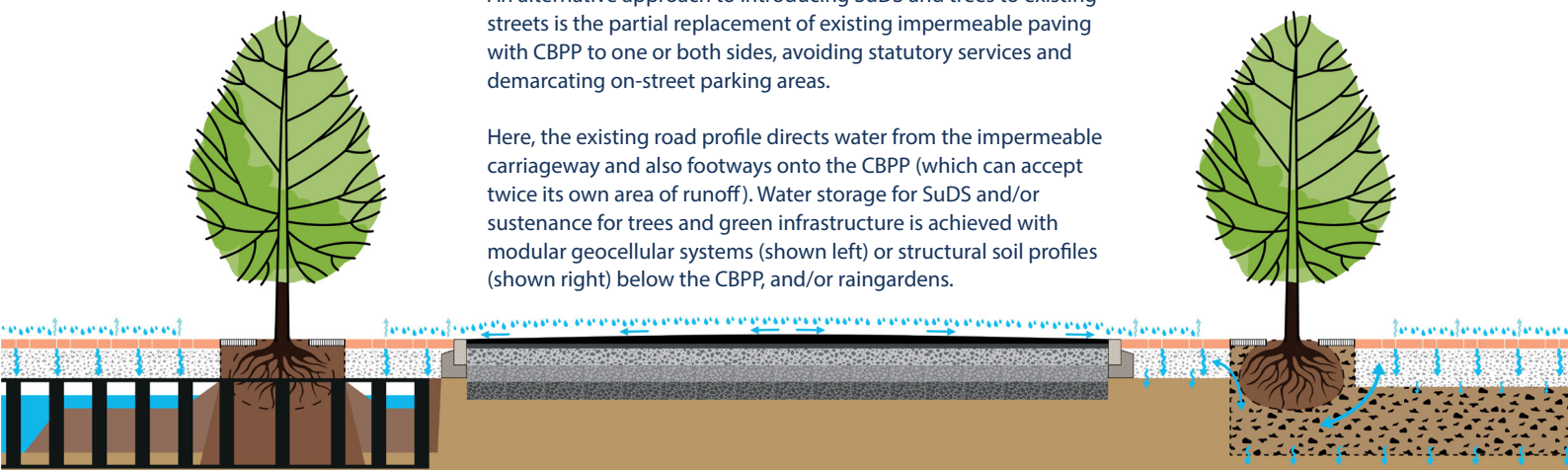
## 3.7 Structural Soils



Structural soils, such as the 'Stockholm System', have been developed using crushed stone compacted to form a load-bearing base with voids enabling tree root growth and support. Biochar, compost or soil can be added to the stone and optimum profiles continue to evolve. CBPP, usually with a CGA aeration layer below, provides water and gas exchange so that aeration wells, gulleys or other devices, and their maintenance, are unnecessary.

Figure 11 : 'Stockholm Solution' tree planting trenches with CBPP. Courtesy of Robert Bray Associates

## 3.8 Partial Street Replacement



An alternative approach to introducing SuDS and trees to existing streets is the partial replacement of existing impermeable paving with CBPP to one or both sides, avoiding statutory services and demarcating on-street parking areas.

Here, the existing road profile directs water from the impermeable carriageway and also footways onto the CBPP (which can accept twice its own area of runoff). Water storage for SuDS and/or sustenance for trees and green infrastructure is achieved with modular geocellular systems (shown left) or structural soil profiles (shown right) below the CBPP, and/or raingardens.

Figure 12: Partial street replacement with CBPP enables trees to thrive.



## 4. Planning SuDS and CBPP

SuDS for developments of all types and sizes throughout England are now an integral part of the planning system, via the latest *National Planning Policy Framework (NPPF)* and new *National Standards for SuDS: 2025* in England. They are also mandatory in Scotland and Wales. SuDS comprise a variety of physical structures that mimic natural drainage features and collect, clean and store runoff from development before release to the wider environment.

With use over time, it has become clear that CBPP is a particularly adaptable SuDS technology. It combines drainage and trafficable hard surfaces for a wide range of applications, with numerous other benefits and opportunities. In particular, the ability of CBPP to collect, clean and store large volumes of polluted road runoff 'at source' and within the construction profile sets it apart from other SuDS techniques.

CBPP also helps meet other planning requirements including street trees, 'net biodiversity gain' (NBG), efficient multifunctional use of land and place-shaping to define the character of a development. To make the most of its multifunctional characteristics, a holistic approach to development design is essential with consideration of all aspects and benefits of CBPP from the very start by the whole design team.

### 4.1 Source Control and Sub-catchments

A critical SuDS concept is 'source control'. It ensures that water flowing onward along a 'management train' on or near the surface is relatively clean, as required by the *National Standards for SuDS (2025)*.

The main generators of polluted runoff within developments are trafficked hard surfaces. Vehicles contribute tyre waste, hydrocarbons, metals and microplastics to road runoff which, with current conventional drainage regimes, washes directly into gully pots and pipes to watercourses, or combined sewers and treatment works.

Nonetheless, safe, accessible hard surfaces are essential in all developments, including those using SuDS. There is a wealth of research available from around the world showing that CBPP is particularly effective at removing the main pollutants of concern.

**CBPP is the only SuDS source control with proven long-term performance designed to collect, treat and store rainfall where it lands on trafficable hard surfaces.**





CBPP therefore provides a controlled flow of clean water for amenity and biodiversity enhancement. However, it can also handle runoff from adjacent impermeable paving double its own area (see section 4.2). So, all low-speed trafficable paving should be either CBPP or impermeable surfaces draining onto CBPP. Then, open basins, wetlands and ponds will be protected from pollution and silt, for the benefit of both people and wildlife.

Use of CBPP with flow controls as discrete 'sub-catchments' (see section 5.1 and 9.3) is also important for water quality. Unattenuated, runoff would flow through a development at different rates depending on the character, slope and nature of surfaces. Any pollution would therefore be transported at different rates through the catchment and be increasingly difficult to isolate and remediate. Sub-dividing a development into sub-catchments enables CBPP to collect and clean the 'first flush' volume carrying most pollution from each area.

Using simple orifice controls with CBPP contributes to the 'residence time' within the pavement profile, maximising cleaning and natural losses 'at source'. It also reduces storage volumes further along the management train, reducing the SuDS footprint. Relatively clean water can then recombine along the management train preventing the mixing of clean and dirty runoff. CBPP provides an effective design mechanism to collect, clean and store the most polluted runoff from developments 'at source', whilst each sub-catchment is managed separately and prevents contamination of the SuDS management train.

## 4.2 Draining Impermeable onto Permeable Areas

One of the strengths of CBPP is a capability to handle runoff from adjacent impermeable areas of paving. For example, in retail car parks parking bays are often constructed using CBPP with access ways of impermeable construction. Where runoff flows from an impermeable surface onto an adjacent permeable surface it is normal practice to limit the ratio of impermeable area to permeable pavement to about 2:1, as a rule of thumb and depending on site parameters (Figure 13). The main reason for this is that silt loads onto the CBPP become excessive at greater ratios and the risk of the surface clogging increases. As an example, if a site has a total area to be drained of 1500m<sup>2</sup> then 1000m<sup>2</sup> can be impermeable draining into 500m<sup>2</sup> of CBPP.

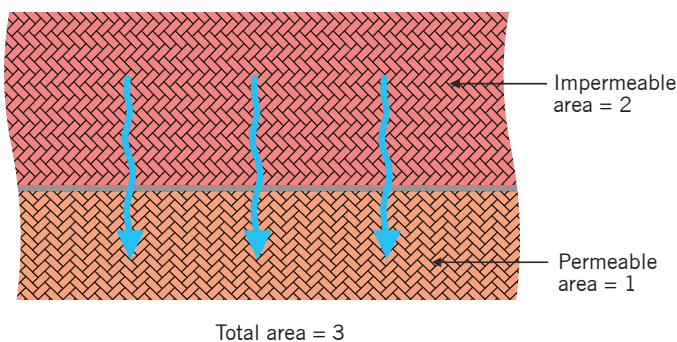


Figure 13: Ratio of impermeable to permeable areas

The water flow onto the CBPP should be spread out along the interface between the two surfaces. Channelised flow onto the CBPP should not occur. Where conventional block paving abuts CBPP, stabilisation of the joints in the former may be considered to avoid migration of jointing sand onto the CBPP.

The design process requires the determination of both the structural thickness and the hydraulic thickness. If the structural thickness is greater than the hydraulic thickness this means that there is spare hydraulic storage capacity that can be utilised to accommodate runoff from adjacent areas. If there is no spare hydraulic capacity and it is required to accommodate runoff from adjacent areas then the hydraulic thickness will need to be increased accordingly. See Section 9.13 for details of how to calculate the additional hydraulic thickness.

Designers may choose to prioritise trafficked hard surfaces (to enable pollution removal) over roof water (which is effectively unpolluted), unless roof water storage is considered to be critical (e.g. in high-density housing developments).



Figure 14: Impermeable paving draining onto CBPP

## 4.3 Draining Roof Water onto CBPP

For domestic roofs and smaller capacities, downpipes can discharge directly onto the CBPP surface or flag paving incorporated into the CBPP for localised diffusion, so that leaves and other debris simply remain on the surface. The maximum ratio of 2:1 should still apply. The additional volume of water entering the CBPP needs to be taken into account when determining the hydraulic thickness. See Section 9.13 for details of how to calculate the additional hydraulic thickness.

For larger outlets and roofs, rainwater can be discharged into the CBPP via filter chambers (accessible for maintenance) leading to diffusers within the permeable base or sub-base. Here, the 2:1 rule need not apply (unless the roof water is being infiltrated within 5m of a building or other structure). It is important to consider the velocity and volume of water entering the pavement when designing the filter chambers and diffusers to avoid excessive 'point loading' and to ensure that water can flow freely into the sub-base. Roof drainage can direct large volumes of water into the pavement very quickly, especially where syphonic drainage is being considered. See Section 12.4 for details.

## 4.4 Sloping Sites

Constructing CBPPs on sloping sites is possible. The maximum gradient of the paver surface should be about 5% (1 in 20) to avoid water running over the surface and failing to enter the pavement. CBPP can be constructed on different levels, each with its own flow control contributing to the site management train. CBPP on higher levels may require a lined construction to prevent uncontrolled flows from the construction profile.

Care is needed when retrofitting CBPP into existing roads with long falls and/or crossfalls. Water flow should not be allowed to channel down the gutter adjacent to the kerb. Areas of impermeable surface upstream of the CBPP should not be allowed to run onto the CBPP as channelised flow at the gutter: this causes severe blockage of the CBPP.

There are various potential solutions to the issue of slopes for all types of CBPP, including:

1. Install dams within the underlying permeable construction to create separate compartments with flow control devices to ensure that water does not flow uncontrolled to the lowest level and come out of the surface. There are various ways of achieving this including bunds formed in concrete, blockwork or proprietary CBPP drainage systems (Figure 15). A low-cost solution is to form a dam with the impermeable geomembranes of adjoining compartments lifted up and folded back.
2. Terrace the site with dams to give relatively level areas of CBPP that have separated compartments with flow control devices (all as above) of underlying permeable construction storage areas (Figure 15).
3. Use high capacity geocellular storage (plastic boxes) at the lower end of the site to increase storage capacity.
4. The underlying permeable construction thickness can be increased to allow for the reduced storage capacity in the CBPP at the top of the slope.

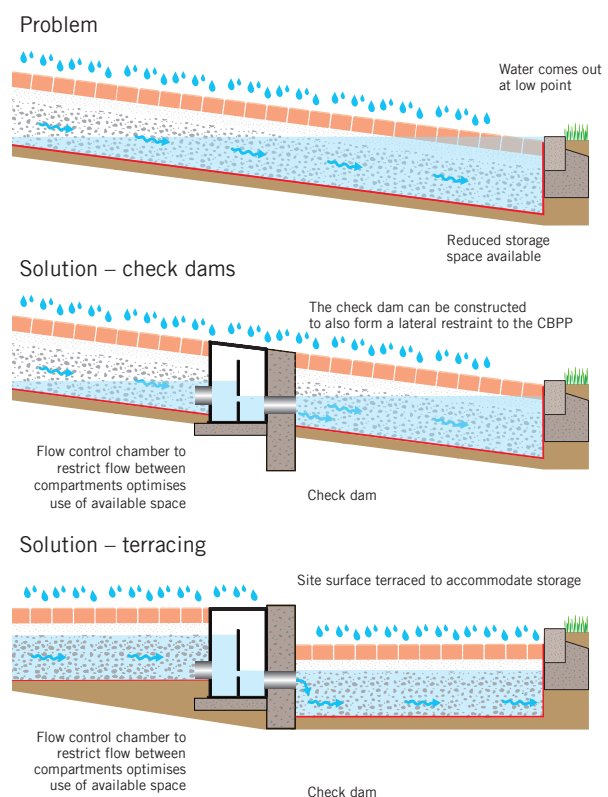


Figure 15: Managing CBPPs on sloping sites.

Guidance on checking the available hydraulic storage on a slope is given in section 9.12.

These precautions are required wherever the underlying permeable construction is used for water storage on sloping sites (including any infiltration systems – i.e. Systems A or B). In all cases careful analysis and detailing is required to ensure that the water flows within the pavement are as predicted and that unexpected 'spring lines' or surface ponding do not occur in the pavement. The exact design will depend on the site area, discharge limits, gradient, etc.

## 4.5 Statutory Services

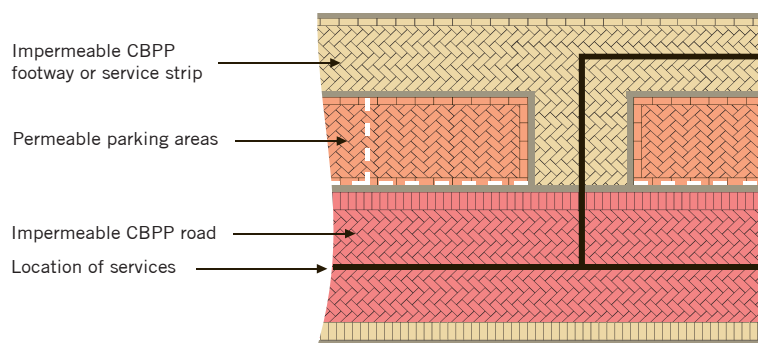
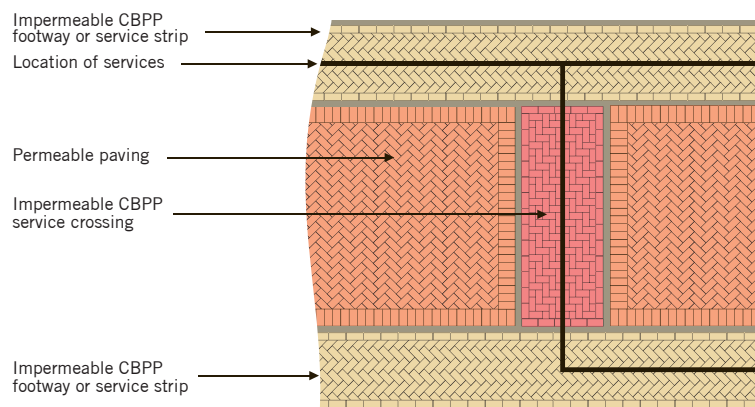


Figure 16: Plan of a layout with services in road and footway.

Sewers and drains are acceptable below CBPP because they have long design lives and excavation is unlikely. Shallow services should be accommodated in impermeable footways for straightforward access, crossing CBPP in ducts. Whenever possible avoid locating other services within CBPP to minimise the need of having to excavate and reinstate the CBPP to repair or replace any services. Design the layout of the roads and parking bays with a combination of CBPP and conventional impermeable pavements and restrict the services to the conventional pavements only.

If this is unavoidable, then create delineated service trenches within the CBPP that can be excavated and reinstated with the minimum disturbance to the permeable pavement layers. The service trench should be constructed using conventional pavement materials. Figure 17 illustrates a typical example of how to achieve this.

Both these approaches can also form a key part of the overall layout design both visually and technically, as shown in Figures 16 and 17.



X-X

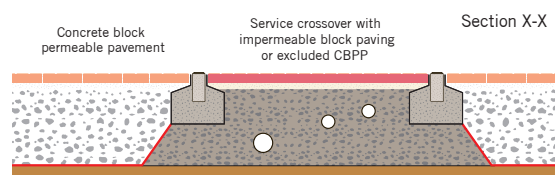


Figure 17: Plan and cross section of a typical service crossing.

## 4.6 Exceedance Routes

As with any drainage system, flood conveyance routes to cater for extreme events should be planned within the overall project layout. Design of CBPPs must also take into account the overland flow routes of water when the design capacity is exceeded. Although exceedance will result in flooding of some areas, the flows should be routed to prevent flooding of buildings for events that are well in excess of the capacity of the system. Further guidance is provided in CIRIA Report C635 (CIRIA, 2006).

## 4.7 Inappropriate Applications

There are a few situations where CBPP may be inappropriate. For example, do not use CBPPs where there will be very heavy silt loads from the proposed use (e.g. stockpiling sawdust or recycling centres), or heavy contamination (e.g. scrap or chemical disposal facilities).



## 4.8 Trees and Green Infrastructure

Street trees and green infrastructure are recognised as central to making our towns and cities liveable and responding to climate change. Trees help deliver carbon sequestration, biodiversity and SuDS, as well as enabling urban cooling through shading and evapotranspiration, biodiversity and biophilia (well-being). Research shows that they also reduce noise, air pollution, stormwater pollution, wind-chill cooling in winter and even crime.

Increasingly, street trees are becoming a requirement in developments and regeneration. The NPPF calls for street trees with long-term maintenance provision on developments. Measures need to be put in place to nurture and allow trees to mature – generally for decades – so that they can actually deliver their real potential. Local authorities will be seeking practical, spatial solutions for maintenance and sustenance.

CBPP offers unique opportunities to collect, attenuate and treat rainwater runoff, removing pollutants for a gradual supply of clean water irrigating green infrastructure. CBPP allows the same pattern of run-off transfer to the ground as natural vegetation. It can provide irrigation with scope for stormwater storage and maximises rainwater capture away from sheltering tree canopies for conveyance to tree roots – essential in summer.

Urban trees and paving have traditionally been seen as in conflict. But this is not the case with CBPP. It enables air to reach roots and poisonous CO<sub>2</sub> to escape. The favourable environment created for tree roots avoids pavement surface disruption and facilitates natural growth into lower levels for stability and longevity. CBPP can be used within new-build, or regeneration schemes with new tree planting and also for ‘rescuing’ mature trees.

As discussed in Sections 3.5 – 3.8, CBPP can be used over standard tree pits, proprietary tree planters, ‘Stockholm System’ or other structural soil installations, enabling irrigation and simple gas exchange essential to trees – without additional reservoirs or pipes. Depending on the site and any other restrictions, some form of tree-root protection system may be prudent. Alternatively, a CBPP overlay can simply discharge horizontally into a raingarden or bioretention planter, perhaps with overflow into an existing, adapted gully. The raingarden stores water during heavy rain for SuDS, retains soil moisture during dry weather and provides additional water quality ‘polishing’, as well as irrigation.

‘The SuDS Manual’ recognises the synergy between CBPP and trees, and it is the preferred surfacing option around trees, rather than tree grilles, according to BS8300-1 (2018).

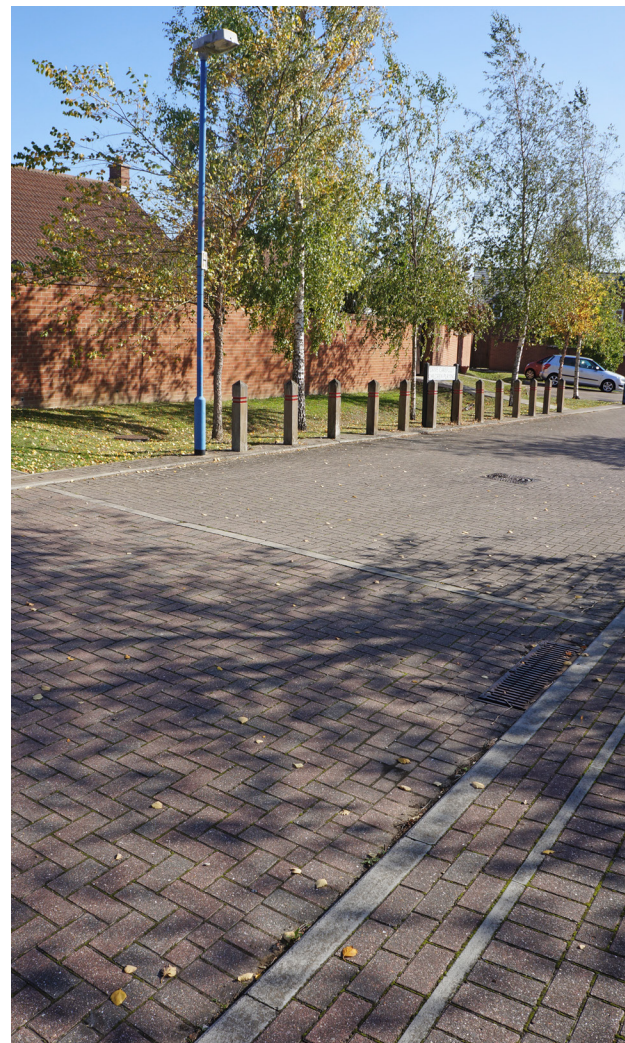


Figure 18: Street trees at the Lamb Drove SuDS Monitoring Project (discussed on page 18).

## 4.9 Biodiversity Net Gain

The recent introduction of Biodiversity Net Gain (BNG) as a planning requirement promises dramatic changes in the design of public open space in new development. BNG requires a 10% increase in biodiversity on new development, a mixture of on-site and off-site BNG or as a last resort, purchase of ‘statutory biodiversity credits’ from the government. BNG enhancements will require agreed habitat management for a period of 30 years.

It is not clear, at the moment, whether nature-based SuDS design features can be included in BNG metric calculations but the synergy between the two approaches to environmental improvement is obvious. The role of CBPP managing runoff ‘at source’ to avoid polluted runoff entering surface features of the SuDS ‘management train’ (see Section 4.1) is a key biodiversity enabler, providing a controlled flow of clean water for habitats, with minimal maintenance over the long term. In addition, CBPP offers no risk of entrapment for wildlife, unlike gulleys.



Figure 19: Wildlife habitat, enabled by SuDS outfall originating from CBPP, at the Lamb Drove SuDS Monitoring Project.



## 4.10 CBPP in Practice

The practical application of the planning and design considerations discussed here are demonstrated in several case study documents (available via [www.mpaprecast.org](http://www.mpaprecast.org)). In particular, the Lamb Drove SuDS Monitoring Project – cited by Defra – exemplifies the numerous benefits of well-designed SuDS with CBPP.

Completed in 2006, Lamb Drove is a 35-homes development on a 1-hectare site in Cambourne, Cambridgeshire, with a conventional layout but still delivering SuDS. It was compared with a similar, neighbouring development using piped drainage.

Lamb Drove demonstrates various techniques to collect, clean, convey and infiltrate, or store and release water at greenfield runoff rates (2 l/s/hectare) from developments to watercourses or sewers. The design is considered as two discrete sub-catchments, each with a micro-catchment of CBPP paved roads – all managed by flow control chambers. This enables full storage within landscape features and permeable paving, while roof-water discharges directly to green space.

Lamb Drove is an integrated SuDS system with predictable performance and is still operating successfully today. The monitoring report highlights lower capital costs – saving £314 per property at the time – and lower maintenance costs, with potential for further improvements and savings. It identifies that the scheme successfully attenuates surface water flows and significantly reduces peak flows, with reductions in concentrations of pollutants and other water quality indicators, and with an increase in wildlife species and diversity.

The report also confirms that: *'The permeable pavement infiltration study specifically illustrates the robustness of the performance of this feature to limited maintenance. The infiltration capacity of the permeable pavement is able to adequately cope with the highest recorded rainfall intensity at the Study Site.'*



*"Overall, both capital and maintenance costs – and therefore whole-of-life costs – associated with the SuDS development were much lower than those for the conventional piped drainage system."*

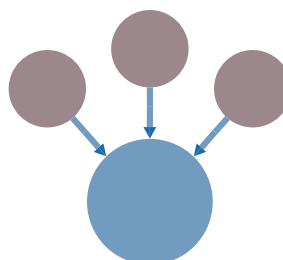
# 5. General Design Considerations

There are a number of considerations to take into account when embarking on the design of CBPP, in addition to structural and hydraulic requirements.

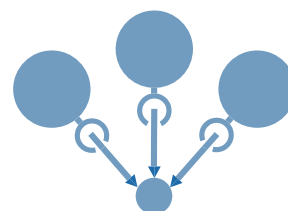
## 5.1 Compartmentation with Flow Control

There are several advantages in considering areas of CBPP as distinct compartments within a sub-catchment, particularly when flow control devices – with access for adjustment – are fitted to the pavement outlet pipes. As discussed earlier, this technique is useful for containing flows through CBPP on sloping sites. It also optimises the time that water remains in the pavement to maximise infiltration potential (where there is no geomembrane liner) and for removal of pollutants, fulfilling a major benefit of CBPP: a controlled flow of clean water within the landscape.

Importantly, CBPP compartments with flow control devices provide demonstrable volume storage deployed around a site, requiring no additional land take (see 9.3). CBPP is therefore not just a collection and conveyance mechanism – it does provide storage that can be used and will reduce (or completely negate) the need to provide other storage on a development.



Conveying collected rainwater directly from hard surfaces results in large components storing polluted water elsewhere on site.



Storing water in CBPP around the site with flow control devices minimises or eliminates the need for further storage components.

Figure 21: Efficient land-use with water storage in CBPP compartments

## 5.2 Proximity to Buildings

In most situations CBPPs can be constructed up against buildings because they allow dispersed infiltration similar to natural vegetation. Therefore, the minimum 5m requirement cited in Building Regulation guidance for soakaways (which, in contrast, provide a single concentrated point discharge) need not apply, as has been specifically clarified by the Government (DTLR Response, April 2002).

However, if a concentrated outflow (such as a roof drainage terminal) is used within the pavement, this should be at a sufficient distance to ensure that the stability of the building is not affected. On many sites, even when the flow from roofs is included, the ratio of area drained to the area of infiltration for a CBPP is much less than that from a traditional soakaway (between 3:1 and 6:1 for a CBPP, compared to 30:1 and 300:1 for a traditional soakaway). Thus, water flows from the base of CBPPs are much less concentrated and, even with the additional roof water, it may be possible to allow infiltration within 5m of a building. Additional information can be found in 'Susdrain Factsheet 12'.



## 5.3 Rainwater Harvesting

Irrespective of ground conditions, System C CBPPs can be designed to collect, treat and store rainwater for re-use for non-potable purposes such as irrigation, washing vehicles or toilet flushing (Figure 22 and Beecham et al, 2010). For rainwater harvesting design purposes, a runoff coefficient of 40% is recommended due to the greater evaporation than with an impermeable surface and other impermeable areas should also drain into the CBPP sub-base. Rainwater harvesting systems are not normally used to provide potable water as this would require specialised treatment and monitoring to manage the contamination risks. See Chapter 11 of the SuDS Manual (CIRIA, 2015) for more information on harvesting. It should be noted that, for the majority of rainfall events, there will be no water entering the sub-base from the CBPP surface.

Extensive research summarised in CIRIA C609 (CIRIA, 2004) has demonstrated that CBPPs will significantly reduce pollution but there may also be a need to treat the water further before use in some cases. In the majority of situations, this is not normally required for toilet flushing and irrigation.

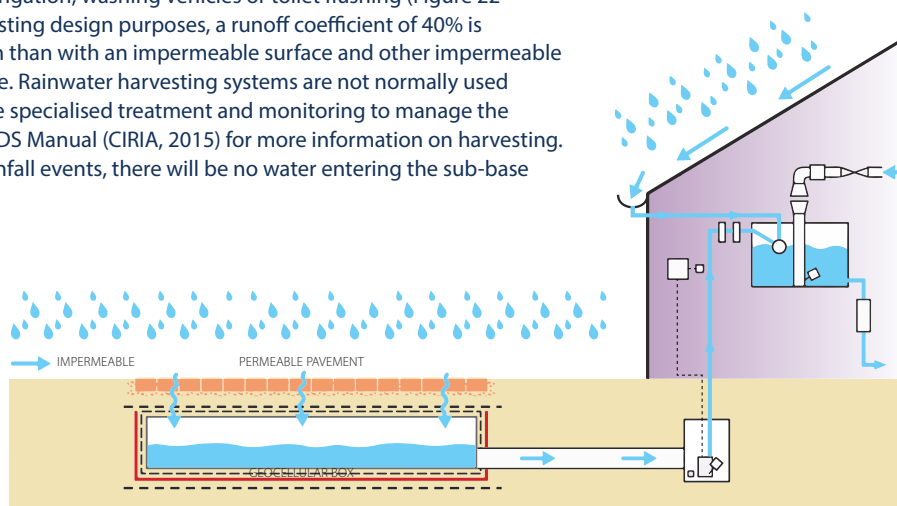


Figure 22: Example of a rainwater harvesting system.

The prioritisation of runoff destinations and other requirements of the *National Standards for SuDS:2025* suggests that the controlled supply of clean water available for harvesting from CBPP on or near the surface is best suited to gravity-fed irrigation, rather than pumped uses such as toilet flushing. As discussed earlier, there will be a long-term need for irrigation to street trees (Section 4.8) and BNG habitats (Section 4.9).

## 5.4 Managing Pollution

Pollution is present on road and car park surfaces as a result of oil and fuel leaks, and drips, tyre wear, dust from the atmosphere, etc. This type of pollution arises from a wide variety of sources, is spread throughout urban areas and is known as diffuse pollution. Rainfall washes the pollutants off the surface. Conventional drainage systems, as well as attenuation tanks, effectively concentrate pollutants, which are flushed directly into the drainage system during rainfall and then into watercourses or groundwater. The impact of this is to reduce the environmental quality of watercourses.

The 'Water Framework Directive' (European legislation) requires that surface water discharges are managed so that their impact on the receiving environment is mitigated. The objective is to protect the aquatic environment and to control pollution from diffuse sources such as urban drainage. This will be a key aspect that will effectively preclude the use of the traditional piped approach to drainage in future.

There is a wealth of research information available from around the world showing that CBPPs are very effective at removing the main pollutants of concern, i.e. total suspended solids, hydrocarbons and metals. The pollutants, such as metals and total suspended solids (TSS), are filtered and trapped in the top of the jointing material and hydrocarbons degrade over time (see Figure 23). If additional treatment is required for higher risk areas, it is more effective to use green SuDS methods such as swales or wetlands, as these also treat a wider range of pollutants.

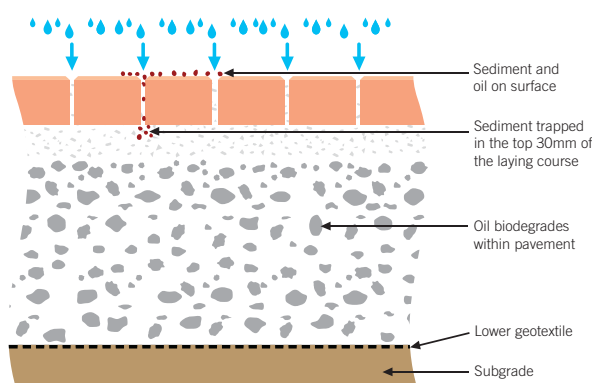


Figure 23: Management of pollutants in CBPP.

It is well-established that oil separators are not required when CBPPs are used. Indeed CBPPs are more effective at removing a wider range of pollutants from runoff than oil separators (CIRIA, 2004), although this is not recognised in the *National Standards for SuDS:2025*.

## 5.5 Designing for Water Quality

Design of SuDS to achieve water quality requirements is explained in the SuDS Manual (2015). Sites are assigned 'Pollution Hazard Indices' for TSS, metals and hydrocarbons, depending on the likely risk of pollution being present. SuDS components are assigned a 'Pollution Mitigation Index', which depends on how effective the component is at removing each of the pollutant categories.

To deliver adequate treatment, the selected SuDS components should have a total Pollution Mitigation Index (for each contaminant type) that exceeds the Pollution Hazard Index (for each contaminant type) i.e.: (for each contaminant type)

|                                                                              |          |                                                               |
|------------------------------------------------------------------------------|----------|---------------------------------------------------------------|
| <b>Total SuDS Pollution Mitigation Index<br/>(for each contaminant type)</b> | <b>≥</b> | <b>Pollution Hazard Index<br/>(for each contaminant type)</b> |
|------------------------------------------------------------------------------|----------|---------------------------------------------------------------|

There are different sets of mitigation indices that depend on the destination of the water discharging from the sub-base of the CBPP and also in which region of the UK the site is located, as follows:

| Principal destination of the runoff                                                                | England                                                                                                               | Wales | Scotland                               | NI |
|----------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|-------|----------------------------------------|----|
| Surface water i.e. there is no infiltration from the SuDS to groundwater                           | Use 'surface water' mitigation indices                                                                                |       |                                        |    |
| Surface water, but small amounts of infiltration may occur from un-lined components (Interception) | Use 'surface water' mitigation indices for main discharge and 'groundwater' mitigation indices for minor infiltration |       | Use 'surface water' mitigation indices |    |
| Groundwater, but discharges to surface waters may occur once the infiltration capacity is exceeded | Use 'groundwater' mitigation indices                                                                                  |       |                                        |    |

The SuDS Manual (2015) recognizes the effectiveness of CBPP in removing pollution and for areas with a low to medium pollution hazard level CBPPs are more than sufficient on their own to provide an adequate pollution mitigation index (see Table 1). For higher risk sites, the CBPP could discharge to another SuDS feature such as a basin or a pond.

| Land use                                                                                                                                                                                                                                       | Pollution Hazard Level | Total suspended solids (TSS) | Metals | Hydro-carbons |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|------------------------------|--------|---------------|
| <b>Pollution Hazard</b>                                                                                                                                                                                                                        |                        |                              |        |               |
| Individual property driveways, residential car parks, low traffic roads (e.g. cul de sacs, homezones and general access roads) and non-residential car parking with infrequent change (e.g. schools, offices) i.e. < 300 traffic movements/day | Low                    | 0.5                          | 0.4    | 0.4           |
| Commercial yard and delivery areas, non-residential car parking with frequent change (e.g. hospitals, retail), all roads except low traffic roads and trunk roads/ motorways <sup>1</sup>                                                      | Medium                 | 0.7                          | 0.6    | 0.7           |
| <b>SuDS Mitigation</b>                                                                                                                                                                                                                         |                        |                              |        |               |
| Mitigation indices for CBPP discharge to surface waters <sup>1</sup>                                                                                                                                                                           |                        | 0.7                          | 0.6    | 0.7           |
| Mitigation indices for CBPP discharge to groundwaters (where a suitable filtration layer is included that provides treatment and including a geotextile at the base separating the foundation from the sub-grade) <sup>1,2</sup>               |                        | 0.7                          | 0.6    | 0.7           |

Note:

1. CBPPs will only deliver these indices if they follow design guidance with respect to hydraulics and treatment set out in the relevant technical component chapters of the SuDS Manual (2015).

2. Designs should generally include a minimum of 1m unsaturated depth of aquifer material between the infiltration surface and the maximum likely groundwater level. In the case of localised and discontinuous perched water tables, the 1m minimum separation might be reduced. This will require the designer to assess the risk to groundwater from pollution in surface runoff.

Table 1: Extract from Tables 26.2, 26.3 and 26.4 of the SuDS Manual (CIRIA, 2015) showing pollution hazard indices for low risk areas and mitigation indices provided by CBPP



## 5.6 Construction Traffic

One final consideration that could affect both the layout of CBPP in conjunction with impermeable paving (Section 4.2) and structural design of the pavement is accommodation for construction traffic.

Often there is a need to use the partially completed or completed CBPPs as access roads or storage areas during the construction of a project. If the sub-base – coarse graded aggregate (CGA) or Type3 – is trafficked, the unbound surface will rut and become clogged. If the hydraulically bound coarse graded aggregate (HBCGA) base or block surface is trafficked it will become clogged. Options to overcome these issues are:

1. Design the layout of the roads and parking bays with a combination of CBPP and conventional impermeable pavements and restrict construction traffic and storage of materials to the conventional pavements only.
2. For System C CBPP use a capping layer to create temporary access. (For CBPPs with a low CBR a capping layer or subgrade improvement layer is required.) Then complete the construction of the CBPP at the end of the project construction. It may be necessary to construct a capping layer thicker than the original design thickness, to cope with the construction traffic loads. It may also be necessary to repair and trim the capping to return it to the design profile before proceeding with completion of the pavement.
3. Complete the CBPP and overlay with a sacrificial layer to protect the surface and prevent clogging of the block joints. Overlaying the block surface with geotextile or some other protective means may be required to protect the surface of the blocks from damage, scuffing and clogging of the joints.
4. For Traffic Category 5 or greater, a base is required. This base can be HBCGA or impermeable asphalt concrete (AC). If AC is selected this can be used as a temporary impermeable surface and just prior to the installation of the block layer, the AC is cored. For Traffic Category 4 or lower, the AC can be incorporated as an additional layer. In both cases it will be necessary to assess the volume of construction traffic and if required, increase the thickness of the AC to allow for the predicted construction traffic - see Section 8.9. Consideration must be given to dealing with the surface water as it will not be able to infiltrate into the lower pavement layers prior to coring the AC.





# 6. Engineering Design Overview

Previous sections of the *Permeable Paving Manual* provide a basic understanding of CBPP and SuDS, essential for effective use of the technical guidance that follows. The engineering design process described here enables the thicknesses and properties of all of the materials within the structure of the pavement to be selected and specified. It aligns with the recommendations of BS 7533-103:2026 *Design and installation of modular permeable pavements* and is consistent with the approach in the *SuDS Manual* (2015). Separate, straightforward design and construction guidance for CBPP on private driveways, patios and other lightly trafficked domestic paving can be found in MPA Precast's *Paving for Rain*.

The design stages discussed here follow the Spatial Planning design of the project and are applied to each area/compartment of CBPP. The design procedure is summarised in Figure 24.

From an engineering perspective, a CBPP must be designed to achieve two aims:

- Support the traffic loads over its design life (structural design)
- Manage surface water effectively (hydraulic design)

The design process requires the determination of both the structural thickness and the hydraulic thickness. The structural and hydraulic thicknesses are compared and the greater thickness selected as the design thickness.

If the structural thickness is greater than the hydraulic thickness, then this means that there exists spare hydraulic storage capacity that can be utilised to accommodate runoff from adjacent areas. If there is no spare hydraulic capacity and there is a requirement to accommodate runoff from adjacent areas, then the hydraulic thickness will need to be increased accordingly. If necessary the sub-base and/or capping layer thickness can be increased to provide additional storage. Finally, the 'half-empty' time is determined and ancillary aspects, such as flow conveyance through the sub-base, outlet spacing and flow control devices, are designed.

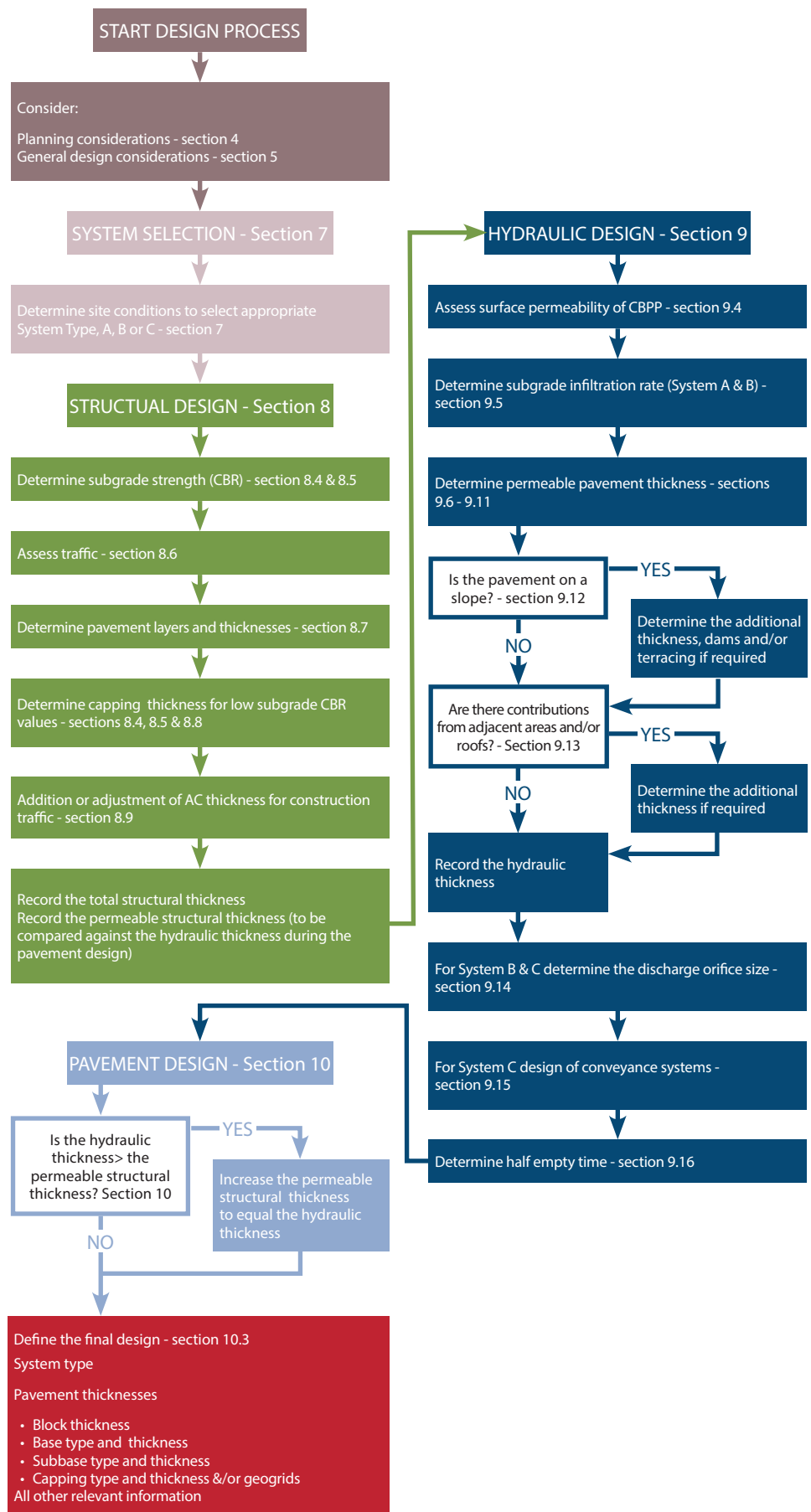


Figure 24: Engineering design  
procedure for CBPP

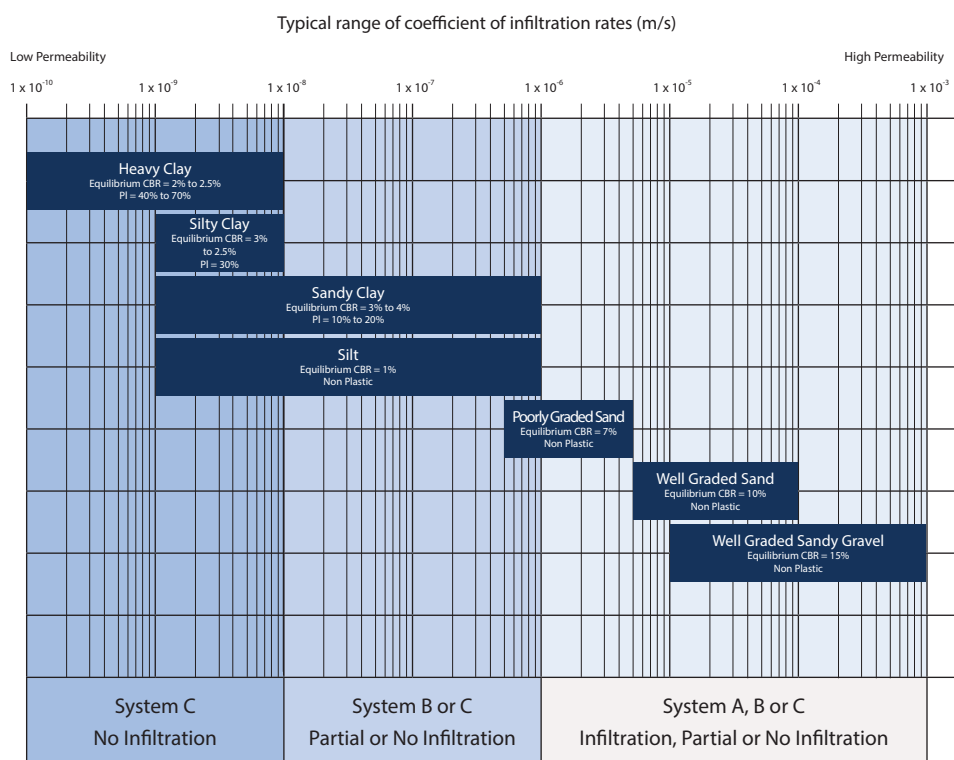
# 7. System Selection

The three types of CBPP construction – Systems A, B and C – are described in Section 3. While sharing the same surface appearance, structural performance and water treatment capabilities, the three systems have very different hydraulic characteristics and applications. System A simply allows all the water to infiltrate to the subgrade after temporary storage, while System C is designed to discharge water to an outlet and System B in effect provides a combination of both.

Unless a liner is required for a specific purpose, unlined systems are preferred, offering significant environmental benefits including support of tree growth within developments. Not having a liner also makes reinstatement much easier. Wherever the overall project design includes containment of the water for harvesting (see 5.3), use within the landscape or other purposes, System C CBPP should be used. Otherwise, the following criteria will determine the appropriate system selection.

## 7.1 Subgrade Infiltration Rate

Subgrade infiltration rate is the key selection criterion, derived from infiltration tests on site (see Appendix 1). However, CBPPs infiltrate water into the ground at much shallower depths than traditional soakaways and tests should be carried out close to the final formation level of the pavement. Generally, this will be less than 1m depth and with a lower head of water, replicating the CBPP behaviour. Guidance on appropriate pavement systems for a range of subgrade and site conditions, including infiltration rates derived from infiltration tests, can be found in Figure 25 and Table 2.



Note: A significant proportion of clay and silt (>15% of particles less than 63µm) will reduce the infiltration rates and CBR values of sand and of gravels.

Figure 25: Soil classification guide



| Ground Characteristics                                                                                                 |                                           | Type A:<br>Total Infiltration | Type B: Partial<br>Infiltration | Type C:<br>No Infiltration |
|------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-------------------------------|---------------------------------|----------------------------|
| Infiltration rate of<br>subgrade (m/s)                                                                                 | $1 \times 10^{-6}$ to $1 \times 10^{-3}$  | ✓                             | ✓                               | ✓                          |
|                                                                                                                        | $1 \times 10^{-8}$ to $1 \times 10^{-6}$  | ✗                             | ✓                               | ✓                          |
|                                                                                                                        | $1 \times 10^{-10}$ to $1 \times 10^{-8}$ | ✗                             | ✗ <sup>(1)</sup>                | ✓                          |
| Highest expected water level within<br>1000mm of formation level                                                       |                                           | ✗                             | ✗                               | ✓                          |
| Pollutants present in subgrade                                                                                         |                                           | ✗                             | ✗                               | ✓                          |
| Ground conditions such that infiltration<br>of water is not recommended (solution<br>features, old mine working, etc.) |                                           | ✗                             | ✗                               | ✓                          |

Note:

1. Partial infiltration systems may be used in soils with infiltration rate less than  $10^{-8}$  m/s but the infiltration of water is not allowed for in the storage design. This helps with the provision of interception.

Table 2: Guidance on selection of a pavement system type

## 7.2 Groundwater Level

For Systems A and B, the highest recorded groundwater level should normally be greater than 1000mm below the bottom of the permeable construction. This is to allow filtration of pollutants in the soil below the pavement and also to prevent groundwater rising and reducing the available storage in the permeable sub-base. In some cases, a minimum of 0.5m is acceptable for CBPP (because the risk of pollution below the treatment system is very low). If there is a high groundwater table, assess the risk of the groundwater level being high for prolonged periods and the consequences of any overland discharge from the permeable pavement.

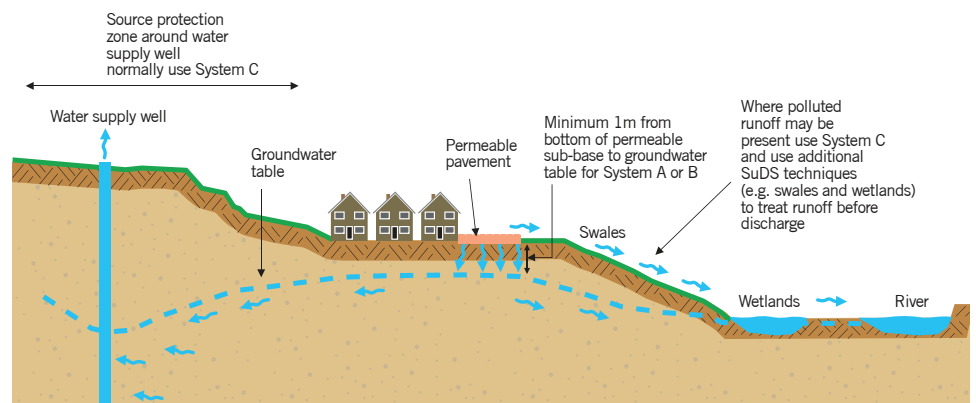


Figure 26: Pollution prevention considerations.

## 7.3 Pollution Prevention

There are defined areas around water supply boreholes known as ‘source protection zones’ (Figure 26). In these areas the use of System A or B CBPPs may not be appropriate and System C with a liner membrane may be necessary (but not always: a risk assessment may show that a liner is not necessary). The use of CBPPs in these locations should follow the advice provided by the Regulator, e.g. in England, Environment Agency (2017).

Detailed groundwater risk analysis following normal good practice can be undertaken to confirm whether CBPP will be acceptable on its own or if additional treatment stages are required. In one example, the use of CBPP within a source protection zone was shown to pose a lower risk to the water supply borehole than the use of a large soakaway outside the zone. This was because the CBPP treated the runoff to remove pollution and dispersed the flows over a wide area at a low intensity when compared to a traditional soakaway.

System A and B infiltrating pavements may be used on brownfield sites when it can be demonstrated that the risk posed by leaching of contaminants is at acceptable levels. It is often possible to show by risk assessment that the dispersed flow from CBPP will not mobilise contaminants in the ground. If any site is classified as a ‘high pollution risk’ and there is an unacceptable risk that stormwater can infiltrate the groundwater, infiltrating CBPPs on their own are not recommended and either System C with a liner should be used or additional treatment stages provided, such as ponds, basins or wetlands (see Figure 26, Table 2 and Environment Agency, 2017). Such applications include: vehicle scrap yards, recycling facilities, petrol stations, service and maintenance facilities, and other locations that handle potentially polluting substances.

## 7.4 Environmental Licences And Permits

Drainage discharges from some high pollution hazard sites either to the ground or to surface watercourses may require an environmental licence or permit. Low to medium hazard sites are not likely to require such permission.

A summary of the UK regulations for discharges to groundwaters is provided below and details of the water quality design and permit requirements can be found in the SuDS Manual (2015).

- The regulators in England and Wales should be consulted if a discharge meets the definition of a ‘groundwater activity’ under the Environmental Permitting (England and Wales) Regulations 2016 and does not meet an appropriate exemption.
- In Northern Ireland, other local regulations apply.
- In Scotland, an authorisation under the Controlled Activity Regulations (CAR) or a pollution prevention and control (PPC) permit may be required. In Scotland, certain discharges to surface waters are automatically authorised by ‘general binding rules’ (GBR). In such cases, it is not necessary to apply for authorisation from SEPA, but the design and discharge must comply with the conditions of the GBR.

# 8. Structural Design

## 8.1 Permeable Pavement Components

Typical components of a concrete block permeable pavement are:

### **Paving Blocks**

The surfacing comprises concrete blocks specifically manufactured for CBPPs. They permit water to enter and infiltrate into the pavement from its surface either by the use of oversize spacer nibs or by special shapes that create a space between adjacent blocks for filling with jointing aggregate. It is also possible to use conventional concrete blocks or paving units, without spacer nibs, or flag paving. These paving units can be laid, with or without separate spacers, to achieve suitable joint spaces for filling with jointing aggregate. They are only suitable for pedestrian and light traffic applications. Advice on suitability of products and applications should be sought from the paving manufacturer.

### **Jointing Aggregate**

The joint spaces or voids between the paving units are filled with aggregate, of a specific grading and physical properties, that allows the infiltration of water into the laying course. Low permeability material such as sand is not permissible.

### **Laying Course**

Paving units are installed over a laying course of aggregate, of a specific grading and physical properties, that allows the infiltration of water into the underlying layer. Low permeability material such as conventional block laying course sand is not permissible.

For the determination of the hydraulic design thickness, the jointing and laying course aggregates are considered to have no hydraulic storage capacity.

### **Base**

For areas subject to Traffic Category 5 or greater (see Table 5) a base is required over the sub-base. The base is a stronger and stiffer layer of pavement material than the sub-base. The thickness of this base is a function of the Traffic Category - refer to Table 5 to determine the base thickness and material type. The base is either permeable hydraulically bound coarse graded aggregate (HBCGA) or impermeable asphalt concrete (AC). HBCGA is CGA with the addition of a cement binder.

For Traffic Category 4 or lower, the AC can be incorporated as an additional layer to protect the CGA during construction. In both cases it may be necessary to increase the thickness of the AC to allow for the predicted construction traffic - refer to Section 8.9 for details.

**Note:** Before the installation of the paving units the AC is cleaned, to remove mud and detritus, then cored or perforated with 75mm diameter holes on a 750mm orthogonal grid to form cored asphalt concrete (CAC), so as to allow the infiltration of water into the pavement layers below. The holes are filled with laying course aggregate.

For the determination of the hydraulic design thickness, CAC is considered to have no hydraulic storage capacity and HBCGA a porosity of 30% (see Table 10).



### **Sub-base**

For Traffic Categories 1 to 8, a permeable sub-base is required. The thickness of the sub-base is a function of the Traffic Category - refer to Table 5 to determine the sub-base thickness. CGA comprises crushed angular aggregate of a particular grading and physical properties, to provide a structural layer.

For the determination of the hydraulic design thickness, CGA is considered to have a porosity of 30% (see Table 10). Higher values may be used if the material is tested on site to confirm the porosity. Not only does it provide a connected network of voids for water but also a large surface area for biological treatment of organic pollution such as hydrocarbons, which is supported by extensive research. This requires free passage both of air (oxygen) and waste products (CO<sub>2</sub>), which is also critical for the enhancement of urban tree growth provided by CBPP.

'MOT Type 3' can also be used with CBPP, as described in BS7533-103 and The SuDS Manual. Type 3 for CBPP has a different grading, with minimal fines, compared to that given for Type 3 in the current version of the Specification for Highway Works.

**Note:** The porosity of HBCGA, CGA and Type 3 needs to be confirmed by testing or certification from the aggregate supplier. The hydraulic design thicknesses given in Table 10 are based upon a porosity of 30%. Therefore, if the proposed aggregate differs from 30%, then adjustments to the hydraulic thicknesses will have to be made.

### **Capping**

For pavements where the subgrade CBR value is below 5%, a subgrade improvement and/or a capping layer will be required. For System A and B (and unlined System C) pavements that allow water to infiltrate into the subgrade the capping must have an infiltration rate equal to or greater than the subgrade and be unaffected by the infiltration of water.

### **Impermeable Geomembrane**

System C pavements may include an impermeable geomembrane which holds all of the water entering the pavement and being detained within it.

### **Geotextiles**

Lower Geotextile - This geotextile may be required as a separation layer between the subgrade and capping.

Upper Geotextile - between the laying course and the underlying pavement layer, whilst not specifically prohibited and which could provide some advantages in specific situations, should generally be avoided for several reasons including structural performance, complications with reinstatement following services access and costs. It is unnecessary when the gradings of the laying course aggregate and the sub-base or base aggregate are compatible, to avoid migration of the laying course into the pavement layer below (see section 11.6).

### **Specifications And Materials**

Refer to Section 11 for details of all the materials and components within a CBPP.

## 8.2 Structural Design Principles

The main principle behind road pavement design is the distribution of concentrated loads from vehicle wheels down through the pavement to the weaker subgrade below so that it can support the loads without excessive deformation or failure. The strongest pavement materials are used at the top, where the wheel pressure is highest, reducing in strength further down the pavement. The layers of a typical CBPP road pavement are shown in Figure 27.

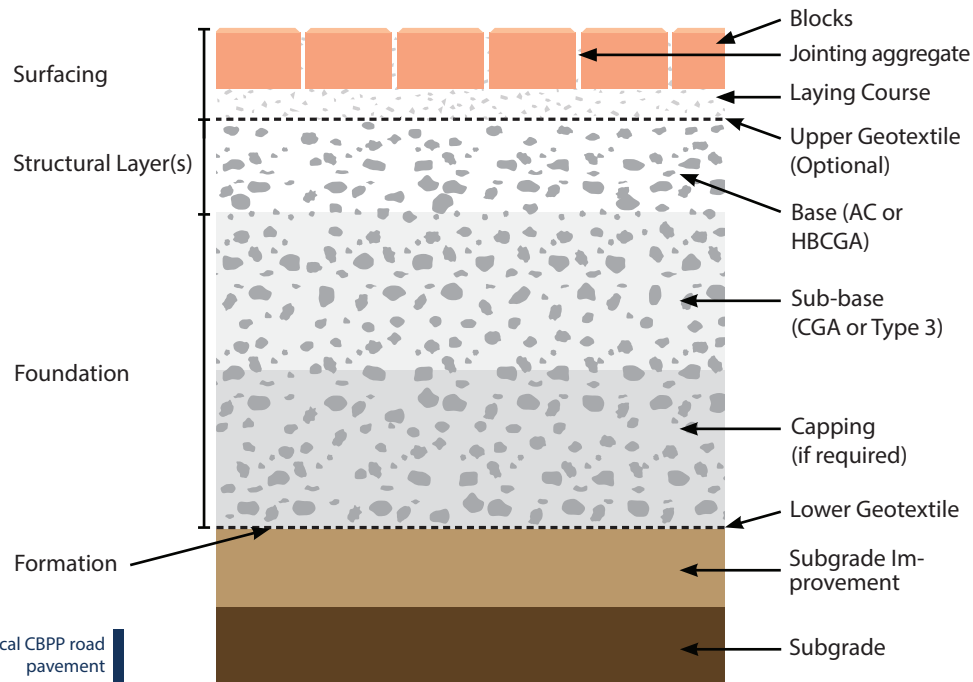


Figure 27: A typical CBPP road pavement

The surfacing comprises concrete paving blocks with permeable jointing aggregate and laying course, and should resist excessive deformation when trafficked. The structural layers, usually comprising either HBCGA or AC, are particularly important where regular HGV traffic is anticipated. The foundation layer provides the base and construction platform for the layers above, spreading loads across the formation layer.

## 8.3 The Structural Design Process

The structural design process comprises the following stages:

### Stage 1 – Subgrade assessment

Use Table 3 to determine the equilibrium CBR value of the subgrade.

### Stage 2 – Traffic assessment

Use Table 4 to select the Traffic Category, from 1 to 9.

### Stage 3 – Pavement layer thicknesses

Use Table 5 to determine the pavement layer thicknesses.

### Stage 4 – Adjustment for low CBR

Adjust the thicknesses from Table 5 for pavements installed over subgrades of CBR less than 5% using Table 7.

### Stage 5 – Construction traffic

Consider the need for site access. CBPP pavement layers must be kept clean during the construction phase. This can be inconvenient when the construction method requires that the roads be installed early and can be used for site access. Various methods can be used to resolve this issue: see Section 13.7.

## 8.4 Subgrade Assessment

The first stage of the design is to assess the CBR value of the subgrade. CBR varies inversely with moisture content (as the latter increases the CBR value decreases). The equilibrium CBR value is the long term value that occurs once the pavement is constructed and the moisture content of the subgrade comes into equilibrium with suction forces (e.g. as a result of unloading due to excavation, groundwater levels and wetting as a result of water storage in the sub-base). It may be possible to use higher CBR values for System C where a robust geomembrane liner is provided.

This can be determined by carrying out laboratory CBR tests in accordance with BS 1377-2 (BSI, 2022) at the equilibrium moisture content as described in LR1132 (Powell et al., 1984). The CBR should be tested after saturation (unless System C is used with a liner). The Interlocking Concrete Pavement Institute (2017) recommends 96 hours saturation period. Alternatively, the value should be estimated based on the type of soil (plasticity index and grading) following the guidance in LR1132 and BS 7533, as provided in Table 3.

| Soil Type                  | Plasticity Index | Guideline equilibrium CBR Value for CBPP design <sup>1,3</sup> (%) |
|----------------------------|------------------|--------------------------------------------------------------------|
| Heavy Clay                 | 70               | 2                                                                  |
|                            | 60               | 2                                                                  |
|                            | 50               | 2                                                                  |
|                            | 40               | 2.5                                                                |
| Silty Clay                 | 30               | 3                                                                  |
| Sandy Clay                 | 20               | 4                                                                  |
|                            | 10               | 3                                                                  |
| Silt <sup>2</sup>          | --               | 1                                                                  |
| Sand (Poorly Graded)       | --               | 7                                                                  |
| Sand (Well Graded)         | --               | 10                                                                 |
| Sandy Gravel (Well Graded) | --               | 15                                                                 |

Notes:

1) Assumes thin construction. If pavement thickness (from surface to subgrade) is greater than 1200mm refer to Interim Advice Note 73/06 Rev 1 (Highways Agency, 2009) to obtain equilibrium CBR values for clay and silt only.

2) Estimated assuming some probability of material saturating.

3) These CBR values assume a high water table and that the subgrade may be wetted during the life of the pavement. If a suitable impermeable membrane is used higher values may be appropriate.

Table 3: Equilibrium Subgrade CBR Estimation for CBPP

The highest values of Plasticity Index measured on a site should be used (to give the lowest CBR value) for the design, unless there are a substantial number of results available to allow the mean or other statistical value to be used with confidence (note that if the mean is used there will be an increased risk of pavement failure in some areas). It may be possible to remove soft spots and therefore ignore those low CBR values which relate to the removed material.

On sites where the CBR varies from place to place, appropriate designs may be provided for different parts of the site using the lowest CBR recorded in each part. Once the subgrade is exposed during construction the CBR value of the soil should be confirmed by laboratory testing of CBR samples (BS1377-2 (BSI, 2022) or using insitu methods (BS 1377-9 (BSI, 2025)). This is the short term CBR value at the time of construction. If the short term CBR is found to be less than the equilibrium CBR, the subgrade must either be improved to achieve the equilibrium CBR or the pavement thickness redesigned. The reason for this is because construction during very wet periods of weather can adversely affect the soil strength and lead to lower CBR values.

In summary the final Design CBR value should be the lower of:

1. The equilibrium CBR value obtained from CBR tests at equilibrium moisture content (saturated for 96 hours unless System C with a liner is used) or based on plasticity and grading results using the correlations above; or
2. The short term CBR value obtained from CBR tests on the subgrade, taken once it is exposed for construction.

Where the CBPP is to be constructed on a subgrade of engineered fill the equilibrium CBR value of the engineered fill should be obtained from CBR tests where the fill material is first compacted into the test mould at optimum moisture content prior to testing. Alternatively, the equilibrium CBR value of the engineered fill may be obtained based on plasticity and grading results using the correlations above.



## 8.5 Subgrade With Low CBR (CBR < 2.5%)

The minimum permitted Design CBR is 2.5% for normal pavements and this also applies to CBPPs. Subgrades with a lower Design CBR are considered unsuitable to support a pavement. In these cases a subgrade improvement layer should be provided to permanently improve the load bearing capacity of the subgrade. This can be achieved by removing the weak material to sufficient depth and replacing it with suitable fill material. The thickness removed may typically be between 0.5 and 1.0m. Although the new material may be of better quality, the new Design CBR should be assumed to be equivalent to 2.5%, in order to allow for effects of any softer underlying material and the potential reduction in the strength of the replacement material to its long-term CBR value.

The existing subgrade materials may also be improved by the addition of lime and/or cement to give an acceptable long term CBR value if the areas with a low CBR are extensive. This will only be possible with System C pavements with a liner (no infiltration) as the permeability of System A and B pavements may be reduced. The impact of water on the stabilised materials should be carefully considered.

The incorporation of a geosynthetic material or geogrid into the foundation design may also overcome the issue of a weak subgrade. Specialist advice should be sought to adopt an alternative design CBR value that may be necessary, based on testing or previous experience with the specific geosynthetic and the materials being used to construct the pavement.

## 8.6 Traffic Assessment

Table 4 shows the Traffic Categories for the design of CBPPs. It also shows the maximum number of standard 80kN axles for each category based upon the assumption that pavements are designed to achieve a life of 25 years' trafficking. Using knowledge of either the number of standard 8000kg axles or the number of commercial vehicles per day, or the end use of the pavement, select one of the Categories. Note that designs for Categories 9 to 11 are not covered by this guidance. Also, there is a significant difference between pavements designed for Traffic Categories 4 and 5.

| Traffic category | Cumulative Standard Axles (msa) | Road Category <sup>1</sup> | Typical application                                                                                                                                                                                           |
|------------------|---------------------------------|----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 9                | ≤30                             | 1                          | Adopted highways and commercial/industrial developments used by a high number of commercial vehicles                                                                                                          |
| 8                | ≤10                             | 2                          |                                                                                                                                                                                                               |
| 7                | ≤2.5                            | 3                          |                                                                                                                                                                                                               |
| 6                | ≤0.5                            | 4                          | Adopted highways and other roads used by a moderate number of commercial vehicles<br>Pedestrian areas subjected to regular overrun of commercial vehicles<br>Industrial premises<br>Petrol station forecourts |
| 5                | ≤0.05                           | N/A                        | Pedestrian areas subjected to occasional overrun of commercial vehicles<br>Car parks receiving occasional commercial vehicular traffic                                                                        |
| 4                | ≤0.007                          | N/A                        | Urban footways with no planned vehicular overrun<br>Pedestrian areas used by light goods vehicles emergency vehicles and maintenance vehicles                                                                 |
| 3                | N/A                             | N/A                        | Footways, pedestrian and cycle areas, domestic driveways or access routes subject to manoeuvring of cars and light goods vehicles<br>No access for other commercial vehicles                                  |
| 2                | N/A                             | N/A                        | Footways, pedestrian and cycle areas, parking spaces subject to cars and light goods vehicles<br>No access for other commercial vehicles                                                                      |
| 1                | N/A                             | N/A                        | Footways, pedestrian and cycle areas, excluding all vehicles                                                                                                                                                  |

**Notes:**

1. For road categories, see *Specification for the reinstatement of openings in highways*, Table S1.1
2. Where mobile elevated working platforms will operate with stabilisers deployed, adopt a minimum of Traffic Category 4.

**Table 4: Traffic Categories for CBPP design.**

## 8.7 Selection of Pavement Layer Thicknesses

Use Table 5 to select pavement layer thickness and material types according to Traffic Category. Note that the resulting pavement will be suitable for subgrades of CBR 5% or greater.

Table 5: Typical construction thickness over subgrade with 5% CBR or greater

| Traffic category (BS7533-101) | Surface layer minimum thickness | Laying course nominal thickness                                                | HBCGA (porous) or AC (cored) | Sub-base – CGA | Design basis                                       |
|-------------------------------|---------------------------------|--------------------------------------------------------------------------------|------------------------------|----------------|----------------------------------------------------|
| 9 and over                    |                                 | Site specific using MPA Precast guide for heavy duty pavements (Knapton, 2008) |                              |                | Knapton (2008)                                     |
| 8                             | 80 mm                           | 50 mm                                                                          | 300mm HBCGA or 220mm AC32    | 150 mm         | ICPI Permeable Design Pro                          |
| 7                             | 80 mm                           | 50 mm                                                                          | 200mm HBCGA or 130mm AC32    | 150 mm         |                                                    |
| 6                             | 80 mm                           | 50 mm                                                                          | 125mm HBCGA or 90mm AC32     | 150 mm         |                                                    |
| 5                             | 80 mm                           | 50 mm                                                                          | 100mm HBCGA or 70mm AC32     | 150 mm         |                                                    |
| 4                             | 80 mm                           | 50 mm                                                                          | --                           | 300 mm         | Knapton et al (2012) and ICPI Permeable Design Pro |
| 3                             | 60 mm                           | 50 mm                                                                          | --                           | 225 mm         |                                                    |
| 2                             | 60 mm                           | 50 mm                                                                          | --                           | 150 mm         |                                                    |
| 1                             | 60 mm                           | 50 mm                                                                          | --                           | 100 mm         |                                                    |

**Notes:**

- For laying patterns appropriate to particular traffic categories, see BS7533-103.
- Some types of paving unit can be machine laid. Advice should be sought from the manufacturer on colours, paving types, paving thickness and suitable laying patterns for particular applications.
- For traffic categories 0 and 1, it is possible to use traditional paving units (e.g. conventional concrete blocks, flags) provided suitable joint spacers are used to create a suitably wide joint for long-term performance. Advice on suitability of products and applications should be sought from the paving manufacturer.
- HBCGA refers to hydraulically bound coarse graded aggregate (conforming to BS EN 14227-1 (BSI, 2013b), minimum cement content 3%, strength class C5/6 as defined in BSI (2013b) and minimum permeability 20,000 mm/hr).
- AC refers to asphalt concrete (AC 32 dense 40/60 designed in accordance with BS EN 13108-1 (BSI, 2006)). This AC is impermeable and is often incorporated to provide temporary access for construction traffic. Prior to the installation of the paving units the AC is cleaned, if required, to remove mud and detritus, cored or perforated with 75mm diameter holes on a 750mm orthogonal grid to form CAC. The holes are filled with CGA, Type 3 or laying course aggregate.
- Pavements sustaining Traffic Categories 5 to 8 include HBCGA or AC32, whereas pavements sustaining Traffic Categories 1 to 4 only require CGA or Type 3. Therefore, if there is any doubt about the level of likely HGV traffic, it is safer to select category 5 or above. Particular care should be taken in the design of shared surfaces where adjacent areas should be protected from HGV overrun or designed for regular overrun.

System A and System B infiltrating pavements include a geotextile material at the interface between the coarse graded aggregate and the subgrade. This geotextile is not brought to the surface at the perimeter of the pavement. Where System C pavements include a geomembrane below the CGA or Type 3 storage layer it is brought up the sides to provide water storage.

It is possible to refine site-specific designs using analytical pavement design or software such as Permeable Design Pro published by the ICPI in the USA. The program has been used to help assess the design thicknesses in the preceding table. The properties assumed for the materials in the designs above are summarised in Table 6.



| Material                                                                                                                                                                                                                            | Elastic modulus (MPa)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Structural layer coefficient for use in ICPI Permeable Design | Poisson's ratio |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------|-----------------|
| Concrete blocks (for CBPP) on a 50 mm laying course that meets requirements of BS7533-103                                                                                                                                           | <p>1000 (based on work by Shackel, 2000).</p> <p>Note, evidence from Knapton and Meletiou (1996) and Knapton (2008) is that the modulus of the surface layer has very little effect on the predicted stress on the subgrade and performance of the pavement.</p> <p>Increasing elastic modulus values of the surface layer to justify a reduction in pavement thickness is not normally recommended, as it requires extremely high construction quality, and there is no guarantee that all the joints will be completely full of jointing aggregate for the life of the pavement to maintain an elevated elastic modulus.</p> | 0.3                                                           | 0.40            |
| Base - AC32                                                                                                                                                                                                                         | 6000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.3–0.44                                                      | 0.30            |
| Base - HBCGA that meets requirements of CBGM B – Cement Bound Granular Mixture Type B with strength class C5/6 in the relevant sections of the <i>Specification for Highway Works</i> (2025) – document(s) CC201, CC 202 and CC 205 | 4000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.24                                                          | 0.25            |
| Sub-base – CGA in accordance with BS7533-103 or Type 3 in the relevant sections of the <i>Specification for Highway Works</i> (2025) – document(s) CC201, CC 202 and CC 205                                                         | 1000 (note that the main factor that affects stiffness is not the Los Angeles test value but the grading and angular nature of the particles)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 0.09                                                          | 0.35            |
| 5% CBR subgrade                                                                                                                                                                                                                     | 50                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | N/A                                                           | 0.45            |

Table 6: Properties assumed in generic CBPP design in Table 5

# 8.8 Adjustment for Low CBR

The thicknesses in Table 5 apply in the case of subgrade CBR  $\geq$  5%. In the case of lower CBR values, a subgrade improvement and/or capping layer is required (from Knapton et al, 2012), shown in Table 7.

Table 7: Subgrade improvement and/or capping layer requirements for CBR < 5%

| CBR (%) | Requirement                                                                                                         |
|---------|---------------------------------------------------------------------------------------------------------------------|
| 1.0     | Subgrade improvement                                                                                                |
| 2.0     | Subgrade improvement layer<br>(may be incorporated into capping layer to provide a total layer thickness of 350 mm) |
| 2.5     | 300mm capping                                                                                                       |
| 3.0     | 225mm capping                                                                                                       |
| 4.0     | 150mm capping                                                                                                       |

The capping layer design can also incorporate geogrid(s) which can provide a reduced thickness of this layer.

The capping layer should be sufficiently permeable to allow water to percolate through it, without it losing strength, unless System C with a membrane is used. It should also have an infiltration rate that is greater than the material below it. It should also be sufficiently durable and wear-resistant. Alternatively, an increased thickness of coarse graded aggregate can be used. The grading for 6F2 capping (Specification for Highway Works, 2025) can be modified to reduce the amount of fines and make it more permeable (ie less than 5% passing the 63 microns sieve and 0–25% by mass passing the 600 microns sieve). This has been used successfully below infiltrating pavements.

The additional capping thicknesses to be provided in the case of low CBR subgrades can only be determined approximately during the design process because the condition of the subgrade will depend upon site drainage conditions, level(s) of water table(s) and recent weather patterns. The aim is to provide sufficient additional material to ensure that the overlying layers can be compacted successfully. The above values have been found to achieve this but the actual thickness must be determined by site trials undertaken by experienced ground workers.

## 8.9 Allowance for Construction Traffic Using an Asphalt Concrete Layer

As discussed in Section 5.6 (Construction Traffic) there is often a need to use the partially completed CBPP as an access road during the construction of a project. However, if the sub-base (CGA or Type 3) is trafficked, the unbound surface will rut and become clogged. Section 5.6 therefore outlines several options to address construction traffic and protection of the CBPP, with Option 4 being the use of an AC layer over the sub-base (CGA or Type 3). The AC is first used as a temporary impermeable surface and then, just prior to the installation of the laying course and paving units, the AC is cored or perforated to form CAC. If this option is used, then consideration must be given to dealing with the surface water as it will not be able to infiltrate into the lower pavement layers prior to coring of the AC.

For Traffic Categories 0 to 5, the sub-base (CGA or Type 3) is overlaid with 80mm of AC. For traffic categories 3 and 4 the sub-base (CGA or Type 3) thickness can then be reduced to 150mm. For Traffic Categories 6 and above, the thickness of the AC layer is as per Table 5 or 100mm, whichever is the greater. As the AC has no water storage capability it will be necessary to check that the underlying permeable layer has sufficient water storage capacity.

The required thicknesses of the AC and underlying sub-base (CGA or Type 3) are related to Table 5 and the rules stated above, and are shown in Table 8 below.

| Traffic category | Thickness of AC (mm)                                                                                                                                     | Thickness of CGA or Type 3 (mm) |
|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|
| 11               | Areas with axle loads greater than permitted by the Road Vehicles (Construction and Use) Regulations (1986) as amended are not included in this document |                                 |
| 10               | Site specific using MPA Precast guide for heavy duty pavements (Knapton, 2008)                                                                           |                                 |
| 9                | Site specific using MPA Precast guide for heavy duty pavements (Knapton, 2008)                                                                           |                                 |
| 8                | 220                                                                                                                                                      | 150                             |
| 7                | 130                                                                                                                                                      | 150                             |
| 6                | 100                                                                                                                                                      | 150                             |
| 5                | 80                                                                                                                                                       | 150                             |
| 4                | 80                                                                                                                                                       | 150                             |
| 3                | 80                                                                                                                                                       | 150                             |
| 2                | 80                                                                                                                                                       | 150                             |
| 1                | 80                                                                                                                                                       | 100                             |

Table 8: Thicknesses of AC and sub-base (CGA or Type 3) for CBPPs to be used by construction site traffic

# 9. Hydraulic Design

## 9.1 Basic Requirements

The most up to date guidance on the hydraulic design of sustainable drainage systems is provided in ‘The SuDS Manual’ (CIRIA, 2015) and BS 8533 (BSI, 2017), both of which recommend a number of design criteria for the hydraulic performance of SuDS that are intended to reduce the frequency, peak flow rate and total volume of runoff from a site, as well as to remove pollution from the runoff.

This goes beyond previous requirements that have mainly concentrated on reducing the peak rate of runoff. The latest requirements are intended to provide drainage systems with outflow characteristics closer to those of a natural site. They extend the basic compliance criteria included in the National standards for sustainable drainage systems (SuDS), 19 June 2025, published by DEFRA and will provide far more effective and robust systems than those that just meet the basic criteria.

The main requirements in the SuDS Manual (CIRIA, 2015) are:

- Ensure that people and property on the site are protected from flooding
- Ensure that the impact of the development does not exacerbate flood risk at any other point in the catchment of the receiving watercourse.
- Manage overland flow to ensure buildings are not flooded.

CBPPs are an ideal solution for achieving all the requirements listed above. The role of CBPP in the SuDS Management Train is discussed in Section 4.1.

One of the most common mistakes made when designing CBPPs is use of incorrect units. This is because the common parameters are quoted in different units and require conversion when carrying out calculations. The common units and conversions are provided in Table 9.

| Parameter                                               | Units |        |                      |        |                                                            |
|---------------------------------------------------------|-------|--------|----------------------|--------|------------------------------------------------------------|
|                                                         | mm/h  | m/h    | m/s                  | l/s    |                                                            |
| Rainfall                                                | 20    | 0.02   | $5.6 \times 10^{-6}$ | 0.0056 | (note these are all/m <sup>2</sup> which is rarely stated) |
| Infiltration rate of soil                               | 3.6   | 0.0036 | $1 \times 10^{-6}$   | 0.001  |                                                            |
| Flow rate into paving surface (through joints) when new | 4500  | 4.5    | 0.0013               | 1.31   |                                                            |

Table 9: Units and conversions.

The SI unit for reporting soil permeability is m/s. Therefore soil infiltration rates are usually also reported in m/s. The infiltration rate of rainwater into the top surface of CBPP is often compared to rainfall intensity. Rainfall intensity is reported in mm/h and therefore the infiltration of water into the pervious surface is reported in these units.



## 9.2 Assessment of Interception Performance

Studies have shown that the frequency of runoff from CBPPs is significantly reduced when compared to normal drainage systems. The studies show that typically this does not occur from CBPPs for rainfall events up to 5mm and, possibly, even greater. This is known as interception. Kellagher (2013) found that very high levels of compliance with interception criteria are achievable through the use of CBPPs, providing there is a nominal level of infiltration available. This is because during small rainfall events the water soaks into the paving units, laying course and underlying permeable base and sub-base and is then released by evaporation after the rainfall has stopped. Obviously the extent of this depends on the antecedent conditions (i.e. what the weather has been like beforehand). Even with System C pavements with a membrane some interception still occurs. The use of rainwater harvesting (using the CBPP as the storage) can also help to achieve interception.

Design of a drainage system for interception should achieve zero runoff for the first 5mm rainfall for 80% of events during the summer (May to October) and 50% in winter (November to April). The SuDS Manual (CIRIA, 2015) explains the conditions in which it can be assumed that CBPPs provide interception.

Where CBPP is only draining rainfall that falls directly on it (i.e. no additional areas such as roofs or adjacent impermeable areas drain onto or into it) then the CBPP can be assumed to provide 5mm interception. The rainfall up to this depth will be absorbed by the pavement and evaporates. There is a limit to how much rainwater a pavement can absorb and evaporate. Therefore, if the pavement is draining adjacent areas the following criteria must be complied with if it is to provide 5mm interception:

- It must be a Type A or B system or unlined System C (i.e. no waterproof geomembrane);
- The impermeable area draining to the CBPP must not be greater than the area of the CBPP.

Where the infiltration capacity of the ground below the CBPP is greater than  $1 \times 10^{-6}$  m/s, up to 5 times the CBPP area can be added as additional contributing area and interception will still be achieved. Note that the maximum additional area could only be achieved if the water was roof water entering directly into the permeable construction and not being discharged onto the surface of the CBPP. If the water is being discharged onto the surface of the CBPP the 2:1 rules in Sections 4.2 and 4.3 would still apply to avoid excessive silt loading, limiting the size of impermeable area for which interception could be achieved.

Where the CBPP also drains an adjacent impermeable area and is lined (System C), the English *National Standards for SuDS:2025* advise that compliance cannot be deemed to have been achieved and additional downstream interception components will be required. However, in some instances the pavement may still provide interception but this will require detailed assessment and justification.

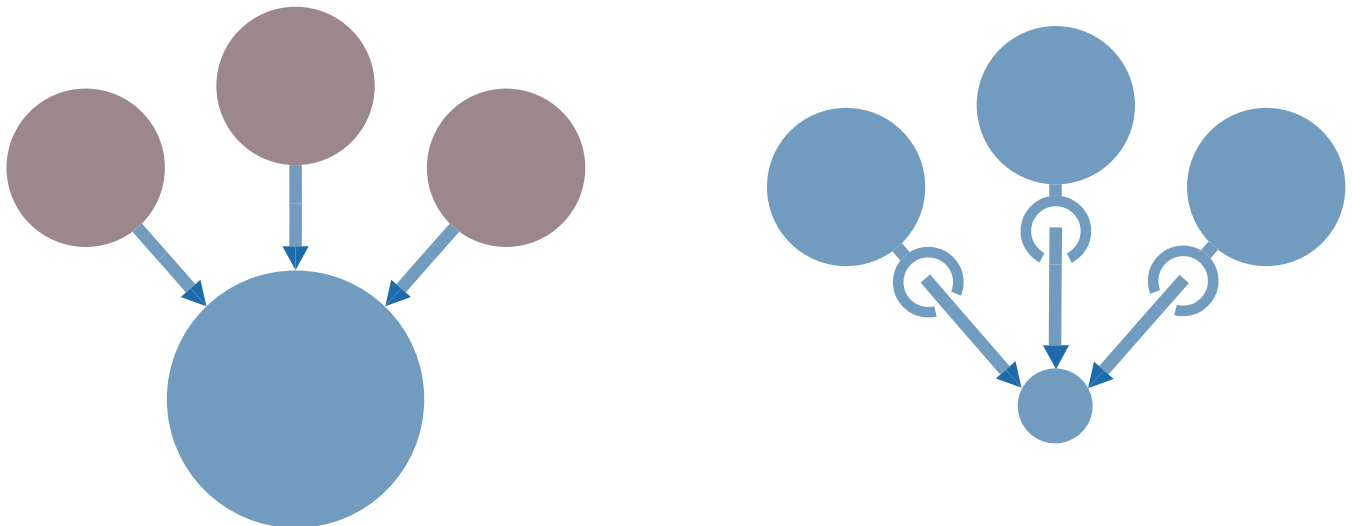
## 9.3 Volume Control and Small Sub-catchments

CBPPs reduce the volume of rainfall that flows out from them significantly and the time it takes for the water to flow out is much longer than for conventional drainage systems. Studies reported in CIRIA report C 582 (CIRIA, 2001) have shown that some 11% to 45% of rainfall flows out from the pavement during a rainfall event. Subsequently over the 2 to 4 days after an event, more water flows out to give a total outfall of between 55% and 100%. Thus CBPP reduces the volume of runoff at critical periods.

However, there are several advantages in considering areas of CBPP deployed around a site as distinct storage compartments, requiring no additional land take. Flow control devices on outfalls of the CBPP can then be used to optimise localised storage and demonstrate compliance with run-off rate requirements for the local authority LLFA. CBPP with flow controls provides an effective design mechanism to collect, clean and store the most polluted runoff from developments 'at source', whilst each sub-catchment is managed separately and prevents contamination of the SuDS management train (as discussed in Section 4.0).

Flow control devices should be robust, simple to maintain and accessible for inspection or adjustment, but do not need protection from blockages, as the water passing from the CBPP will be free of debris. They should be specifically designed for the relatively shallow construction thicknesses and outfall levels typical of CBPPs. See Section 12.6.

Figure 28: Efficient land-use with water storage in CBPP compartments



Conveying collected rainwater directly from hard surfaces results in large components storing polluted water elsewhere on site.

Storing water in CBPP around the site with flow control devices minimises or eliminates the need for further storage components.



## 9.4 Assess Surface Permeability of CBPP

The CBPP must have a surface permeability (or surface infiltration rate) that is sufficient to allow the design rainfall to pass through into the underlying permeable construction without causing ponding on the surface. The SuDS Manual (2015) considers a minimum value of 2500 mm/h (for new pavements) reasonable for a pavement surface to be considered pervious in respect of surface water management. The infiltration capacity of the surface materials is normally stated by the supplier or manufacturer. There is no standard UK or European test procedure for measuring the surface infiltration rate of pervious surfaces. However, ASTM C1781/C1781M-21 has been developed for CBPP (ASTM International, 2015). The SuDS Manual (2015) recommends that manufacturers should provide surface infiltration rates measured using this test method and that it should be adopted as a standard method in the UK with the following amendments:

1. The results should be stated in both mm/h and m/s.
2. Sealing the infiltration ring to the surface to be tested should be achieved using mastic sealant, rapid set mortar or other suitable sealant material.

The amount of water that can pass through a CBPP is dependent on the infiltration rates of joint aggregate, laying course, base and sub-base materials, not the proportion of open area in relation to concrete surface. Geotextiles in the upper layers can also affect the infiltration rate. The percolation through joints will vary with the aggregate used but a typical value for newly laid block paving is 4,000 mm/h which is well in excess of the 2,500mm/h requirement. The sub-base aggregates will have a percolation rate many times this, at least 40,000 mm/h.

Regardless of the high percolation rate of the aggregates used in the openings and base, a key consideration is the lifetime design infiltration of the entire pavement cross-section including the subgrade.

A conservative approach should always be taken when establishing the design infiltration rate of a pavement system. The surface infiltration rate will decrease but stabilize with age, due to the build-up of detritus in the jointing aggregate. This effect is summarised in Figure 29 and it can be seen that long service lives can be expected from CBPPs, which is borne out by experience of older pavements. To ensure a long service life, it is essential that care is taken to protect the pavement during construction and from landscape runoff.

American and German experience recommends that the design surface infiltration rate should be 10% of the initial rate, to take into account the effect of clogging over a 20-year design life without maintenance.

Even after allowing for clogging, studies have shown that the long-term infiltration capability of CBPPs will normally substantially exceed UK hydrological requirements (for example, an extreme storm of 100mm/hour is shown blue in Figure 29). Therefore CBPPs can be designed to handle both prolonged rainfall and short duration storms. CIRIA Report C582 gives further information on measured infiltration rates.

The above does not apply to the infiltration rate of water into the ground below the pavement foundation which is a different parameter to the surface infiltration rate of the block paving.

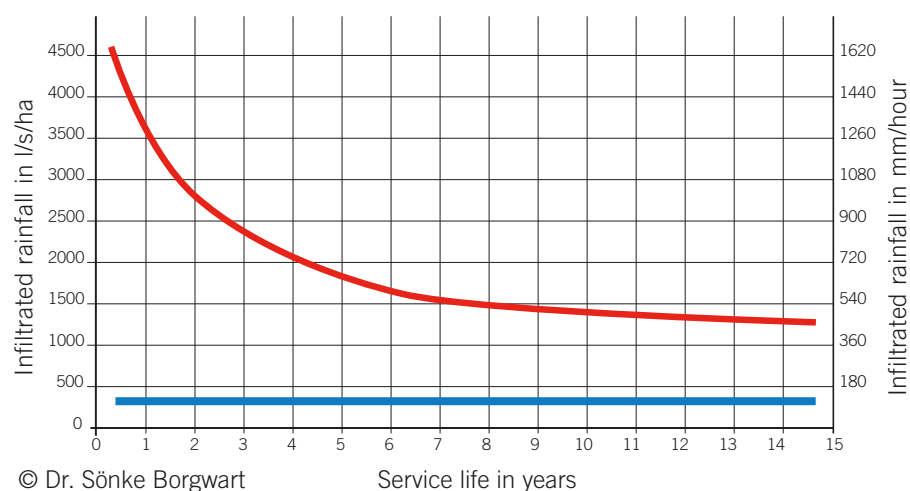


Figure 29: Typical reduction of surface infiltration rate over time.

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Service life in years

## 9.5 Determine Subgrade Infiltration Rate (Systems A and B)

The infiltration rate or coefficient is a measure of how quickly water soaks into the subgrade below the bottom of the CBPP. Infiltration tests should always be undertaken in order to determine infiltration coefficients for design purposes: see Appendix 1. Any testing should be as extensive as possible and supported by evidence of wider soil characteristics, in order to avoid misrepresentation of relevant soil properties. Testing may be carried out as part of the site investigation report.

## 9.6 Determine Rainfall Characteristics and Allow for Climate Change

There are a number of methods that can be used for estimating rainfall and runoff from developed sites, which are discussed fully in the SuDS Manual (2015).

It is accepted that the earth's climate is changing. The most recent studies have predicted that:

- Winters will become milder and wetter with more intense rainfall events.
- Summers will be hotter and drier.
- Heavy rainfall events will become more frequent.

The 'Foresight Flooding Future Report' (Evans et al 2004) concluded that effective land management (including drainage) must be put into place to protect urban areas from flooding in the future. To allow for climate change the rainfall intensity should be increased by an appropriate amount. Typical values of 30% increase on the 1 in 100 year rainfall intensity is commonly required by the regulators but is site specific.

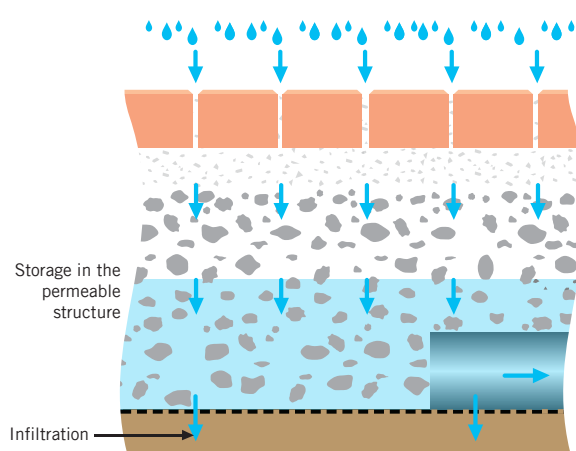
The CBPP limits the peak rate of runoff from a site (usually to the green-field runoff rate). The calculations are completed for a range of return periods and durations and the maximum storage from the calculations is the design storage requirement.

## 9.7 Determine Required Sub Surface Storage Capacity

The volume of permeable construction required for attenuation storage is typically calculated using common drainage design software. For smaller sites, simple software such as that found at [www.uksudstools.com](http://www.uksudstools.com) or the design tables in this document may be used.

For the majority of systems the volume of water that enters the CBPP during a storm is greater than the volume of water that flows out. Therefore the excess water (defined below) must be stored within the underlying permeable construction to prevent surface flooding (Figure 30).

Figure 30: Attenuation and infiltration storage volume.



**Excess volume of water  
requiring storage**

**=**

**volume of rainfall –  
volume of outflow**



## 9.8 Design Criteria

SuDS are designed to allow water to infiltrate into the ground or discharge via pipes. Where discharge is via pipes, the flow is restricted to either greenfield runoff rate or some other reduced flow rate agreed with the LLFA.

In both cases, during a rainfall event, the water leaves the sub-base at a rate that is slower than it enters. Therefore, the sub-base must provide temporary storage of water. The volume of storage required is the difference between the volume of runoff entering and the volume of water leaving.

Key elements of the hydraulic design are therefore:

- **Rainfall estimation** - Lead Local Flood Authorities will require any surface water drainage design to use Flood Estimation Handbook (FEH) rainfall data.
- **Infiltration rate and testing** (for infiltration systems, System A and B) – see Appendix 1. Permeable pavements allow water to infiltrate to the ground below them at shallow depth. For small rainfall events up to 5mm the water soaks into the blocks, jointing, laying course and sub-base materials before evaporating. Water accumulates in the sub-base and soaks into the ground only during larger rainfall events. This means that the ground below the sub-base is only partially saturated when most infiltration occurs. The head of water in the sub-base is shallow and, in many cases, less than 300mm depth. Thus, large and deep BRE infiltration tests are not appropriate to determine the infiltration rate below permeable pavements and the BRE 365 method should not be used. Furthermore, the infiltration test methods that are suitable for permeable pavement are not limited to those described in BS8582 (7.6.2). Advice on suitable infiltration tests is provided in Appendix 1.
- **Greenfield runoff rate** (for System C attenuation systems) - a rough estimate of the runoff that would occur from a natural catchment. Various methods of calculation are available (See the SuDS Manual) and the approach used should be agreed with the LLFA. For small sites, values between 2l/s/ha and 5l/s/ha may be used for outline design.

## 9.9 Design Methods

The design of permeable pavements is normally undertaken using drainage design software packages that incorporate the FEH data. This approach is especially important on larger sites, sloping sites or ones that are very flat to ensure that adequate compartmentalisation is provided and the whole system will work as intended. Using modelling software also ensures that use of available storage is optimised. The design calculations ensure that the sub-base is sufficiently thick and has sufficient void space (porosity) to temporarily store and then drain the excess water.

The UKSuDS website ([www.uksuds.com](http://www.uksuds.com)) also provides tools that may be used for outline design.

## 9.10 Designs Using Software

Drainage design software can be used to design drainage systems that include CBPPs. This allows the performance of the whole drainage system and the impact of the CBPP to be modelled and tested to satisfy all the required design criteria. The simplest approach is to consider the CBPP as an infiltration or storage device, taking into account the following factors:

- Storage volume in the underlying permeable construction
- Rate of infiltration or restricted outflow rate.

For larger sites, those that are terraced or ones that are very flat, the use of modelling software is recommended to ensure that the whole system will operate as anticipated and that use of the available storage is optimised.

Another approach is to consider the CBPP as a sub-catchment that provides a hydrograph to be applied to the network model. Simple bulk mass balance and simplified flow equations can be used to model the movement of water into and out of the underlying permeable construction. Other factors that can be taken into account include:

- Evaporation
- Initial infall loss
- Runoff routing.

Once the required storage in the CBPP is estimated from the model the thickness of underlying permeable construction can be determined.

The available storage in the base/sub-base layer is determined by the volume of the permeable construction, the effect of any slopes that will decrease the available storage and the usable voids (ie voids that are freely draining) within the aggregate. A commonly used value of porosity is 30% for the aggregates that meet the requirements for coarse graded aggregates in BS7533-103. Care should be taken, if using values higher than this, that all the voids in a material are free draining (e.g. clay soils may have a porosity but the voids are very small and not suitable for storing water).

**Note:** The porosity of HBCGA, CGA and Type 3 needs to be confirmed by testing or certification from the aggregate supplier. The hydraulic design thicknesses given in Tables 10 are based upon a porosity of 30% for pavements with zero slopes. Therefore, if the proposed aggregate differs from 30%, then adjustments to the hydraulic thicknesses will have to be made.

The available storage volume is provided by the void space in the permeable construction:

$$\text{Available attenuation storage in the permeable construction} = \text{Volume of permeable construction} \times \text{porosity in the soil/aggregate/geocellular layers designed to be the storage volume}$$

## 9.11 Simple Designs Using Tables

For very small sites the thicknesses in Tables 10 and 11 may be used for outline design purposes for Systems A and C. More detailed design is required for System B. These simple designs are based on FEH rainfall data and will provide interception, attenuation and long-term storage.

**Interception and volume control** - The SuDS manual and BS 8582 both require that SuDS design controls the volume of runoff, as well as the rate of runoff, from a site. The volume of water is partly managed by providing interception and partly by delaying runoff from a site. BS8582 advises that permeable paving provides effective interception (providing it is not managing runoff from excessively large adjacent impermeable areas). Interception provided by CBPP prevents runoff being discharged from a site for the majority of small, frequent rainfall events. Volume control involves reducing the overall volume of runoff from longer return period events.

| Infiltration rate (m/s) | Location       | 1 in 10 years (10% AEP) | 1 in 30 (3% AEP) | 1 in 100 (1% AEP) | 1 in 100 years + 40% climate change |
|-------------------------|----------------|-------------------------|------------------|-------------------|-------------------------------------|
| 1 x 10 <sup>-7</sup>    | Manchester     | 0.207                   | 0.271            | 0.360             | 0.519                               |
|                         | London         | 0.193                   | 0.262            | 0.358             | 0.517                               |
|                         | Inverness      | 0.208                   | 0.265            | 0.341             | 0.493                               |
|                         | Glasgow        | 0.183                   | 0.234            | 0.303             | 0.440                               |
|                         | Durham         | 0.209                   | 0.268            | 0.347             | 0.501                               |
|                         | Sheffield      | 0.236                   | 0.306            | 0.402             | 0.578                               |
|                         | Birmingham     | 0.184                   | 0.241            | 0.318             | 0.460                               |
|                         | Plymouth       | 0.212                   | 0.271            | 0.349             | 0.505                               |
|                         | Merthyr Tydfil | 0.352                   | 0.443            | 0.566             | 0.807                               |
|                         | Edinburgh      | 0.217                   | 0.275            | 0.351             | 0.506                               |
| 1 x 10 <sup>-6</sup>    | Manchester     | 0.086                   | 0.128            | 0.193             | 0.295                               |
|                         | London         | 0.097                   | 0.150            | 0.233             | 0.355                               |
|                         | Inverness      | 0.063                   | 0.093            | 0.139             | 0.223                               |
|                         | Glasgow        | 0.068                   | 0.100            | 0.147             | 0.241                               |
|                         | Durham         | 0.067                   | 0.101            | 0.152             | 0.241                               |
|                         | Sheffield      | 0.075                   | 0.115            | 0.176             | 0.287                               |
|                         | Birmingham     | 0.084                   | 0.128            | 0.194             | 0.300                               |
|                         | Plymouth       | 0.096                   | 0.145            | 0.216             | 0.340                               |
|                         | Merthyr Tydfil | 0.127                   | 0.192            | 0.287             | 0.473                               |
|                         | Edinburgh      | 0.054                   | 0.080            | 0.119             | 0.208                               |
| 1 x 10 <sup>-5</sup>    | Manchester     | 0.036                   | 0.061            | 0.103             | 0.157                               |
|                         | London         | 0.042                   | 0.073            | 0.128             | 0.195                               |
|                         | Inverness      | 0.018                   | 0.031            | 0.052             | 0.084                               |
|                         | Glasgow        | 0.018                   | 0.030            | 0.048             | 0.080                               |
|                         | Durham         | 0.021                   | 0.036            | 0.061             | 0.098                               |
|                         | Sheffield      | 0.025                   | 0.043            | 0.076             | 0.120                               |
|                         | Birmingham     | 0.031                   | 0.055            | 0.096             | 0.149                               |
|                         | Plymouth       | 0.028                   | 0.050            | 0.089             | 0.141                               |
|                         | Merthyr Tydfil | 0.025                   | 0.046            | 0.085             | 0.142                               |
|                         | Edinburgh      | 0.012                   | 0.020            | 0.034             | 0.057                               |

Table 10: Sub-base thickness for outline hydraulic design – System A

The minimum allowable sub-base depth is 150 mm. For highlighted cells this is greater than the depth required for water storage. Half empty times well in excess of 24 hours – between 110 and 260 hours: if this is not acceptable increase sub-base thickness.

**Notes:**

1. Site is assumed to be level.
2. Permeable construction is assumed to have a porosity of 30%.
3. Minimum practical layer thickness for some aggregates used in permeable construction is 150mm or greater.
4. Thickness of permeable construction needs to be sufficient to meet structural design requirements.
5. For System A an infiltration rate greater than or equal to the stated value is required.
6. Factor of safety on infiltration rate for System A is 1.5.

| Discharge rate (l/s)/<br>(l/s/ha) | Location       | 1 in 10 years<br>(10% AEP) | 1 in 30<br>(3% AEP) | 1 in 100<br>(1% AEP) | 1 in 100 years<br>+ 40% climate<br>change |
|-----------------------------------|----------------|----------------------------|---------------------|----------------------|-------------------------------------------|
| 0.9 l/s                           | Manchester     | 0.158                      | 0.214               | 0.295                | 0.451                                     |
|                                   | London         | 0.153                      | 0.213               | 0.309                | 0.454                                     |
|                                   | Inverness      | 0.161                      | 0.209               | 0.276                | 0.420                                     |
|                                   | Glasgow        | 0.138                      | 0.183               | 0.246                | 0.368                                     |
|                                   | Durham         | 0.162                      | 0.211               | 0.280                | 0.427                                     |
|                                   | Sheffield      | 0.184                      | 0.244               | 0.336                | 0.504                                     |
|                                   | Birmingham     | 0.141                      | 0.191               | 0.266                | 0.396                                     |
|                                   | Plymouth       | 0.161                      | 0.211               | 0.284                | 0.417                                     |
|                                   | Merthyr Tydfil | 0.284                      | 0.371               | 0.501                | 0.741                                     |
|                                   | Edinburgh      | 0.168                      | 0.216               | 0.288                | 0.440                                     |
| 1.5 l/s                           | Manchester     | 0.133                      | 0.181               | 0.253                | 0.390                                     |
|                                   | London         | 0.134                      | 0.192               | 0.281                | 0.417                                     |
|                                   | Inverness      | 0.133                      | 0.176               | 0.236                | 0.370                                     |
|                                   | Glasgow        | 0.117                      | 0.156               | 0.209                | 0.320                                     |
|                                   | Durham         | 0.132                      | 0.178               | 0.240                | 0.376                                     |
|                                   | Sheffield      | 0.152                      | 0.209               | 0.288                | 0.443                                     |
|                                   | Birmingham     | 0.124                      | 0.171               | 0.241                | 0.358                                     |
|                                   | Plymouth       | 0.141                      | 0.189               | 0.257                | 0.382                                     |
|                                   | Merthyr Tydfil | 0.248                      | 0.323               | 0.433                | 0.669                                     |
|                                   | Edinburgh      | 0.137                      | 0.185               | 0.247                | 0.381                                     |
| 2.1 l/s                           | Manchester     | 0.116                      | 0.160               | 0.227                | 0.353                                     |
|                                   | London         | 0.123                      | 0.178               | 0.265                | 0.393                                     |
|                                   | Inverness      | 0.110                      | 0.151               | 0.209                | 0.330                                     |
|                                   | Glasgow        | 0.104                      | 0.139               | 0.189                | 0.291                                     |
|                                   | Durham         | 0.111                      | 0.151               | 0.210                | 0.335                                     |
|                                   | Sheffield      | 0.129                      | 0.182               | 0.255                | 0.401                                     |
|                                   | Birmingham     | 0.113                      | 0.157               | 0.226                | 0.337                                     |
|                                   | Plymouth       | 0.123                      | 0.167               | 0.232                | 0.348                                     |
|                                   | Merthyr Tydfil | 0.216                      | 0.287               | 0.392                | 0.603                                     |
|                                   | Edinburgh      | 0.116                      | 0.156               | 0.215                | 0.339                                     |

Table 11: Sub-base thickness for  
outline hydraulic design – System C

The minimum allowable sub-base depth is 150 mm. For highlighted cells this is greater than the depth required for water storage.

Half empty times well in excess of 24 hours: if this is not acceptable increase sub-base thickness.

**Notes:**

1. Site is assumed to be level.
2. Permeable construction is assumed to have a porosity of 30%.
3. Minimum practical layer thickness for some aggregates used in permeable construction is 150mm or greater.
4. Thickness of permeable construction needs to be sufficient to meet structural design requirements.
5. For System C a flow control limiting flow to a rate greater than or equal to the stated value is required.
6. Factor of safety on outflow for System C is 1.0.



The tables are based on the following generally conservative assumptions:

- Storage is provided for development design rainfall events of 1 in 30 yr, 1 in 100 yr and 1 in 100 yr plus 20% and 30% increase for climate change but the greenfield runoff rates of 3, 5 and 7 l/s/ha are around a 1 in 2 year event.
- 100% runoff from the CBPP is assumed.

The calculations have been carried out for a range of rainfall durations up to 24 hours and the maximum thickness is provided in the tables (i.e. the thickness at the critical duration). The tables also assume that there is no impermeable area draining onto or into the CBPP.

System B (partial infiltration) can be designed in two ways:

1. Ignore the infiltration capacity in the design for water storage and use Table 10 to design the permeable construction thickness.
2. Carry out site-specific design calculations allowing for the infiltration that occurs as water is stored. This is quite complex and is best carried out using one of the proprietary drainage design/analysis packages such as Micro Drainage or Info Works.

Table 10 assumes that the permeable construction is level. If this is not the case water will run to the low point and the available storage capacity is reduced. It will then be necessary to check and, if necessary, adjust the pavement thickness accordingly.

## 9.12 Impact Of Slope On Available Storage

On slopes the water will run to the low end of the pavement construction and the volume available for storage will be reduced (Figure 31). It will then be necessary to check that there is sufficient hydraulic storage and, if required, the pavement thickness increased and/or dams or terracing introduced. Alternatively, software can be used to assess and adjust the pavement thickness. Various solutions to sloping sites are discussed in section 4.4

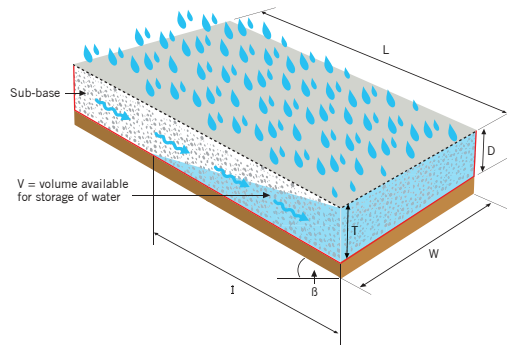


Figure 31: Calculation of available storage for water on sloping sites.

The available volume for storage on a level site is given by:

$$V_L = W \times L \times D$$

Where:

$V_L$  = volume of storage in permeable construction on a level site

$W$  = width of pavement

$L$  = length of pavement

$D$  = thickness of permeable construction

For a sloping site the volume of storage is given by:

$$V_s = 0.5 \times I \times T$$

Where:

$I$  = length of permeable construction where water can be stored =  $T / \tan \beta$

$T$  = thickness of permeable construction measured vertically (on most shallow sloping sites this can be taken as being equal to  $D$ )

$\beta$  = slope angle

## 9.13 Draining Impermeable Areas onto Permeable Areas

It is quite common to design areas where the CBPP is required to handle runoff from adjacent impermeable areas including roofs. It is normal practice to limit the ratio of impermeable area to permeable pavement to about 2:1, as discussed in section 4.2.

To allow for the extra rainfall being collected, the permeable construction thickness may have to be increased if there is no spare hydraulic storage capacity, to give a larger storage volume. If the thickness of pavement needs to be increased, the following equation can be used.

$$T = t (A_i + A_p) / A_p$$

Where:

$T$  = Thickness of permeable construction to store water from impermeable and permeable contributing areas

$t$  = Thickness of permeable construction to store water from permeable area only (from Tables 10 and 11)

$A_i$  = Area of impermeable surfacing draining onto the permeable area

$A_p$  = Area of CBPP.

## 9.14 Flow Control Devices

In order for the permeable construction to act as a storage layer the flow of water out of it must be restricted using a flow control device. The restricted flow rates will either be the greenfield runoff rate or some other value agreed with the regulators. When the flow is restricted at the outlet water backs up into the permeable construction where it is stored temporarily. The permeability of the permeable construction is relatively high and it will not on its own restrict flow to the low levels required, except for very large areas of pavement. Therefore a specific flow control device will normally be required.

There are a wide variety of flow control devices available, but the simplest and most cost effective for CBPPs is an orifice plate located in a shallow inspection chamber. There is rarely a need for more complex or expensive controls. There are also benefits to be gained from using this type of control. An orifice is designed to mimic natural run off and produces a progressive discharge that increases with head of water. In short return period storms discharge is minimised and more of the available storage is used to reduce runoff. As the size of the storm increases flows through the control increase as a greater head of water occurs. This better simulates the behaviour of green field systems.

An orifice is a circular or rectangular opening of specified shape and size that allows a controlled rate of flow when it is submerged. The flow rate depends on the height of the water above the opening, the size of it and the nature of the edge of the opening. CBPP is particularly effective at filtering out silt and other material, delivering clean water, so the risk of the orifice blocking is negligible. As a precautionary measure protection against blockage may be provided, as illustrated in Figure 33. Flow control devices can incorporate overflows where necessary. (See the SuDS Manual (2015) for further advice).

For a simple orifice constructed in a weir wall within a chamber the equation below may be used assuming a free outfall, i.e., the orifice is not submerged on the downstream side. The head of water is the maximum head that occurs behind the orifice within the permeable construction.

$$Q = C_d A_o \sqrt{2gh}$$

Where:

$Q$  = orifice discharge rate ( $\text{m}^3/\text{s}$ )

$C_d$  = coefficient of discharge (0.6 if material is thinner than orifice diameter; 0.8 if material is thicker than orifice diameter; 0.92 if edges or orifice are rounded)

$A_o$  = area of orifice ( $\text{m}^2$ )

$h$  = hydraulic head (m)

$g = 9.81 \text{ m/s}^2$

When the orifice is discharging as a free outfall, the effective head is measured from the centre of the orifice to the upstream (headwater) surface elevation. If the orifice is submerged, then the effective head is the difference in elevation of the headwater and tailwater surfaces, as shown in Figure 32.

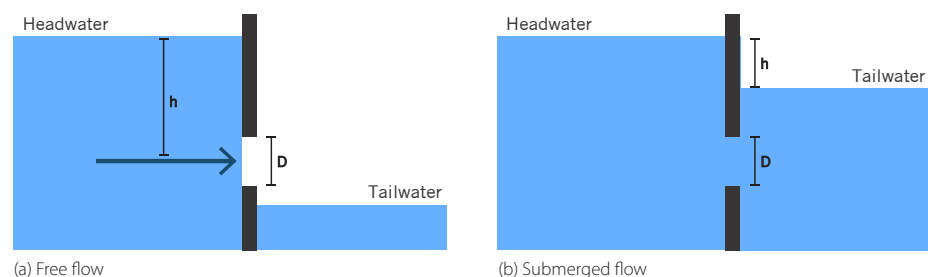


Figure 32: Effective head for orifice discharge calculations.

A number of flow control devices may be required to manage the flow of water from different parts of a CBPP system.

In drainage systems that use gullies, channels and pipes it is possible for quite large obstructions to enter the drainage system. For this reason water companies would limit the orifice size in a normal drainage system to a minimum between 75mm and 150mm diameter. Water entering a CBPP is filtered and therefore the risk of blocking the flow control device is negligible. Thus it is possible to use flow control devices as small as 15mm diameter in these systems, provided that they are protected from blockage and maintained as described in the SuDS Manual (2015). An example is shown in Figure 33 of a perforated guard with holes of a smaller diameter (generally 10mm) than the internal orifice. There are examples of these small flow controls that have operated with little, if any, maintenance for 15 years without issues.

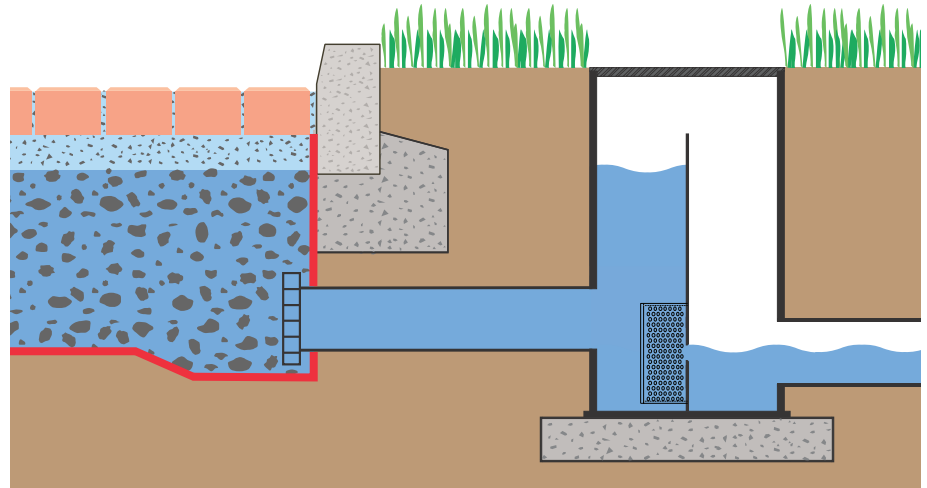


Figure 33: Protected orifice flow control device from CBPP

A 75mm diameter orifice with 450mm driving head will limit flows to 7.8 l/s. If the greenfield runoff rate is 7l/s/ha then the minimum catchment area this can effectively control is 1.1ha or 11,000m<sup>2</sup>.

A 15mm orifice with 450mm head of water will limit flows to 0.3l/s. If the greenfield runoff rate is 7l/s/ha then the minimum catchment area this can effectively control is 0.043ha or 428m<sup>2</sup>.

Thus the use of small diameter orifices allows the effective management of runoff from much smaller areas of permeable paving such as modest parking areas. For small areas of shallow CBPP, simple unguarded orifice flow control devices may be used, such as the example shown in Figure 34.

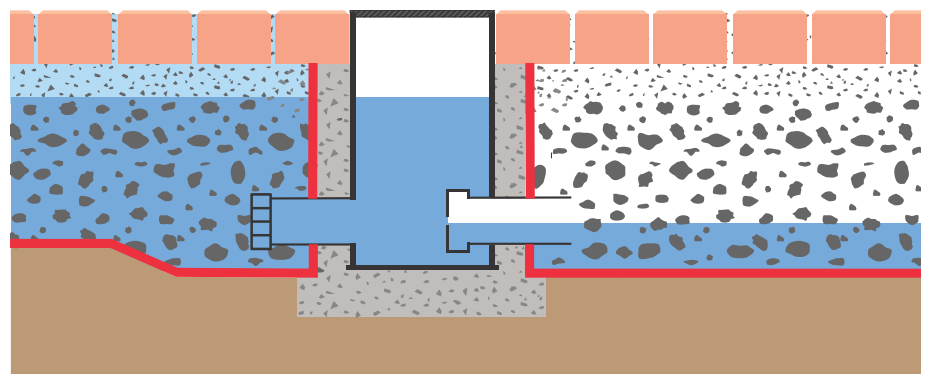


Figure 34: Simple shallow flow control device for small areas of CBPP



## 9.15 Conveyance of Water to Outfall

In System C pavements the water will need to flow horizontally through the underlying permeable construction towards an outfall. In many designs the permeable construction will be present as discrete areas below the CBPP, separated by impermeable construction. Careful consideration is required of water flows between different areas of permeable construction to ensure that it is held in storage in the correct area and can flow to the outfall where necessary. Flow control devices on outfalls can assist with achieving and demonstrating this within a design.

Other options to collect and discharge water include outfall pipes within or below the permeable construction. Water can be moved between areas using pipes, geocellular boxes or a layer of coarse graded aggregate. Water can also flow along areas of permeable construction. There should be sufficient capacity in pipes, boxes or permeable construction to convey the water to the outlet(s). On sites that are level it is usually possible to use flow control devices to ensure that the use of storage in each area of permeable construction is optimised. In this case the main consideration is ensuring that all conduits for water flow (pipes, permeable construction, etc.) have sufficient flow capacity to drain the area without causing a restriction that would increase the volume of water being stored. On sloping sites a greater number of flow control devices are usually required to hold water in the appropriate storage area, as discussed in section 4.4.

The spacing of the outlet pipes or collector pipes for System C pavements can be determined in an approximate manner using guidance provided by Cedergren (1974). The maximum surface runoff rate that can be removed by a flat permeable sub-base can be estimated using the equation given in Figure 35.

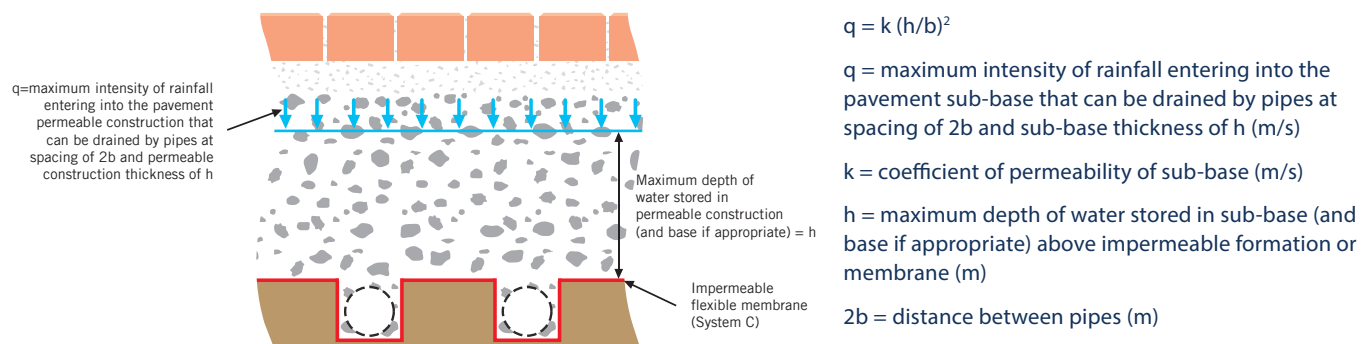


Figure 35: Estimating outfall pipe spacing

Water must flow horizontally through the sub-base to reach the outlet collection systems and there must be sufficient capacity in any aggregate to convey the rates of flow required. Horizontal water flows can very crudely be estimated using Darcy's law (Interlocking Concrete Pavement Institute, 2017) as follows.

$$Q = A \cdot k \cdot i$$

Where:

$Q = \text{flow capacity of sub-base (m}^3/\text{s)}$

$A = \text{cross-sectional flow area, ie height x width of sub-base through which water is flowing (m}^2\text{)}$

$k = \text{coefficient of permeability of sub-base (m/s)}$

$i = \text{hydraulic gradient (assumed to be the slope of the subgrade towards the outlet – generally a conservative assumption) (m/m)}$

Outflow from the permeable construction should be via a system of perforated pipes, fin drains or a proprietary CBPP drainage system that provide a large surface area for water to flow into. Outlets that comprise simply the open end of a pipe (wrapped in geotextile) are prone to clogging and are not suitable. Perforated pipes should extend at least 1m into the sub-base and the pipes should be slotted or have circular holes formed as part of the manufacturing process. Perforations should not be made in pipes by site operatives. The perforated section of pipe should have sufficient flow capacity through the walls to manage the anticipated flows and the perforations should be compatible with the aggregate size such that migration of aggregate particles into the pipe is prevented. The capacity of the pipe to convey water along it should also be sufficient to manage anticipated flows. The open ends of any pipes that end in contact with gravel should be capped.

The choice of outlet pipe spacing is normally influenced by the physical layout of the CBPP (eg in roads and car parks where the areas of discrete CBPP are relatively narrow and constrained by kerbs, etc.). The pipe diameter should be chosen so that it can manage the rate of water that will discharge from the pavement. For small areas such as a row of parking bays (24 bays at 2.5m x 5m) or a small road (6m wide by 50m long) with a design rainfall intensity of 75mm/h a 100mm diameter pipe at a gradient of at least 1 in 100 should be sufficient according to BS EN 752-4 (BSI, 1998).

For larger areas the pipe spacing should be calculated using the above equation. For example, a pavement with the following parameters would require 100mm diameter pipes spaced at 13m centres:

Rainfall intensity,  $q = 75\text{mm/h}$

Sub-base permeability,  $k = 1 \times 10^{-2}\text{m/s}$  (conservative assessment without any permeability test results on the sub-base)

Maximum depth of stored water,  $h = 0.3\text{m}$

Results in  $b = 6.5\text{m}$  and pipe spacing of  $2b = 13\text{m}$ .

## 9.16 Half Empty Time

The permeable construction should empty from full to half-full within a reasonable time so that the risk of it not being able to manage a subsequent rainfall event is minimised. Where pavement systems are designed to manage the 1 in 10 year or 1 in 30 year event it is usual to specify that half emptying occurs within 24 hours so that sufficient empty volume is available to store runoff in subsequent events. This is a fairly conservative assumption when pavements are designed to manage events of 1 in 100 year plus an allowance for climate change. When a long return period is combined with infiltration rates at the low end of the acceptable range of permeability or where very low discharge rates are allowed the requirement to half empty in 24 hours may prove difficult to achieve in a cost effective manner.

In such instances the requirement to half empty in 24 hours should be relaxed and a longer emptying time allowed such that storage is provided after 24 hours for a subsequent 1 in 10 year or 1 in 30 year event. The decision to allow longer emptying times for systems designed to manage longer return period events should be based on an assessment of the performance of the CBPP and the risk and consequences of consecutive rainfall events and exceedance occurring.

# 10. Pavement Design

## 10.1 Design Thickness

To determine the design thickness, the total thickness of the permeable layers derived from the structural design process, which could include capping, CGA or Type 3 sub-base and HBCGA base, is compared with the permeable thickness from the hydraulic design process. Note that the paving layer and CAC base have no hydraulic storage capacity. Therefore the thicknesses of these layers are not used in this comparison.

Software is available to design the complete pavement or just the hydraulic thickness required. If drainage software is used to design the hydraulic thickness only, then the determination of the structural thickness must be undertaken separately and the thicknesses from both designs compared to determine the design thickness.

If the hydraulic thickness is greater than the structural thickness, then the design thickness will be the thickness determined by the hydraulic design process. So, effectively the permeable structural thickness is increased, as shown in the following example.

If the structural design thickness was determined to be:

Paving layer - 120mm

Base - HBCGA 100mm

Sub base – CGA 150mm

and the hydraulic design thickness, required a permeable thickness of 300mm, then the design thickness would be:

Hydraulic thickness > structural thickness

$300\text{mm} > 100\text{mm} + 150\text{mm}$

$300\text{mm} > 250\text{mm}$

Therefore, the design thickness is defined as 300mm.

## 10.2 Spare Hydraulic Capacity

If the structural thickness is greater than the hydraulic thickness, then the design thickness will be the thickness determined by the structural design. This will result in spare hydraulic capacity, as shown in the following example.

If the structural thickness was determined to be:

Paving layer 120mm

Base - HBCGA 125mm

Sub base – CGA 150mm

and the hydraulic design thickness required a permeable thickness of 210mm, then the design thickness would be:

Hydraulic thickness > structural thickness

$210\text{mm} > 125\text{mm} + 150\text{mm}$

$210\text{mm} > 275\text{mm}$

Therefore the design thickness is defined as 275mm.

With a design thickness of 275mm, but only 210mm required for the temporary storage of water, there would be 65mm of spare hydraulic storage capacity. It may be possible to utilise this spare hydraulic capacity by draining adjacent impermeable areas, such as roofs or parking bays into the permeable pavement. Often this is achieved at no or nominal additional cost.

If adjacent areas are drained into the permeable pavement to use up the spare hydraulic capacity, the hydraulic design process and the determination of the design thickness must be repeated to ensure that the hydraulic thickness does not come to exceed the structural thickness.

## 10.3 Defining The Final Design

In addition to recording all the design parameters, it is recommended that outcomes from the design process are recorded and should include the system type, paving unit thickness and laying course thickness, pavement layer types and thicknesses and any other relevant information.

# 11. Specification and Materials

## 11.1 Paving Blocks

MPA Precast members manufacture concrete paving blocks specifically for use in permeable pavements. Paving blocks should be manufactured and tested in accordance with BS EN 1338:2003 - ‘Concrete paving blocks - Requirements and test methods’ (BSI, 2003a).

The strongest laying pattern is herringbone and guidance on appropriate laying patterns is provided in BS7533-103. Some types of paving unit can be machine laid. It is recommended for Traffic Category 4 or greater that the paving unit thickness is 80mm. For all other traffic categories the paving unit thickness can be 60mm. Advice should be sought from the manufacturer on colours, paving types, paving thickness and suitable laying patterns for particular applications.

## 11.2 Laying Course and Jointing Aggregate

The laying course aggregate must be sufficiently coarse to allow the free vertical flow of water and to prevent its intrusion into the underlying CGA, Type 3 or HBCGA, and yet be sufficiently fine to permit the accurate installation of the paving units. It should also have sufficient durability to resist traffic loads and comply with the physical properties stated in Table 14 except for the grading requirements.

Typically, the laying course and jointing aggregate should fall within the Particle Size Distribution envelope of Table 12, but advice should be sought from the manufacturer on specific gradings suitable for their products/systems. The aggregate should comply with the requirements of an aggregate of type 2/6.3 Gc 80/20 according to BS EN 13242:2007 ‘Aggregates for unbound and hydraulically bound materials for use in civil engineering works and road construction’ (BSI, 2007) as shown in Table 12. Note that the term 2/6.3 means that the aggregate has particle sizes that are predominantly within the range of 2mm to 6.3mm. This is the way in which aggregates, including fine aggregates, are designated in BS EN 13242:2007 which states: “This designation accepts the presence of some particles which are retained on the upper sieve (oversize) and some which pass the lower sieve (undersize)”, i.e. there is a small proportion of aggregate that is greater than 6.3mm and less than 2mm.

Paving block manufacturers produce permeable paving units that have specific joint sizes or voids. Therefore it is important to ensure the aggregate used for jointing will be able to flow freely into the full depth of the joint during the joint filling and compaction operation to ensure good structural integrity of the paving surface. Advice can be sought from the manufacturer on their recommendations.

Table 12: Typical Particle Size Distribution limits for laying course aggregate

| BS Sieve Size (mm) | Percentage Passing (%) |
|--------------------|------------------------|
| 14                 | 100                    |
| 10                 | 98-100                 |
| 6.3                | 80 - 99                |
| 2.0                | 0 - 20                 |
| 1.0                | 0 - 5                  |



## 11.3 Hydraulically Bound Coarse Graded Aggregate (HBCGA)

In the case of more heavily trafficked CBPPs (Traffic Categories 5 – 8), a layer of HBCGA is included to strengthen and stiffen the pavement.

The HBCGA should be manufactured using aggregate that meets the requirements of Section 11.5. Usually compliant CGA is cement modified to produce HBCGA and should comply with the following:

### Cement Bound Mixtures

- BS EN 14227-1:2013. 'Hydraulically bound mixtures – Specifications – Part 1: Cement bound granular mixtures' (BSI, 2013b).
- Minimum cement content by mass = 3%. Strength Class = C5/6 (As defined in Table 2 of BS EN 14227-1:2013.)
- Minimum permeability 20,000mm/hour.
- The 28 days Elastic Modulus would be expected to be approximately 10,000MPa but this is not a specification requirement.

## 11.4 Asphalt Concrete (AC)

The AC should be an **AC32 dense base 40/60 des** mixture classification as defined in PD 6691 – 2022 'Guidance on the use of BS EN 13108, Bituminous mixtures'. The AC base layer should be constructed in accordance with the general requirements of BS 594987: 2024 'Asphalt for roads and other trafficked areas. Transport, laying, compaction and product type testing protocols. Specification'. An asphalt laying contractor certificated for asphalt laying activities to an ISO 9001 Quality Management System is recommended. Prior to the installation of the paving units the AC is cleaned, if required, to remove mud and detritus and then cored or perforated with 75mm diameter holes on a 750mm orthogonal grid to form CAC. The holes are filled with laying course aggregate.

## 11.5 Sub-Base – Coarse Graded Aggregate (CGA)

The sub-base should have a minimum porosity that is consistent with the design calculations (normally at least 30%). The sub-base should also have a minimum permeability that is consistent with the design calculations. Typically the open graded sub-base aggregates in Table 13 will have a permeability greater than  $1 \times 10^{-2}$ m/s. Sub-base should generally conform to the general requirements of the Specification for Highway Works (2025) Document CC201 for sub-base and unbound mixtures (noting that there are specific different grading requirements for 4/20 coarse graded aggregate in this document)

The requirement for low fines content means that the surface loading will essentially be carried by point-to-point contact between aggregate particles in the sub-base. In order to maximise the friction between particles and thus increase strength, the particles should be rough and angular to give good interlock. Crushed rock (granite, basalt, gabbro) or concrete with > 90 % fracture faces or blastfurnace slag is required to achieve this. Sand and gravel with rounded particles should not be used in CBPP sub-base construction. Aggregates should comply with BS EN 13242 (BSI, 2007) or BS 12620 (BSI, 2008). The choice is a compromise between stiffness, permeability and storage capacity. Typical

| Sieve Size (mm) | Percentage Passing                                     |                                                     |
|-----------------|--------------------------------------------------------|-----------------------------------------------------|
|                 | Coarse graded aggregate 4 mm to 20 mm (4/20) BS7533-13 | Type 3 sub-base 0 mm to 40 mm (0/40) SHW Series 800 |
| 80              | --                                                     | 100                                                 |
| 63              | --                                                     |                                                     |
| 40              | 100                                                    | 80 - 99                                             |
| 31.5            | 98 - 100                                               |                                                     |
| 20              | 90 - 99                                                | 50 - 78                                             |
| 10              | 25 - 70                                                | 31 - 60                                             |
| 4               | 0 - 15                                                 | 18 - 46                                             |
| 2               | 0 - 5                                                  | 10 - 35                                             |
| 1               | --                                                     | 6 - 26                                              |

Table 13: Typical grading requirements for sub-base aggregates (BS7533-103)

gradings for sub-base aggregates are provided in Table 13. Other gradings, such as 4/40 and 10/63, may be used if they are more readily available and meet all the necessary requirements, and provided the quarried aggregate is sufficiently durable. Type 3 sub-base has an increased proportion of sand sized particles and this makes it more stable for asphalt laying machines laying the AC layer (where specified) compared to the 4/20 aggregate which is prone to rutting.

As the sub-base will be in contact with water for a large part of the time, the strength and durability of aggregate particles when saturated and subject to wetting and drying should be assessed. The aggregates should also not crush or degrade either during construction or in service. The specification of 'Los Angeles' test values, micro deval tests and flakiness tests will address these issues. Sub-base aggregate physical property requirements are summarised in Table 14. The properties in this table should be applied to all the different types of sub-base aggregate (including recycled aggregates). **Note that these durability requirements are as, if not more, important than the grading and should not be ignored.**

| Properties                                                                                                             | Category to BS EN 13242 or BS 12620                                                                                                                                                             |
|------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Grading                                                                                                                | 4/20 (preferred) or 4/40, G <sub>c</sub> 85/15 (GT <sub>c</sub> 20/17.5)                                                                                                                        |
| Fines content                                                                                                          | f <sub>4</sub>                                                                                                                                                                                  |
| Shape                                                                                                                  | Fl <sub>20</sub>                                                                                                                                                                                |
| Resistance to fragmentation                                                                                            | LA <sub>30</sub> *                                                                                                                                                                              |
| Durability:<br>Water absorption to BS EN 1097-6:2000, Clause 7 – for WA > 2%, magnesium sulphate soundness             | WA <sub>24</sub><br>MS <sub>18</sub>                                                                                                                                                            |
| Resistance to wear                                                                                                     | M <sub>DE</sub> 20                                                                                                                                                                              |
| Acid-soluble sulphate content:<br>– aggregates other than air-cooled blastfurnace slag<br>air-cooled blastfurnace slag | AS <sub>0.2</sub><br>AS <sub>1.0</sub>                                                                                                                                                          |
| Total sulphur:<br>– aggregates other than air-cooled blast-furnace slag<br>air-cooled blast-furnace slag               | ≤ 1% by mass<br>≤ 2% by mass                                                                                                                                                                    |
| Volume stability of blast furnace and steel slags:<br>air-cooled blastfurnace slag<br>– steel slag                     | Volume stability of blast furnace slags: Free from dicalcium silicate and iron disintegration in accordance with BS EN 13242:2013.<br>V <sub>5</sub>                                            |
| Leaching of contaminants                                                                                               | Blastfurnace slag and other recycled aggregates should meet the requirements of the Environment Agency 'Waste Acceptance Criteria' for inert waste when tested in accordance with BS EN 12457-3 |

Table 14: Physical property requirements for sub-base.

**Note:** \* The durability of aggregates will depend on the nature of the source. In some instances a lower value of LA may need to be specified based on local experience.

Recycled aggregate reduces demand on primary aggregates and contributes to the circular economy. They can be used for permeable paving sub-base where a source is conveniently available, but care should be taken that this is of consistent quality, has an appropriate grading and is free of unacceptable materials such as organic matter or steel scrap. Just as primary aggregates, these materials should conform to European aggregate standards and national specifications.

Leachate from crushed concrete is likely to have a high pH value, which could impede vegetation growth and thus lead to soil erosion at the drain outlet and/or cause the growth of precipitates at the drain outlet. Therefore, outlets from recycled concrete sub-bases below pervious surfaces should be designed to minimise blockage by having a large surface area through which water is collected, and the outlets must be accessible to remove build up of precipitates.

Blast furnace slags have a proven track record of successful deployment as CGA and Type 3 structural layers. To ensure physical performance, the slag aggregate must conform to the current active edition of BS EN 13242 (2013). Environmental integrity is verified by carrying out batch leaching tests under BS EN 12457-3 (2002); the material is deemed acceptable only if the leachate profile satisfies the Environment Agency's inert Waste Acceptance Criteria (WAC) guidelines. The quality protocol sets out end of waste criteria for the production and use of aggregates from inert waste. If the criteria are met, the aggregates will normally be regarded as having been fully recovered and to have ceased to be waste. A quality protocol identifies the point at which waste, having been fully recovered, may be regarded as a non-waste product that can be used in specified markets, without the need for waste management controls. Further information can be obtained from the .GOV website.

Details on the availability and suitability of sub-base aggregates should be obtained from paving block manufacturers or local aggregate suppliers.

## 11.6 Laying Course and Permeable Construction Grading Compatibility

The gradings of the laying course aggregate and the sub-base or base aggregate should be compatible to avoid migration of the laying course into the pavement layer below and a geotextile is not required between these two layers. Therefore, it is necessary to verify that the gradings of these two layers meet the criteria set out below.

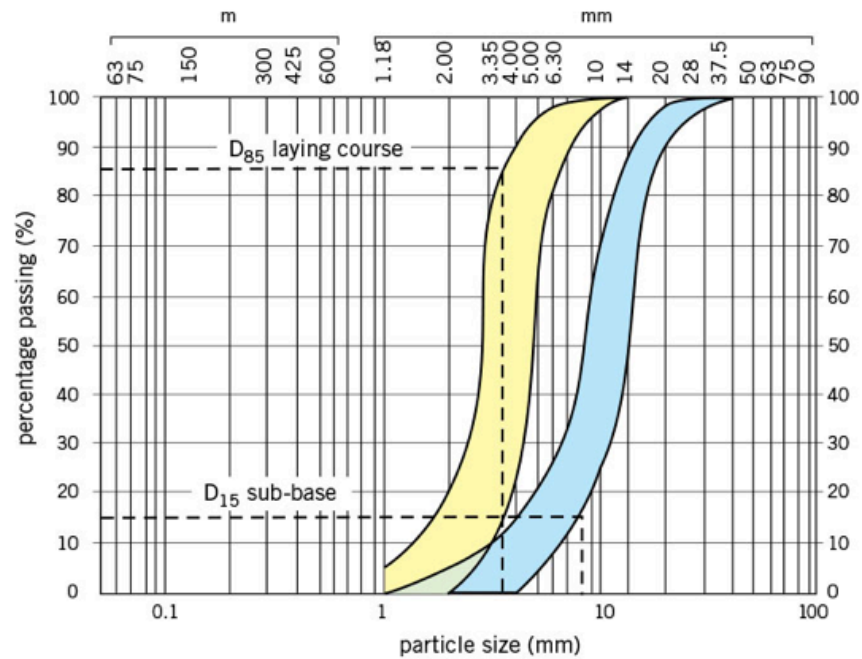


Figure 36: Grading compatibility curve.

The aggregates should meet the following criteria:

$$\frac{D_{15} \text{ permeable construction}}{D_{85} \text{ laying course}} \leq 5$$

and

$$\frac{D_{50} \text{ permeable construction}}{D_{50} \text{ laying course}} < 25$$

Where  $D_x$  is the particle size at which  $x$  percent of the particles are finer. For example  $D_{15}$  is the particle size of an aggregate for which 15% of the particles are smaller than  $D$  and 85% are coarser.

The example shown in Figure 36 gives -

$$D_{15} \text{ permeable construction} = 8.0\text{mm} \text{ and } D_{85} \text{ laying course} = 3.7\text{mm}$$

$$\frac{8.0\text{mm}}{3.7\text{mm}} = 2.16 \leq 5, \text{ therefore OK}$$

It is advisable to check visually that the laying course particles fit into the voids of the permeable construction material without excessive migration into the permeable construction.

An aggregate meeting the average of the laying course and permeable construction grading limits recommended in this guide should meet these requirements. However, a check should always be made on the actual aggregates proposed for use on a site to make sure they are compatible with each other.

## 11.7 Capping

Capping is required if the subgrade has a design CBR value less than 5%. Fill materials for capping normally comprise low cost locally available aggregates capable of achieving a CBR of 15%.

The two recommended fill materials are either 6F1 (finer aggregate) or 6F2 (coarser aggregate) as defined in Table 6/1 of Highways Agency's 'Specification for Highway Works – CC 601 – Earthworks'. In the case of 6F2 fill materials, when used in a lined System C pavement, it may be necessary to blind the surface with fine aggregate to protect the overlying impermeable geomembrane. A capping layer may also be used below System A, B and unlined System C pavements. In this case the capping layer must have a permeability that is at least equal to the design infiltration rate of the soil below including the relevant factor of safety and be unaffected by infiltration of water.

## 11.8 Impermeable Geomembrane

System C pavements may include an impermeable geomembrane which holds all of the water entering the pavement and being detained within it. However, the assumption should be that a membrane is not required unless shown otherwise. The impermeable geomembrane is brought to just below the surface of the pavement at its perimeter to maximise the detention volume of the pavement.

Geomembranes used below CBPP are typically manufactured from high density polyethylene (HDPE), polypropylene or ethylene propylene diene monomer rubber (EPDM). Whatever the base material the geomembranes should be:

- Durable, robust and able to withstand construction and operational forces
- Resistant to puncture, multi-axial stresses and strains associated with movement and environmental stress cracking (or protected by geotextile or sand layers above and below as required; the greatest risk of puncture is often from the sub-base aggregate laid on top of the geomembranes). Consideration can be given to protecting geomembranes with geotextile fleeces where the risks associated with puncture are particularly high
- Unaffected by potential pollutants
- Installed with fully watertight joints and discharge outlets unless the design is based on an assumption of some water leakage from the pavement. The SuDS Manual (2015) recommends that where joints between geomembrane sheets are required to be watertight then they should be welded. Fully waterproof joints can only be provided by welding and they should be tested to ensure the integrity of the system. Taped joints are not suitable for water retaining applications and it is unlikely that taped joints could be formed effectively with a geomembrane laid below a CBPP. Effective forming of taped seams requires firm even support to allow pressure to be applied with a roller. This would not be provided by most road pavement formations. Joints in geomembranes below pavements are also likely to be subject to tear and shear stresses during trafficking and taped joints will provide less resistance to these stresses.

Advice on specifying appropriate properties for geomembranes is provided in CIRIA Report C748.

The membrane should be protected from puncture using sand blinding or geotextile fleeces.

It is important that all joints and seams are visually inspected and, in cases where the geomembrane is critical, possibly tested on site to ensure they meet the required standard. The main places where leaks are likely to occur are around penetrations such as where a pipe passes through the material (e.g. where a pipe passes into a lined geocellular tank). Advice on inspection and testing methods that can be applied to geomembranes below CBPPs in critical locations is provided in CIRIA Report C735.

Thickness of a geomembrane is very important when considering welding. Geomembranes less than 1mm thick are much more prone to problems when welding, especially burning holes in the material (Schiers, 2009). However, thinner geomembranes of the same material tend to be more flexible and are easier to install especially around corners and other details. Flexible geomembranes can also be prefabricated into panels in the factory. There is therefore a trade-off between robustness and the risk of defects due to difficulty of installation. If a geomembrane is less than 1mm thick it should be shown (by testing a trial joint using a seam test) that it can be welded in a satisfactory manner to give the same joint strength as the strength of the parent material.

In the case of impermeable geomembranes installed on roads or decks over occupied buildings (including car parks), seek specialist advice.

## 11.9 Geotextiles

Geotextiles may be used within concrete block CBPPs (shown in Figure 37):

- An optional upper geotextile at the laying course/sub-base (or base) interface may be included according to the paving block manufacturer's recommendations or if the grading of the laying course and base or sub-base are not compatible - see Section 11.6. An upper geotextile should generally be avoided for several reasons including silt build-up and blockage, structural performance, complications with reinstatement following services access and costs. Normally there is little if any benefit in including the upper geotextile.
- Between the subgrade or capping and the sub-base.

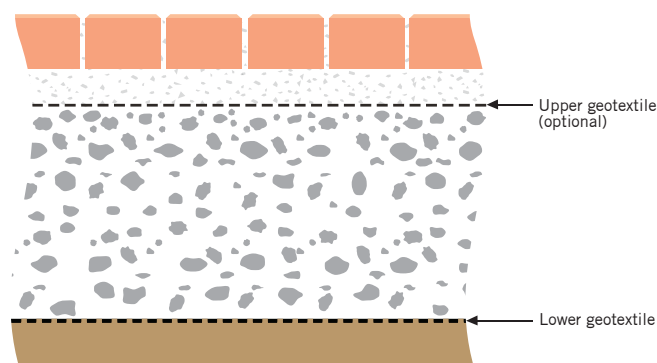


Figure 37: Locations of geotextiles

A report prepared by The Environmental Protection Group Limited (EPG) on the efficacy of geotextiles used in CBPPs is available to download from [www.mpaprecast.org](http://www.mpaprecast.org).

The geotextile should function as a filter and separator, and must be installed according to the manufacturer's requirements, and should be submitted for approval by the engineer. The geotextile can be either a monofilament woven, non-woven firmly bonded or needle punched non-woven fabric. The geotextile should be manufactured from a suitable polyethylene or polypropylene filament able to withstand naturally occurring chemical and microbial effects.

Geotextiles should be specified in accordance with BS8661 (BSI 2019), Specification Profile 1 or 2. The tensile properties of the material should be verified in accordance with EN ISO 10319 by both internal quality assurance and external quality control and assurance by an independent authorised laboratory. The production of the geotextile shall be EN ISO 9001 certified. Each roll shall have at least one identification label with roll number and product type in accordance with EN ISO 10320, and carry a CE mark.

Adjacent rolls of the geotextile should be overlapped by at least 300mm, without any folds or creases. All vehicles should be prevented from trafficking directly over the material. The material should be protected from ultraviolet light.



# 12. Detailing

This section considers a selection of details for a range of typical situations to illustrate the basic principles involved. These and other details are available at [www.mpaprecast.org](http://www.mpaprecast.org). In addition, much of the guidance in BS7533-102 for conventional block paving also applies to CBPP: where there are specific requirements for CBPP, these are provided in BS7533-103.

## 12.1 Edge Restraints

As with conventional block paving, the provision of adequate edge restraints is vital to the successful performance of a CBPP. Research and experience shows that correctly laid concrete block paving develops an inherent interlock, uniting the surface of even the largest areas. There is therefore no need to artificially introduce restraints to contain the paving units. However, restraints at the edges of a pavement or where changes in the paving (such as materials, shapes or laying patterns) interrupt the interlock are essential. If suitable edge restraint is not provided the paving units can rotate, joints can spread and loss of laying course aggregate can cause surface settlement. The form of restraint normally used is a precast concrete kerb or edging placed in a concrete haunch (as shown in Figure 38 and 39). Further advice is available via the Concrete Kerbs guide at [www.mpaprecast.org](http://www.mpaprecast.org) and in BS7533-102.

It is recommended that the geomembrane is trimmed after the screeding of the laying course prior to the placement of paving units to ensure that the top of the geomembrane is at the correct level and effective in containing all the surface water.

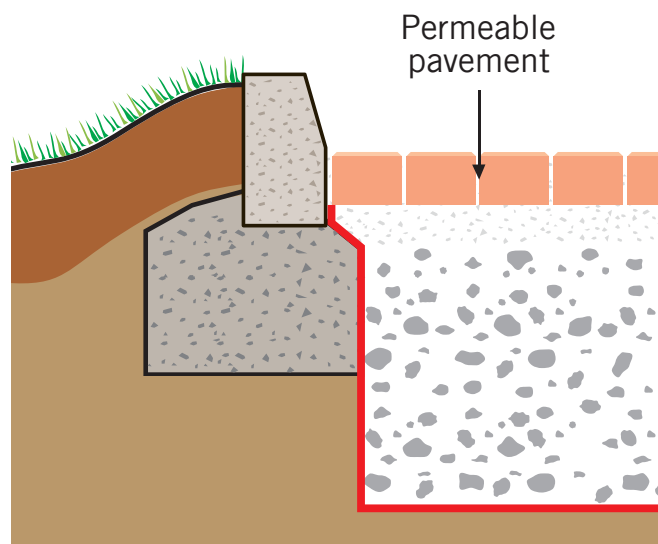


Figure 38: Typical concrete kerb edge restraint (shown with System C) with grass sloping away from the kerb.

## 12.2 Edges Adjacent To Soft Landscaping

Landscaping should be designed so that it does not cause soil and mulch to be washed onto the CBPP and cause clogging. Detailing of the landscape edge is especially important and, wherever possible, landscape areas adjacent to CBPPs should have a topsoil level that is at least 50 mm below the top of the kerb. Preferably, the areas should slope away from the CBPP (see Figure 38). Where landscaping slopes towards the pavement, an under-drained swale can be used to intercept runoff and silt (see Figure 39).

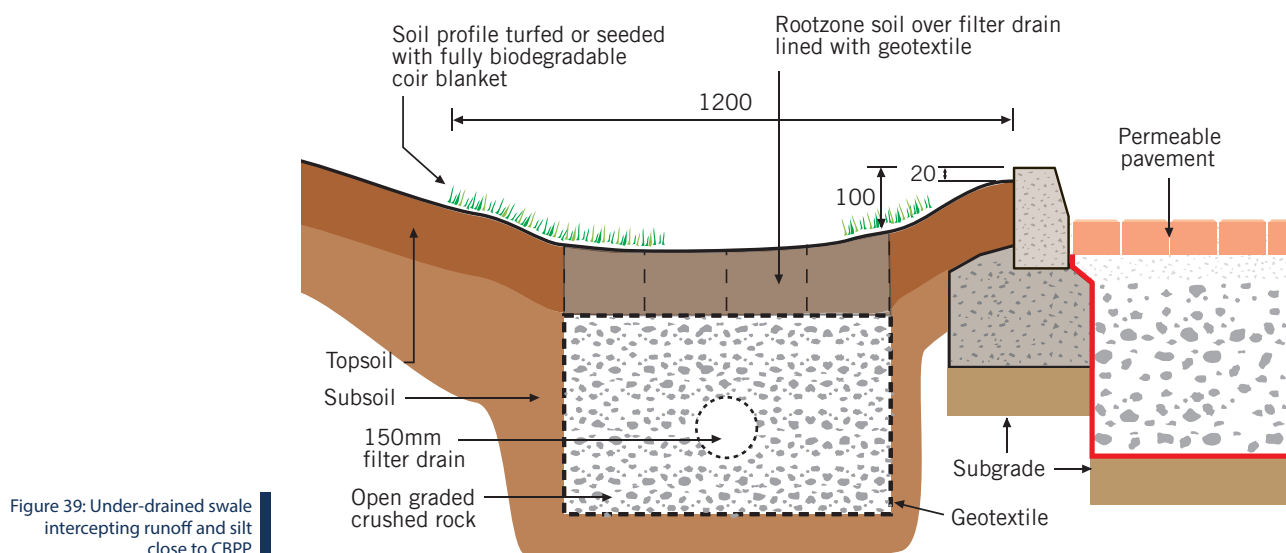


Figure 39: Under-drained swale intercepting runoff and silt close to CBPP

If the possibility of runoff from soft landscaping onto CBPP cannot be eliminated, clogging should be minimised through more frequent sweeping regimes. The required frequency of sweeping should be established through visual monitoring of the surface, particularly following intense rainfall.

Trees or woody shrubs to be planted close to CBPP should be carefully selected. The CBPP below or near trees/shrubs may require more regular sweeping to maintain the surface infiltration rate, although this is not likely to be excessive.

## 12.3 Transitions

There may be a need to differentiate areas of CBPP or abut CBPP with conventional block paving (shown in Figure 40) or other surfaces such as asphalt, without a level change, using a flush concrete kerb. This delineation may be needed for visual design considerations or other techniques discussed in Sections 4.2 and 4.5.

Where conventional block paving abuts CBPP, stabilisation of the joints in the former may be considered to avoid migration of jointing sand onto the CBPP. Migration of water from unlined CBPP into an adjacent sub-base or below the adjacent pavement is not likely and a membrane liner is not necessary.

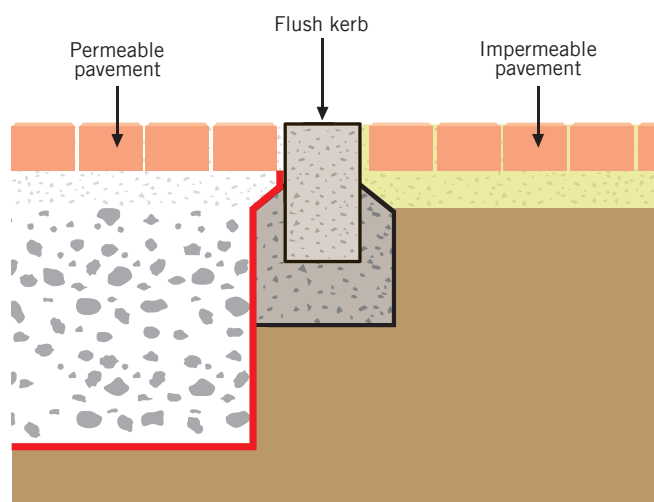


Figure 40: Flush transition of CBPP with conventional block paving

## 12.4 Inlets from Roof Drainage

As discussed in section 4.3, CBPP can generally accept runoff from roofs. For smaller areas and capacities, downpipes can discharge directly onto the CBPP surface. The water discharged from the downpipe should be directed away from the building so as not to scour the jointing aggregate between the blocks. This can be achieved with discharge onto the centre of a larger block or concrete paving flag introduced in the location of the roof water discharge. This method may be preferable to systems that connect directly into the sub-base because no maintenance of filters is necessary.

For larger outlets and roofs, rainwater can be discharged into the CBPP via accessible filter chambers leading to diffusers within the sub-base (see Figure 41).

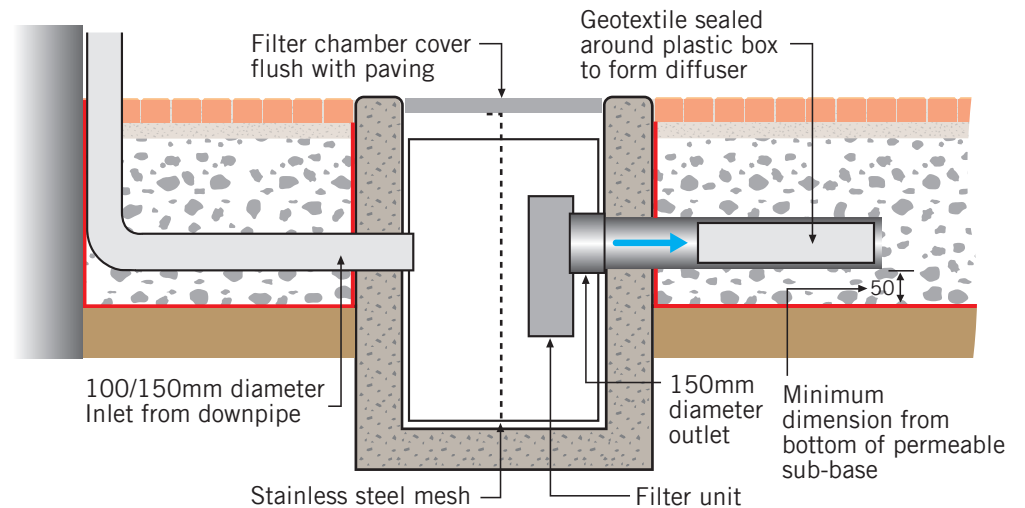


Figure 41: Typical roof drainage outlet within CBPP construction

Syphonic roof drainage can also be connected to CBPPs. However, this type of roof drainage directs large volumes of water into the pavement very quickly which results in very high flow velocities. Therefore inlet diffusers that connect the syphonic drainage into the permeable sub-base should be designed to allow the water into the pavement without affecting the flow rate. The manifold should be designed by the syphonic drainage design consultant.

Unlined CBPP can be used next to buildings. In some cases, an impermeable geomembrane below the permeable sub-base can be used to prevent water infiltration from rainwater discharge close to the foundations. This would typically extend for 1m to 5m depending on the ground conditions and the risk of water adversely affecting the foundations. A typical detail is shown in Figure 42.

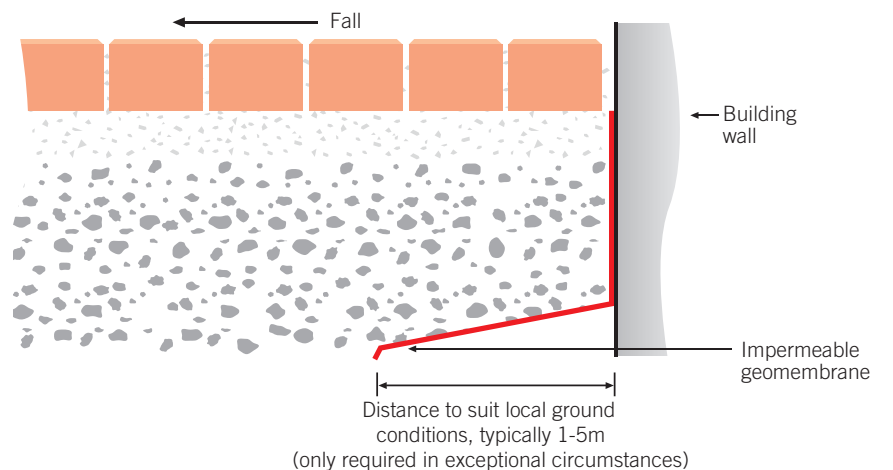


Figure 42: Typical abutment to building where rainwater is discharged.

## 12.5 Outlets and Conveyance

System B and C pavements require an outfall from the permeable sub-base to allow the water to drain. There are various ways of collecting the water from the permeable sub-base. The main concern is to ensure that a large surface area is provided to allow water to flow through and that watertight joints are achieved.

The most effective ways of connecting the permeable sub-base to the drainage system in Systems B and C is to use fin drains (see Figure 43), proprietary CBPP drainage systems (see Figure 44) or perforated pipes. However, perforated pipes need sufficient cover to carry vehicle loads and may need to be installed in a trench below the permeable sub-base to achieve this (see Figure 45).

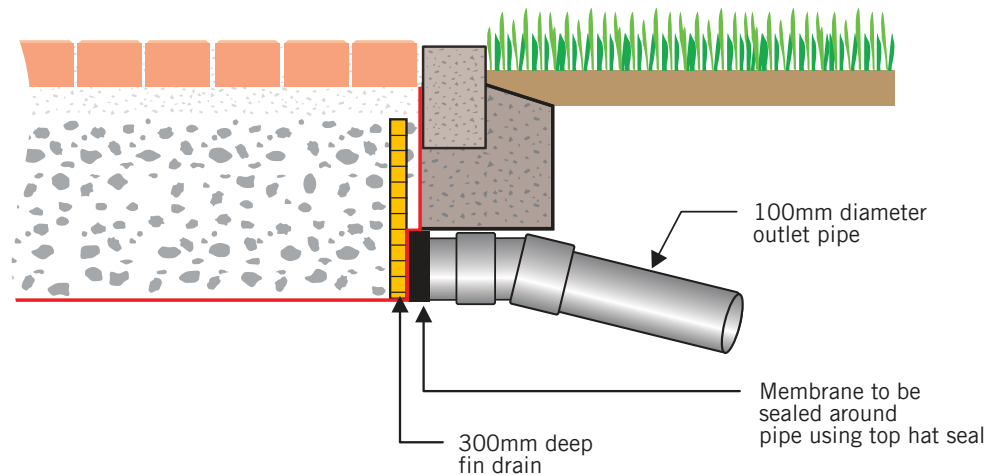


Figure 43: Collection of water by perimeter fin drains

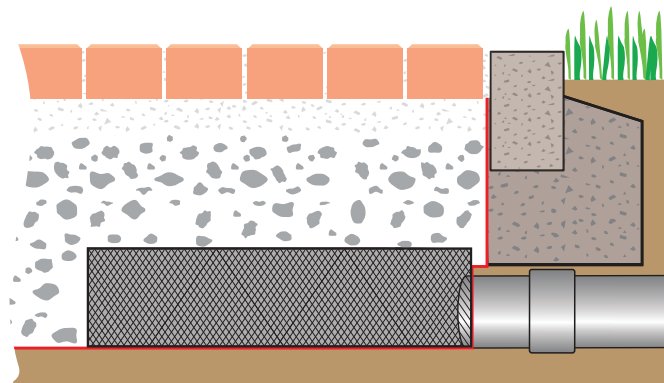


Figure 44: Proprietary CBPP drainage systems e.g. outlet collector box units factory-wrapped in 2mm mesh

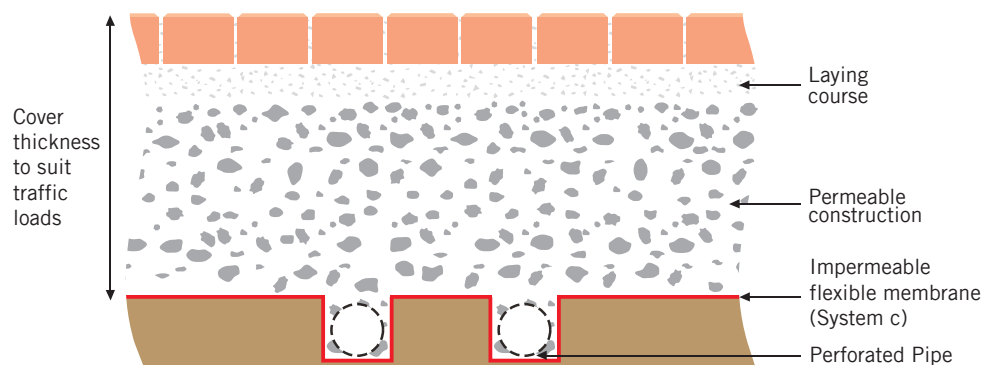


Figure 45: For large areas of CBPP perforated collector pipes in trenches can be used to collect the water

## 12.6 Chambers

Chambers related to CBPP are required when collecting and discharging runoff from roofs (see Figure 41) or to accommodate flow controls. Depending on the volume and velocity of the discharge, more than one chamber may be required. Where there is a requirement to restrict discharge flow so that collected runoff is temporarily stored within the pavement, a chamber containing a flow control device will be required (see Section 9.14). Depending on the size of the pavement and volumes of runoff to be temporarily stored, more than one outflow and flow control chamber may be required. Other chambers unrelated to CBPP, for example foul water sewers, may also be needed within the pavement.

Wherever possible, all chambers should be located outside areas of CBPP, as recommended for services (see Section 4.5). If this is not possible, chambers can be constructed within CBPP as for other pavements.

Other considerations when designing chambers are:

- simplicity of construction;
- resistance to clogging, blocking or mechanical failure;
- invert level in relation to the CBPP to avoid discharging out of the top of the chamber during an extreme event, and
- accessibility, visibility and ease of maintenance.

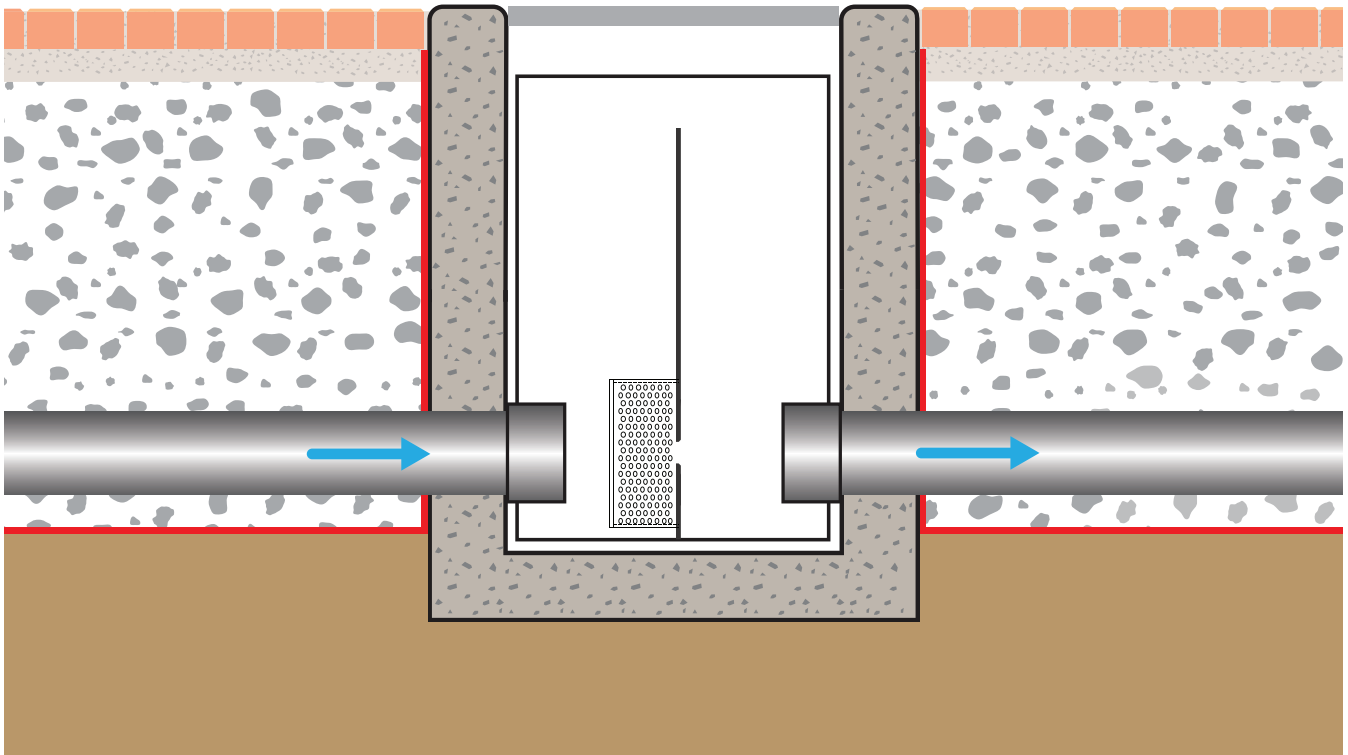


Figure 46: A typical flow control chamber, located within CBPP



# 13. Construction

The following guidance is specific to CBPP and additional to general best-practice and other guidance available at [www.mpaprecast.org](http://www.mpaprecast.org). Advice is also provided in BS7533-102 and -103.

## 13.1 Site Precautions

Preventing and diverting impermeable contaminants such as soil and mud from entering the base and pavement surface during construction is essential. Simple practices such as keeping muddy construction equipment well away from the area, installing silt fences, staged excavation and temporary drainage swales which divert runoff away from the area should be considered.

## 13.2 Subgrade

Proof rolling of the formation below System A, B and unlined System C CBPP is not recommended as it can reduce the infiltration rate of the subgrade. Subgrade soft spots can be identified using a handheld MEXEcone or similar (i.e. an instrument to measure in situ CBR values). If soft spots are identified (that have a CBR value lower than the design value), they should be excavated and backfilled with suitable well-compacted aggregate and, for System A and B pavements, the aggregates should be of similar permeability to the surrounding subgrade.

However, if proof rolling is required then the infiltration of the subgrade should be determined after this operation.

The formation should be prepared by trimming to level in accordance with 'Specification for Highways Works' (Highways Agency 2025), to a tolerance of +20mm to -30mm. If subgrade improvement is employed, testing will be needed to demonstrate that the design CBR values have been consistently achieved and, for System A and B pavements, that the infiltration rate of the subgrade is equal to or greater than the rate used for the hydraulic design.

The formation below System A and B pavements should be protected from any operations that could reduce the infiltration rate of the soil (e.g. heavy construction traffic, stockpiling fine materials or mixing concrete on it).

## 13.3 Geotextile

Any geotextile required between layers should be installed in accordance with the manufacturer's instructions and with overlaps between adjacent strips a minimum of 300mm wide, without any folds or creases. It is recommended that specialist advice be sought from the manufacturer or supplier of the geotextile. On slopes, the upper geotextile strip should overlap above the lower strip.

## 13.4 Impermeable Geomembrane

Impermeable geomembranes are sometimes used with System C (no infiltration) and must be correctly specified, installed and treated with care to ensure that they are not damaged during construction.

## 13.5 Permeable Sub-Base

As permeable sub-base aggregates (CGA or Type 3) lack fines, there is potential for segregation during the transportation and construction process. Care should be taken to avoid segregation but, if this occurs, remedial, corrective action must be taken. Segregation can be minimised by using an angular, crushed aggregate with high surface friction.

The nature and grading of the permeable sub-base will vary between different sources. Typical sub-base aggregate (CGA) is shown in Figure 47.



Figure 47: Typical 4/20 coarse graded aggregate sub-base

CGA and Type 3 sub-base should be moistened, laid in 100 - 150mm layers and compacted to ensure that the maximum density is achieved without crushing the individual aggregate particles. This is usually achieved by rolling with little or no compaction. The surface levels should be in the range +20mm to -15mm. An earthworks trial may be required to determine the appropriate methodology to moisten, lay and compact this layer.

With the exception of plant and equipment needed for the installation of the paving units, or if overlaid with HBCGA or AC, no other traffic or equipment should be allowed onto the completed layer as the surface is easily damaged and rutted. Care and precautions are also needed to ensure that the surface is not damaged, rutted or clogged with mud and detritus from the plant and equipment whilst installing the next pavement layer. Precautions should be undertaken to avoid runoff from adjacent areas.

## 13.6 Base

### 13.6.1 Production

HBCGA contains only a nominal quantity of binder (cement) and this binder must be evenly distributed throughout the mix to ensure that all the aggregate particles are coated in cement paste. To achieve this it is recommended that HBCGA is produced in a mixing plant as opposed to site mixing in a concrete truck mixer.

### 13.6.2 Construction

HBCGA shall be constructed in accordance with the relevant sections of the 'Specification for Highway Works' (Highways Agency, 2025) – document(s) CC201, CC 202 and CC 205.

Site trials may be necessary to determine an appropriate construction methodology and, where necessary, advice should be sought from the HBCGA.

Care must be taken to avoid segregation of the aggregate during transportation and construction. If this occurs, then remedial corrective action must be taken to ensure that the completed base has evenly distributed aggregate particle sizes.

The HBCGA should be laid in 100 – 150 mm layers, levelled by hand or machine and compacted to ensure that the maximum density is achieved for the particular aggregate type and grading, without crushing the individual particles, which could reduce the voids and permeability below the design value. The aggregates are relatively self-compacting and heavy vibrating compaction is not usually required. Satisfactory results may be achieved by rolling without vibration, with four to five passes of the roller often proving to be adequate. The surface level tolerance shall be within +20 mm to –15 mm of the design levels.

Setting times for HBCGA vary dependent upon many factors including the ambient temperature and wind speed. Compaction of the HBCGA must be completed before the onset of setting.

The HBCGA should not be laid during heavy or persistent rain as there is a danger that the cement paste will be washed off the surface of the aggregate and be flushed into the lower layers of the pavement.

Being open textured, fresh HBCGA loses water rapidly to the atmosphere. As a consequence it needs to be placed and compacted as soon as possible after mixing. During hot weather, there is a danger that the HBCGA will dry out rapidly during transport, laying and compaction and so care must be taken to ensure that the HBCGA does not dehydrate. On warm or dry days it may be necessary to dampen down the sub-base on which the HBCGA is to be placed in order to prevent the sub-base excessively drying out the HBCGA.

Care must be taken for 24 hours to 48 hours after placing the HBCGA to prevent it drying out too quickly and not curing adequately. On warm or dry days it may be necessary to cover the surface of the HBCGA to maintain moisture. The HBCGA surface must also be protected from rain and surface water runoff during the first 48 hours after placing. No construction traffic should be allowed upon the HBCGA surface and care must be taken to ensure that it is kept clean and free of any detritus and contaminants.

## 13.7 Protection from Construction Traffic

As discussed in Section 5.6 there is often a need to use the partially or completed CBPP as access roads or storage areas during the construction of the project. If the CGA or Type 3 sub-base is trafficked, the unbound surface will rut and the surface will become clogged. If the HBCGA base or paver surface is trafficked, it will become clogged.

There are various options to overcome these issues that should be considered at the concept and design stage and construction programming, such as:

- For a lined System C, construct a normal capping layer and use this as the temporary road surface. Construct the CBPP over it towards the end of construction.
- Construct the permeable sub-base and then cover it with a sacrificial layer of geotextile and hardcore (100mm thick). Use this as the temporary road surface. Towards the end of construction remove the sacrificial layer and construct the laying course and paver surface. The removed geotextile should not be re-used as an upper geotextile layer.
- Consider the construction process during design and identify areas and routes for construction traffic and others that are prohibited. Use conventional construction in the former and CBPP in the latter.
- Construct the permeable sub-base and then cover it with an impermeable layer of AC. Use this as the temporary road surface. The AC forms part of the structural design of the pavement (see Section 8.9) and should be constructed as described in 13.8.

## 13.8 Asphalt Concrete (AC) Layer

Construct the permeable sub-base and then cover it with an impermeable layer of AC (see Table 8 for AC layer thicknesses). Use this as the temporary road surface. The AC should be an **AC32 dense base 40/60 des** mixture classification as defined in PD 6691 – 2022 'Guidance on the use of BS EN 13108, Bituminous mixtures'. The AC base layer should be constructed in accordance with the general requirements of BS 594987: 2024 'Asphalt for roads and other trafficked areas. Transport, laying, compaction and product type testing protocols. Specification'. An asphalt laying contractor certificated for asphalt laying activities to an ISO 9001 Quality Management System is recommended.

Experience has demonstrated that a tracked asphalt-paving machine (see Figure 48) is easier to manoeuvre over 'unbound' CGA or Type 3 sub-base than a wheeled paving machine. Towards the end of construction, core holes in the AC to form CAC and fill the holes with the laying course aggregate. Construct the laying course and paver surface over the CAC. Typically, holes should be 75mm diameter on an orthogonal grid of 750mm. The CAC layer remains in situ throughout the service life of the pavement.



Figure 48: Tracked asphalt paving machine installing AC over a permeable sub-base

## 13.9 Paver Surface Construction Procedures

The following flowchart illustrates the step-by-step procedures for the construction of the paver surface for a CBPP. It follows the basic recommendations in BS7533-102, but, where appropriate, changes and modifications have been incorporated based upon best practice.

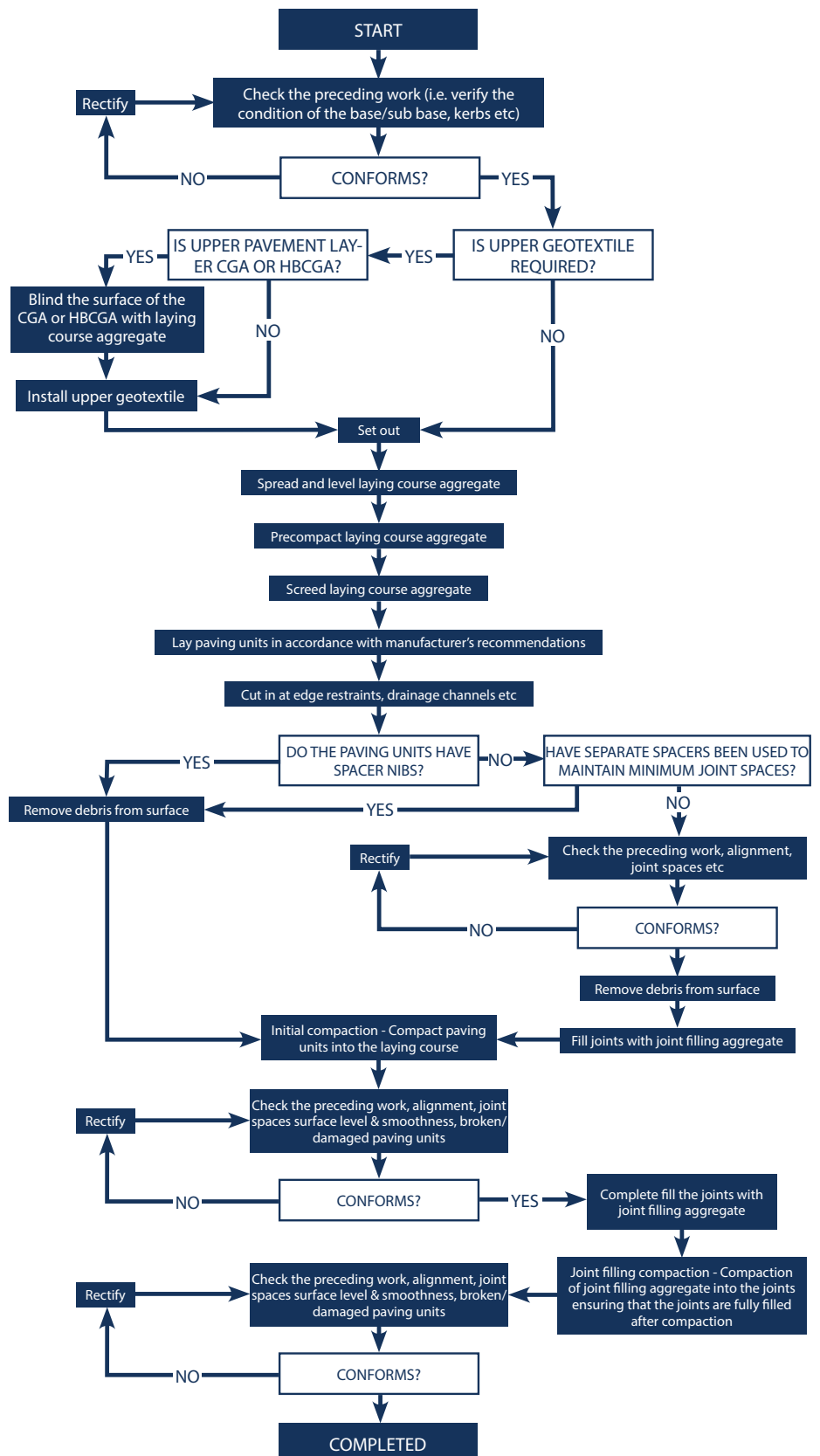


Figure 49: Flowchart of paver surface construction sequence



### 13.9.1 Laying Course and Joint Filling

If upper geotextile is to be installed between the CGA, Type 3 or HBCGA and the laying course, it is recommended to blind the surface of these layers with a small amount of laying course aggregate prior to installing the geotextile. This process will fill voids in the surface and avoid the geotextile “spanning voids” and potential settlement.

The laying course thickness should be  $50\text{mm} \pm 20\text{mm}$ .

When either machine laying (see Figure 50) or hand laying paving units on a CGA or Type 3 sub-base or HBCGA base, with no upper geotextile, the laying course aggregate is compacted to ensure that the surface of the underlying layer is fully blinded by the laying course aggregate.

For the recommended grading requirements and physical properties of the laying course aggregate see Section 11.2.



**Figure 50:** Machine laying of concrete paving blocks offers a particularly efficient solution for permeable as well as conventional block pavements

### 13.9.2 Joint Spaces

Unlike conventional block paving that requires joint spacing between 2 and 5mm, the requirements for joint spacing for permeable paving varies depending on the paving unit type. Therefore information needs to be sought from the manufacturer on the recommended joint spacing.

### 13.9.3 Joint Filling

For concrete paving units specifically manufactured for CBPPs, or other types of paving unit laid with separate spacers, the filling and compaction of the joint filling aggregate into the joints should proceed after the compaction of the paving into the laying course, and after compliance checks and corrections have been undertaken. Joint filling must not be undertaken prior to compaction of the paving units into the laying course.

For concrete paving units with no spacers, compliance checks and corrections are undertaken prior to the filling and compaction of the joint filling aggregate into the joints.

In all cases, the laying course aggregate can be used for joint filling, but care needs to be exercised to ensure that the maximum aggregate size particles can infiltrate into the joints.

Completely full joints are necessary to ensure structural integrity of the paving surface layer. It is recommended that in the early life of the pavement, inspections are undertaken and if necessary the joints topped up with jointing aggregate. Topping up and compaction should also be repeated 3 months and then 12 months following completion.

To minimise the risk of damage and contamination of the surface it is recommended that at the cessation of each workday, the paver surface layer is fully compacted and jointed to within 1m of the laying face.

### 13.9.4 Joint Sealing

If required, joint sealants specifically designed to bond the jointing aggregate but also to allow infiltration of all the surface water are available: only these types of sealants should be used on CBPPs. Advice should always be sought from the sealant manufacturer on the appropriate type and method used. Never use conventional block pavement sealants.

### 13.9.5 Manufacturer Specific Requirements

Information should also be sought from the manufacturer on laying patterns for particular paving unit types and any special design or construction requirements.

# 14. Operation and Maintenance

CBPP technology has proven itself over decades of successful use in the UK and around the world - notably Germany since the mid-1980s. Experience of CBPP in use in the UK over more than 30 years has demonstrated its long-term performance with minimal, if any, maintenance. Routine maintenance should be no more onerous than for impervious paving and the maintenance required for conventional below-ground gulley and pipe drainage is eliminated.

## 14.1 Infiltration Performance

The infiltration rate into CBPP will decrease but stabilise with age, due to the build-up of detritus in the jointing aggregate. The stabilised infiltration rate is more than adequate to deal with UK rainfall. This effect is discussed in Section 9.4 and summarised in Figure 29, where it can be seen that long service lives can be expected from permeable pavements, which is borne out by experience of older pavements. To ensure a long service life, it is essential that care be taken to protect the pavement during construction and from landscape runoff.

## 14.2 Cold Weather Performance

'Frost heave' is not a problem for CBPP as water drains through the pavement before there is time for it to freeze. CBPPs have been used successfully in particularly cold climates. In the unlikely event that freezing does occur, it generally does not develop in a uniform manner and this allows the water displaced by the expanding ice to move within the open graded permeable construction, thus limiting the heave effects on the pavement.

Frost heave does not occur if the pavement is designed correctly. If the pavement is full and prolonged freezing does occur (a virtually impossible combination as the pavements are designed to drain down quickly after a rainfall event) then ice 'mushrooms' may appear at the surface in the joints between the paving units as the water expands in the pore spaces between the aggregate. The only record of this happening is in the Midwest of the USA where the winter climate is far more severe than the UK.

It is of note that one of the most comprehensive studies into the performance of CBPPs undertaken in the USA by Ferguson (2005) failed to find an example of a CBPP in a cold climate that had failed due to frost damage. This included one example of a 550mm deep pavement in an area with frost penetration up to 1800mm that had not experienced any significant distortion over 10 years. It was also found that frost penetration was shallower below CBPPs than below conventional dense construction because of the insulating effect of the pavement.

## 14.3 Health and Safety

There is sometimes a perception that water within a CBPP might cause a potential health and safety issue, either due to stagnation of the water or freezing. This is not the case, as the systems are designed to drain quickly after a rainfall event and thus there should not be water standing for any significant period of time. In fact, CBPPs provide a firm, level, well-drained surface that meets current accessibility requirements. Research in Ireland also shows that CBPPs without slopes improve safety when using shopping trolleys in retail car parks, where discharged trolleys could run away into vehicles or pedestrians.

There is less risk of sheet ice forming on CBPPs compared to normal pavements because puddles do not form on the surface. However hoar frosts may occur slightly more frequently than on impermeable surfaces (CIRIA, 2001). Hoarfrost is a white frosting that can appear on any surface after a cold night. It comprises a covering of minute ice crystals, formed from the atmosphere at night upon the ground and any exposed objects when they have cooled by radiation below the dew point.

Hoarfrost can be slippery, depending on people's choice of footwear. It is mostly dealt with by gritting or salting surfaces to make them less slippery. Apart from hoarfrost, all types of pavements can also become slippery when ice forms in cold weather after a damp spell, or when snow gets compacted or re-freezes after melting. CBPP is no exception and can be salted in the same way as other pavements. If grit is used, then the granules should be sufficiently large not to clog up the joints between paving units.

## 14.4 Routine Maintenance

Correct design, detailing and construction are essential to the long-term performance of CBPP and minimising maintenance. In particular, the following aspects have been discussed earlier in this Guide:

- design and detail soft landscaping to prevent soil and mulch being washed onto the CBPP.
- prevent impermeable contaminants such as soil and mud from entering the base and paving surface both during and after construction.
- ensure that joints between blocks are filled with the correct, permeable jointing aggregate. Joints should be filled to within 10mm or so of the block surface.

Over time, detritus and silt collects in the upper part of the jointing aggregate between blocks where a surface 'crust' is formed, protecting the laying course and permeable construction material while allowing infiltration. As discussed in Section 9.4, reduction in the infiltration rate of CBPP stabilises with age, normally well above UK hydrological requirements. Also, the performance of CBPP is not significantly affected by moss or weeds in the joints, or by leaves collecting on the surface.

Generally, any problems will be revealed on the surface by ponding (permeability issues) or damaged or displaced blocks (structural issues). In the absence of these indications, no remedial action is necessary. Current routine maintenance regimes for other paving can be applied to CBPP as follows:

- **Cosmetic Cleaning** – the same regime as would be adopted for an impermeable surface in the same location. The method of cleaning should be non-aggressive brushing of the whole surface (avoiding disruption of the jointing aggregate, with suction rates and brush angles/speed adjusted, based on a trial), either manually or mechanically, which will help maintain performance and appearance. This can be carried out at the same intervals as for conventional pavements (to suit local rotas), annually or at intervals resulting from local observations of silt and debris build-up. More information on cleaning concrete block surfaces generally can be found in MPA Precast's guide '*Concrete Block Paving*'.
- **Visual inspections** - should be carried out and recorded during maintenance visits. Inspection of piped outfalls (where used) and flow control devices is also advised.
- **Winter maintenance** - controlled use of standard road de-icing techniques including rock salt may be used without detrimentally affecting the CBPP performance. De-icing chlorides should be used in accordance with suppliers' recommendations and are unlikely to result in an increase in ground chloride levels. CBPP generally requires less de-icing than impervious paving, although it can exhibit hoar frost sooner.
- **Weed control** – excessive weed growth, typically where vehicles do not pass over (trafficking prevents weed growth), can be managed by localised spot-treatment with weed killers containing Glyphosate, in accordance with suppliers' recommendations.

## 14.5 Remedial Actions

If there is an unacceptable loss of permeability indicated by ponding on the surface of CBPP, it can be cleaned to restore it. In this event and in affected areas only, water-jetting or agitation brushing (either manually or mechanically with a suction brush set at a 30° angle to the pavement, to prevent aggregate migration) can be used to dislodge the affected jointing aggregate. Joints should then be refilled with the correct, clean aggregate and compacted into the joints. This will be required rarely, if at all, on a limited number of pavements.

Information on structural repairs and reinstatement for block paving generally can be found at [www.mpaprecast.org](http://www.mpaprecast.org).

## 14.6 Commuted Sums

The maintenance over time of CBPP is no different to impermeable paving and highway authority 'commuted sums' should be the same as for an impermeable pavement (with associated gullies, pipes and chambers) in the same location.

## 14.7 Reinstatement

As discussed in Section 4.5, underground services can be located outside CBPP to avoid the need for disturbance to gain access, or located within service corridors. However, there may be situations where this is not possible, such as sewers located below CBPP because they cannot run with other services and, as a result, future excavation may be unavoidable. Localised structural failures of the pavement may also require reinstatement (as with any other pavement).

Unlike other pavement materials, with CBPP as well as concrete block paving, reinstatement work can be carried out with no visual evidence that a repair has been undertaken. Reinstatement techniques for both types are discussed in detail in guidance available at [www.mpaprecast.org](http://www.mpaprecast.org) while the following additional guidance applies specifically to CBPP.

### Understanding the CBPP

- Is the pavement System A or B (infiltration), or System C (non-infiltration)? This may influence how you manage the water passing through the pavement and prevent any flooding on the upstream side.
- How deep is the open-graded CGA or Type 3 aggregate? This will influence how to dam the opening so that water passing through does not interfere with the works.
- Consider the area to be excavated. Think about the angle of repose for the open-graded aggregate or use of damming or supporting features for the permeable construction.

### Opening-up the Pavement

- Remove the blocks as for conventional block paving and retain.
- Remove laying course aggregate.
- Excavate into pavement taking care to note the presence of any geotextile or geogrid layers. Where present, carefully cut out these layers.
- Consider the angle of repose for the unbound aggregates as this may dictate a larger excavation than with impermeable materials or the unbound sub-base is restrained around the perimeter of the excavated area so that no aggregates enter. Any restraints need to be removed prior to the completion of the works.
- The nature of the excavation will influence how any water in the pavement is to be managed. For example, an excavation within the body of the pavement allowing water to pass either side may be acceptable. However, a trench running across the carriageway may create a dam effect within the base, in which case consideration as to how to manage the water flow (e.g. temporary pipework passing through the excavation) should be given.

### Reinstatement

- Any temporary and/or permanent reinstatement must ensure that the hydraulic performance of the pavement is retained.
- Only 'like-for-like' permeable construction, base, sub-base and laying course aggregates should be used.
- Ensure that the excavated base is fully compacted prior to reinstatement.
- Replace geomembranes, geotextiles, geogrids, etc., on a 'like-for-like' basis with original installation. Tie-in these items with the remaining originals (which may involve sealing geomembranes to retain impermeability).
- Compact each layer to the correct thickness.
- Reinstatement the block surface, ideally with blocks previously lifted. Otherwise, compatible replacement blocks should be used.
- Replacement of any Asphalt Concrete layers must be cored to form CAC (as Section 13.8).



# 15. References

Where materials, design or installation references in British Standards or other referenced publications are updated after publication, advice from the supplier or the Mineral Products Association should be sought to confirm any updated specification requirements.

|                                |         |                                                                                                                                                                                                                                                                                                                          |                                                                                                                              |
|--------------------------------|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| ASTM International             | (2021)  | <i>ASTM C1781/C1781M-21 - Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems</i>                                                                                                                                                                                                      |                                                                                                                              |
| ASTM International             | (2025)  | <i>ASTM D5126-25 - Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in Vadose Zone</i>                                                                                                                                                                                              |                                                                                                                              |
| Beecham S, Lucke T and Myers B | (2010)  | <i>Designing porous and permeable pavements for stormwater harvesting and re-use</i>                                                                                                                                                                                                                                     | In: Proceedings of the 1st European Congress of the International Association for Hydro-Environment Engineering and Research |
| British Standards Institution  | (2022)  | <i>BS 1377-2:2022 - Methods of test for soils for civil engineering purposes. Classification tests and determination of geotechnical properties</i>                                                                                                                                                                      |                                                                                                                              |
| British Standards Institution  | (2025)  | <i>BS 1377-9:2025 - Methods of test for soils for civil engineering purposes - In-situ tests</i>                                                                                                                                                                                                                         |                                                                                                                              |
| British Standards Institution  | (2017)  | <i>BS EN 752:2017 - Drain and sewer systems outside buildings — Sewer system management</i>                                                                                                                                                                                                                              |                                                                                                                              |
| British Standards Institution  | (2019)  | <i>BS EN ISO 10320:2019 - Geosynthetics — Identification on site</i>                                                                                                                                                                                                                                                     |                                                                                                                              |
| British Standards Institution  | (2002)  | <i>BS EN 12457-3:2002 - Characterisation of waste. Leaching. Compliance test for leaching of granular waste materials and sludges. Two stage batch test at a liquid to solid ratio of 2 l/kg and 8 l/kg for materials with a high solid content and with a particle size below 4 mm (without or with size reduction)</i> |                                                                                                                              |
| British Standards Institution  | (2003a) | <i>BS EN 1338: 2003 - Concrete Paving Blocks – Requirements and test methods.</i>                                                                                                                                                                                                                                        |                                                                                                                              |
| British Standards Institution  | (2018)  | <i>BS EN ISO 14689:2018 - Geotechnical investigation and testing — Identification, description and classification of rock</i>                                                                                                                                                                                            |                                                                                                                              |
| British Standards Institution  | (2007)  | <i>BS EN 13242:2002+A1:2007 - Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction</i>                                                                                                                                                                       |                                                                                                                              |
| British Standards Institution  | (2008)  | <i>BS EN 12620:2002+A1:2008 - Aggregates for concrete</i>                                                                                                                                                                                                                                                                |                                                                                                                              |
| British Standards Institution  | (2026)  | <i>BS 7533-103:2026 - Pavements constructed with clay, natural stone or concrete pavers. Guide for the design of permeable pavements constructed with concrete paving blocks and flags, natural stone slabs and setts and clay pavers</i>                                                                                |                                                                                                                              |
| British Standards Institution  | (2025)  | <i>BS 7533-102:2025 - Pavements constructed with clay, natural stone or concrete pavers. Code of practice for laying precast concrete paving blocks and clay pavers for flexible pavements</i>                                                                                                                           |                                                                                                                              |

|                                                                                |         |                                                                                                                                                         |                                                                            |
|--------------------------------------------------------------------------------|---------|---------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| British Standards Institution                                                  | (2017)  | <i>BS 8533:2017 - Assessing and managing flood risk in development. Code of practice</i>                                                                |                                                                            |
| British Standards Institution                                                  | (2012)  | <i>BS EN ISO 22282-2:2012 - Geotechnical investigation and testing. Geohydraulic testing. Water permeability tests in a borehole using open systems</i> |                                                                            |
| British Standards Institution                                                  | (2013a) | <i>BS 8582:2013 - Code of practice for surface water management for development sites</i>                                                               |                                                                            |
| British Standards Institution                                                  | (2013b) | <i>BS EN 14227-1:2013 - Hydraulically bound mixtures. Specifications. Cement bound granular mixtures</i>                                                |                                                                            |
| British Standards Institution                                                  | (2024)  | <i>BS EN ISO 10319:2024 - Geosynthetics. Wide-width tensile test</i>                                                                                    |                                                                            |
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| British Standards Institution                                                  | (2024)  | <i>BS 594987:2024 - Asphalt for roads and other trafficked areas. Transport, laying, compaction and product type testing protocols. Specification</i>   |                                                                            |
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| British Standards Institution                                                  | (2022)  | <i>PD 6691:2022 Guidance on the use of BS EN 13108 Bituminous mixtures — Material specifications</i>                                                    |                                                                            |
| Building Research Establishment                                                | (1991)  | <i>Soakaway Design</i>                                                                                                                                  | BRE Digest 365                                                             |
| Cedergren HR                                                                   | (1974)  | <i>Drainage of highway and airfield pavements</i>                                                                                                       | Wiley                                                                      |
| CEN                                                                            | (2005)  | <i>CEN/TR 12566–2–2005, Small wastewater treatment systems for up to 50 PT - Part 2: Soil infiltration systems</i>                                      |                                                                            |
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# 16. Appendices

## Appendix 1 - Infiltration Testing

Infiltration tests for permeable paving should be undertaken using one of the test methods listed in Table 15. The testing should also be accompanied by an assessment carried out by a competent ground engineering professional that includes:

- Infiltration test result with a statement of which stratum it applies to and what reduced level
- Statement that the test results are consistent with the ground conditions described on trial pit or borehole records
- Statement that there are no geotechnical hazards to be aware of
- Statement that the ground is suitable for infiltration and there are no limitations in terms of extent of permeable layers, etc.

Table 15: Infiltration test methods for CBPP.

| Test method                                                                                                                                                                | Standards or guidance                                                                                                                                                                                                                            |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Single or double ring infiltrometer                                                                                                                                        | BS EN ISO 22282-5:2012 (Geotechnical investigation and testing - Geohydraulic testing - Part 5: Infiltrometer tests). These should be completed in the base of shallow excavations (that are stable and safe to allow the work to be undertaken) |
| Permeameter test in borehole                                                                                                                                               | ASTM D5126-25 Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in Vadose Zone<br><br>CEN/TR 12566-2-2005, Small wastewater treatment systems for up to 50 PT - Part 2: Soil infiltration systems            |
| Falling or rising head permeability tests in a borehole<br>(The ground around the well should be pre-saturated and the results analysed as a test in the unsaturated zone) | BS EN ISO 22282-2:2012 Geotechnical investigation and testing - Geohydraulic testing - Part 2: Water permeability tests in a borehole using open systems.                                                                                        |

A sufficient number of tests should be undertaken and a guide is provided in Table 16.

Table 16: Number of infiltration tests

| Area of permeable pavement                                                     | No of tests                                   |
|--------------------------------------------------------------------------------|-----------------------------------------------|
| Single driveway to a single house (2.5m by 5m) or developments up to 3 houses  | 1 per single driveway                         |
| Single driveways (2.5m by 5m) in a housing development > 3 houses, < 30 houses | 1 for every 5 single driveways (minimum of 3) |
| Single driveways (2.5m by 5m) in a housing development > 30 houses             | 1 for every 10 single driveways               |
| Rows of parking bays in car parks or alongside roads                           | 1 for every five parking bays (minimum of 3)  |
| Large areas of continuous permeable paving such as car parks                   | 1 every 200m <sup>2</sup> (minimum of 3)      |

On larger sites with variable geology sufficient tests should be completed to characterise each different stratum. In that case the minimum number of tests applies to each stratum.

The minimum result should be used as the design infiltration rate unless there is macro structure, when the mean value may be used as the design infiltration rate.

# 17. Glossary

Note that definitions are given in terms of CBPP.

## **Asphalt**

A homogenous mixture typically of coarse and fine aggregates, filler aggregate and bituminous binder which is used in the construction of a pavement.

## **Asphalt concrete (AC) (formerly known as dense bitumen macadam DBM)**

Asphalt concrete is a composite material pavement layer. It consists of aggregate bound together with asphalt, laid in layers, and compacted.

## **Attenuation**

Reduction of peak flow rate and increased duration of a flow event. This is achieved through the storage and subsequent slow release of run-off.

## **Attenuation storage**

Volume in which runoff is stored when the inflow to the storage is greater than the controlled outflow.

## **Attenuation tanks**

Device for the storage of attenuated runoff.

## **Base**

A pavement layer stiffer than the sub-base, that is positioned immediately above the sub-base layer. Base can be either asphalt concrete (AC) or hydraulically bound coarse graded aggregate (HBCGA). This layer is part of a CBPP system and is capable of carrying traffic loads and, if HBCGA is used, the temporary storage of rain water.

## **California Bearing Ratio (CBR)**

An empirical penetration test for evaluation of the mechanical strength of a subgrade of natural ground or engineered fill beneath new pavement construction.

## **Capping**

Layer of material placed immediately above the subgrade. Depending on the permeable pavement system type, this material may have to be permeable and must not be adversely affected by the infiltration of water.

## **Channelised traffic**

Traffic where the vehicle track width and the traffic lane width are virtually the same.

NOTE: Normal lane widths in a highway do not constitute channelised traffic.

## **Coarse graded aggregate (CGA)**

An aggregate with specific grading and physical characteristics to form a permeable sub-base.

## **Commercial vehicle**

Vehicles defined as those over 3.5 tonnes gross vehicle weight.

## **Concrete block permeable pavement (CBPP)**

A permeable pavement surfaced with concrete paving units, capable of carrying traffic loads with joints, voids or openings that allow water to pass through the pavement construction into an open graded sub-base that is designed for storage or attenuation of storm water.

## **Conventional pavement**

A pavement that does not specifically allow storm water to pass through, and be stored in, its layers.

## **Conveyance**

Movement of water from one location to another.

## **Cored asphalt concrete (CAC)**

An impermeable asphalt concrete base, cored or perforated with 75mm diameter holes on a 750mm orthogonal grid to allow water to infiltrate to the underlying layers via the cored or perforated holes.

## **Cumulative traffic or design traffic**

The design traffic is the commercial vehicle loading over the design period, expressed as the number of equivalent standard axles; it is calculated using the commercial vehicle flow, traffic growth and wear factors and is measured in million standard axles (msa).

## **Design CBR**

The lower of the equilibrium (long term) and short term CBR values.

## **Design Thickness**

The permeable structural thickness and the hydraulic thickness are compared and the greater thickness is deemed to be the design thickness, measured in mm. Note that this measurement excludes the thickness of the paving units, laying course, capping and any other layer that may be incorporated in the CBPP that does not store water.

## **Diffuse pollution**

Pollution from widespread activities with no one discrete source, e.g. acid rain, pesticides, urban runoff.

## **Drainage system**

Drainage is the collection and transportation of rainwater and sub-surface water from an area.

## **Dynamic loading**

Spectrum of loads normally occurring on highway pavements at vehicle speeds exceeding 30 mph (50 km/h).



**Equilibrium CBR**

The long term value of CBR that occurs once the pavement is constructed and the moisture content of the subgrade comes into equilibrium with suction forces, e.g. as a result of unloading due to excavation, groundwater levels and wetting as a result of water storage in the sub-base.

**Evaporation**

Evaporation is the process by which water changes from a liquid to a gas or vapour.

**Exceedance design**

Designing a system to manage effectively events that exceed (i.e. are bigger and rarer than) the drainage system's required level of service.

**Exceedance event**

A rainfall event or flow event that exceeds (i.e. is bigger and rarer than) the design event, not to be confused with an extreme event.

**Exceedance flows**

Flows on the surface that result from:

- a) the occurrence of events that exceed the design capacity of the drainage system; or
- b) run-off that is unable to enter the drainage system; or
- c) blockage and/or structural failure of any part of the drainage system; or
- d) flood levels in the receiving water body limiting the capacity of the drainage system.

**Exceedance routes**

Overland flow routes of exceedance water.

**Extreme event**

A rainfall or flow event that is relatively rare. Generally considered to be an event with a return period of 1 in 30 years or more, not to be confused with an exceedance event.

**Fin-drains**

Fin drains, also known as geocomposite drains, are proprietary products which can be used for pavement drainage purposes. They normally comprise a plastic core and are wrapped in geotextile filter material.

**Fines**

Small soil particles less than 63 microns in size.

**Flow control device**

A device used to limit the flow of water through the outlet from a SuDS component (such as CBPP), usually necessary to meet a required discharge rate.

**Formation level**

Surface of an excavation prepared to support a pavement or other overlying structure.

**Frequency of rainfall**

The number of times, during a specified period of years, that precipitation of a certain magnitude or greater occurs.

**Geo-cellular box system**

A proprietary storm water storage system comprising a series of modular plastic units clipped together to form a void for the storage of storm water.

**Geocomposite**

A form of geosynthetic that is made by creating a single component from two or more elements (e.g. a drainage core and geotextile).

**Geogrids**

Layers of plastic reinforcement inserted between construction layers to increase structural performance and reduce the thickness of sub-base or capping material.

**Geomembrane**

An impermeable sheet, typically manufactured from polypropylene, polyethylene or other geosynthetic material, used to form an impermeable liner system.

**Geotextile**

A permeable fabric that can separate, filter, reinforce, protect or drain.

**Greenfield runoff**

The surface water runoff regime from a natural site.

**Greenfield runoff rate**

The greenfield runoff measured in l/sec/ha.

**Half empty time**

The time it takes to reduce the volume of water in a CBPP to half its maximum capacity.

**Hoar frosts**

A deposit of needle like ice crystals formed on the ground by direct condensation at temperatures below freezing point.

**Hydraulically bound coarse graded aggregate (HBCGA)**

An aggregate with specific grading, physical characteristics and the inclusion of a cement or other binder, to form a permeable base. Usually HBCGA is CGA with the addition of cement.

**Hydraulic thickness**

The total thickness of the sub-base and permeable base (if required), to temporarily store the storm water for the site conditions and storm predictions, measured in mm.

**Infiltration rate**

The velocity or speed at which water enters soil (or the surface of a permeable pavement – see surface infiltration rate), measured in m/s.

**Initial compaction**

The process of bedding the paving units into the laying course using a vibrating plate compactor.

**Initial rainfall loss**

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

**Interception**

The prevention of runoff from a site for the majority of small (frequent) rainfall events (or for the initial depth of rain for larger events).

**Joint filling aggregate**

An aggregate used to fill the joints or voids between adjacent paving units. Permeability is achieved by specific grading characteristics of the aggregate.

**Joint filling compaction**

Sometimes referred to as the final compaction. The process of compacting the joint filling aggregate into the joints with a vibrating plate compactor.

**Joint Space**

The distance or gap, measured in mm, between adjacent paver units (recommended by the paving manufacturer).

**Lower geotextile**

Geotextile positioned between the subgrade and sub-base, or subgrade or capping, for System A or B pavements.

**Management train**

The sequence of drainage components that collect, convey, store and treat runoff as it drains through the site.

**Overland flow route**

The route taken by water flowing over the ground surface from a conveyance or storage component once the capacity of that component is exceeded.

**Particle Size Distribution**

Particle size distribution, also known as grading, refers to the proportions by dry mass of a soil or aggregate distributed over specified particle-size ranges.

**Pavement**

An impermeable road or pedestrian surface and underlying structure, surfaced with asphalt, concrete or concrete block paving and capable of supporting traffic loads.

**Paver or paving unit (permeable)**

Sometimes referred to as block paving. Concrete paving units specifically designed for use in CBPPs. These paving units have spacer nibs larger than nibs on conventional pavers, to create larger joints to facilitate the infiltration of storm water between paving units. Alternatively, permeability between adjacent paving units is achieved by voids created by the geometric shape of the paving unit.

**Paver surface**

A structural surface consisting of paving blocks laid on permeable laying course and the joints or voids between adjacent paving blocks filled with permeable aggregate.

**Peak flow rate**

The highest flow rate of water from a given rainfall event.

**Perforated pipe**

A pipe which has small slots or holes through which water can flow.

**Permeability**

The ability of a material to allow water to pass through it.

**Permeable pavement**

A pavement that is designed to allow rain water to pass from the surface to the underlying layers.

**Pollution**

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

**Porosity (of the permeable base or sub-base)**

Porosity is the amount of air space or void space between aggregate particles. Infiltration and storage of water occur in these void spaces. The porosity is the ratio of the volume of pore space in a unit of material to the total volume of material, measured as a percentage. (In permeable pavement design, the porosity of the base and sub-base are assumed to be 30% but this should always be confirmed by testing or certification).

**Porous Surface**

Infiltrates water across the whole surface via pores within the material itself (unlike permeable paving that infiltrates water through joints between impermeable modular units).

**Rainfall event**

A single occurrence of rainfall before and after which, there is a dry period that is sufficient to allow its effect on the drainage system to be defined.

**Rainfall intensity**

Amount of rainfall occurring in a unit of time generally expressed in mm/h.

**Rainwater**

Water that has fallen as, or been obtained from, rain.

**Return periods**

An estimate of the likelihood of a particular event occurring. A 100-year storm refers to the storm that occurs on average once every hundred years. In other words, its annual probability of exceedance is 1% (1:100).

**Roof drainage**

Rainwater collected from a roof.

**Runoff**

Water flow over the ground to the drainage system. This occurs if the ground is impermeable, saturated or if the rainfall is particularly intense.

**Runoff coefficient**

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

**Runoff route**

The path that rainwater or other surface water takes as it flows over land due to gravity.

**Separate spacer**

A device inserted between adjacent paving units to achieve the minimum joint space for paving units that do not have cast spacer nibs.

**Sewer**

A pipe or channel conveying foul and/or surface water from buildings and surrounding areas.

**SHW Type 3**

An alternative sub-base to Coarse Graded Aggregate (CGA). Type 3 is a permeable aggregate compliant with the Highway Agency's Specification of Highway Works (SHW), 2025. (The porosity of Type 3 should be checked for any regional variations.)

**Short term CBR**

The value of CBR obtained from CBR tests on the subgrade, taken once it is exposed for construction.

**Source control**

The control of runoff at or near its source, so that it is delayed, 'cleaned' and attenuated before it enters the drainage system.

**Source Protection Zones**

Defined by the Environment Agency as zones in the catchment area for sources such as wells, boreholes and springs used for public drinking water supply. They show the level of risk to the source from contamination. This could be from any activity that might cause pollution in the area including infiltration of surface water runoff.

**Spacer nibs**

Projections cast on the side of paving units to achieve the minimum joint space between adjacent paving units.

**Spare hydraulic storage capacity**

Spare hydraulic storage capacity is where the structural thickness is greater than the hydraulic thickness. This difference is measured in mm.

**Standard axle**

A vehicle axle carrying a load of 80kN or 8,200 kg.

**Structural thickness**

The total thickness of the sub-base and base (if required), to carry the predicted traffic loadings for the site conditions, measured in mm.

**Storm**

An occurrence of rainfall, snow or hail.

**Storm water**

Water from a storm.

**Sub-base**

A permeable aggregate layer positioned immediately above the capping layer or subgrade comprising of either coarse graded aggregate (CGA) or SHW Type 3. This layer is part of a CBPP system and is capable of carrying traffic loads and the temporary storage of storm water.

**Subgrade**

Upper part of the soil, natural or constructed, that supports the loads transmitted by the overlying pavement.

**Subgrade improvement layer**

Layer of granular or treated material at the top of the subgrade to provide an improved load bearing capability of the subgrade.

**Surface infiltration rate (of a CBPP)**

The velocity or speed at which water enters the surface of a permeable pavement. Measured in mm/h and m/s.

**Surface water**

Water bodies or flows that appear as a result of rainfall.

**Sustainable drainage system (SuDS)**

Individual or multiple linked drainage components designed to collect, manage, control and treat surface water run-off and, where possible to provide amenity, biodiversity and climate resilience benefits.

**Swale**

A shallow vegetated channel designed to convey, treat and occasionally store surface water, and may also permit infiltration.

**Time of entry**

Time taken for runoff from rainfall to reach an inlet into the drainage system.

**Total volume**

Total volume of runoff from a site.

**Upper geotextile**

Optional geotextile positioned between the laying course and HBCGA base or sub-base.

**Water courses**

A term including all rivers, streams, ditches, drains, cuts, culverts, dykes, sluices and passages through which water flows.

**Water harvesting**

The collecting of rainwater from surfaces on which rain falls, and subsequently storing this water for later use as non potable water.

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