D3.2 Sustainable assessment of measures and treatment systems for road runoffs: Survey of guidelines

CEDR PROPER PROJECT

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Executive summary

This report is the second Deliverable of WP3 (Sustainable assessment of measures and treatment systems for road runoff) of the CEDR PROPER project. Drawing on the findings of D3.1 (Comprehensive literature review of blue-green treatment solutions) this report addresses the guidelines which exist for designing these treatment systems. The emphasis is initially on the guidelines which have been established for the installation of these systems in the UK but then expands the scope to cover geographical regions which possess different climatic characteristics.

The UK guidelines which have been developed for systems designed to treat urban runoff are discussed in Section 2 of this report by drawing on the most recently published documents. The emphasis is on road runoff drainage with an initial overview of the general design aspects which are important when considering this source of contaminated waters. Each of the most widely used treatment systems for highway runoff is then considered separately with specific attention given to the design criteria relevant to each component including inlets, pre-treatment systems (e.g. forebays), the main system and outlets. Additionally, the maintenance and management regimes needed to keep the treatment systems operating efficiently are described as well as how best to blend them into the existing landscape. For vegetated systems, the most appropriate planting scenarios are discussed and where there is the possibility of spillage containment this is covered.

In Section 3 details are provided of the considerable US guidance material which exists in terms of the pan-state adoption of a generally consistent process-based selection approach and a common structural framework for criteria-based design and implementation. This includes a review of the selection criteria and procedures for quality control of highway runoff which are relevant to the different climatic conditions compared to those encountered in the UK. The southern US states and Australia are considered as representative of semi-tropical biomes whilst Sweden and Canada are taken as cold climate representatives. There has been a tacit acknowledgement that urban drainage in cold climates poses very specific problems in terms of approaches to and design of sustainable control and management, particularly in respect of the treatment of winter highway snowmelt runoff.

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1. Introduction

It is widely recognised that urban runoff, particularly from highways, contains a range of pollutants that can have detrimental impacts on both ground and surface receiving waters. The aim of this Deliverable is to review the readily accessible guidance on the design, construction, operation and maintenance of treatment systems that are appropriate for effectively attenuating the volumes and flow rates of discharges deriving from predominantly rural highway surfaces and for improving the water quality of the runoff prior to discharge to a receiving water body. Although the prime function of treatment systems is to protect the water regime into which the highway runoff discharges they can additionally, enhance the immediate landscape, contribute to biodiversity and nature conservation, and improve the amenities available to the local population (although the latter is likely to be limited in busy highway environments). Maintenance and management of treatment systems is essential to facilitate their efficient operation and to ensure continuing sustainable protection for receiving waters. It is important that landscape, amenity and/or nature conservation values should be compatible with this function and should not inhibit the maintenance work required for the correct functioning of the system.

There are a number of different descriptive names which have been used to describe the treatment systems available for improving the quality of highway runoff. These include Sustainable Drainage Systems (SuDS), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Low Impact Development (LID), Green Infrastructure (GI) and Blue Green Treatment Solutions. The latter definition was widely used in Deliverable 3.1 but strictly it refers to vegetated systems which is not necessarily relevant for all treatment systems such as, for example, porous surfacing. The objective of all these treatment systems is to mimic natural processes (e.g. infiltration, evaporation, evapotranspiration) and typically to manage rainfall close to where it falls. They constitute drainage systems that convey or retain stormwater whilst also being environmentally beneficial and causing minimal or no long-term detrimental damage. Both structural and non-structural management practices can be utilised to efficiently and sustainably drain surface water, while minimising pollution and managing the impact on water quality of local water bodies. LID and WSUD also emphasise the importance of the beneficial re-use of stormwater but this option is rarely considered to be an important option for highway runoff (as opposed to general urban runoff).

This Deliverable consists of two major sections dealing with detailed guidelines for the construction, operation and maintenance of treatment systems for highway runoff (Section 2) and comparing existing guidance manuals for countries with different climatic conditions (Section 3). Although the information provided in Section 2 is specifically based on guidance material prepared for the UK its generic nature means that it is relevant to other countries, including many within Europe, which experience temperate climates. Section 3 focusses on guidance appropriate to both warmer and colder climates. The southern US states and Australia are used to illustrate the demands imposed on highway runoff treatment in sub-tropical conditions with Sweden and Canada providing examples of countries where cold climates influence the design criteria for treatment systems. Additionally, the relevant literature is identified for a large number of other countries including Germany, Austria, France, Norway, Denmark, Ireland, The Netherlands, Portugal, Switzerland, Slovenia, Latvia/Estonia, New Zealand and India.

2. UK Guidelines for Highway Runoff Treatment Systems

This Section reviews the existing UK guidelines for the construction, operation and maintenance of treatment systems for highway runoff. The main sources of information are the CIRIA SuDS Manual (CIRIA Report C753, 2015) and Volume 4 of the Design Manual for Roads and Bridges (Design Manual for Roads and Bridges, 2006) with supplementary guidance being provided by the Guidance Manual for Constructed Wetlands (Ellis, Shutes and Revitt, 2003), the Review of the Use of Stormwater BMPs in Europe (Revitt, Ellis and Scholes, 2003) and the web-sites supported by Susdrain and SuDS Wales.

2.1. General aspects relating to the treatment of road runoff

Surface water is required to be removed as quickly as possible from the highway surface and subsequently managed both at its sources and on the surface, where this is feasible. Ideally treatment systems should be cost-effective to operate and maintain over their design life including minimising the use of energy and taking into account the likely effects of climate change. The selected treatment or treatment train should reduce the impact of road runoff on the quality of receiving water bodies (to acceptable standards) and limit the effect that roads can have on local hydrology and therefore on flood risk. This is consistent with the objectives of the EU Water Framework Directive which aims to prevent deterioration of, and to enhance and restore, bodies of surface and ground water so they achieve good chemical and ecological status. The generation of waste during both construction and operation of treatment systems is expected to be minimised. They may also contribute to the landscape, amenity and nature conservation value of the surrounding area providing this does not interfere with their prime flood and treatment functions.

Wherever possible all runoff from existing land drainage systems should be kept separate from the road drainage system. When designing new highway drainage systems or managing and operating existing highway drainage, new surface water connections from sites and/or proposed developments adjacent to the road are generally not accepted. Surface water flows from Local Authority side roads may be considered where there is no adequate alternative outfall.

When selecting appropriate treatment system(s) for highway runoff there are a number of factors to be taken into consideration. These include:

- the traffic levels on the road expressed as annual average daily traffic (AADT) and the proportion of heavy goods vehicles
- the area of road surface drained to one outfall
- local landscape e.g. site gradient
- geology e.g. permeable substrata, soil type
- hydrology and residence time within the treatment system
- climate e.g. storm event characteristics
- local river catchment and quality
- the risk of accidental spillages
- practicality of maintenance
- land availability.

Residence or retention time is the period of time during which the runoff is retained within the drainage system and is defined by the equation $R_t = V/Q$ (where Q is the outflow and V is volume of the system). It is a critical design parameter for those treatment systems which depend on the settlement process for the removal of sediment and particulate associated metals and organics. Minimum recommended residence times are of the order of 24 hour but longer periods may be required for very fine sediment where settlement is the primary removal process. Residence times need to take into account the occurrence of follow-on storms (or storm sequences) in terms of appropriate sizing and frequently retention time standards are stated in terms of a 24 hour retention per 40 m^3/ha runoff equivalent for the 1:100 storm event. Important design factors influencing the residence/retention time include:

- permanent pool storage capacity
- hydraulic gradient (<1%)
- length-width ratio (>3:1)
- uniform cross-section
- flow path (e.g. zig-zag)
- the presence of flow arrest structures, such as submerged islands/weirs, vegetation across flow
- the design of outfall structures

The hydraulic loading plays an important role in affecting the efficiency of a treatment system with a reduction observed with an increased loading. High flow rates under storm conditions and associated low residence times (< 1 hour) can result in the remobilisation of deposited sediment and therefore a bypass structure may be required.

The worst case scenario for a highway runoff treatment system occurs when an intense storm follows a long dry period during which there has been a build-up of pollutants on the road surface. The result is that the runoff deriving from the first 5-10mm of rainfall can be highly polluted (often referred to as the ‘first flush’ effect) and is most likely to pose a pollution threat to receiving waters compared to discharges from longer rainfall events which provide higher dilution. Therefore, although treatment systems should normally be designed to treat all the water discharged during a rainfall event, where this is not possible, every attempt should be made to treat the runoff arising from the first 5-10 mm of rainfall. If this has to be achieved separately, it is important to ensure that the time taken for the runoff to reach the highway outfall from the furthest point (the time of concentration) is similar for all drain runs entering any one outfall. Otherwise, if one run is much longer, it will continue to discharge the more polluted ‘first flush’ for longer, and separate treatment will not be readily achievable. Similarly practical limitations, such as land availability, may mean that, whilst a system can be designed to provide storage for the design event, its treatment efficiency will reduce during extreme events. In these circumstances pollutant concentrations are likely to be reduced because of the high volume of runoff related to the antecedent pollution build-up, and because dilution of the attenuated flow will be high.

The characteristics of the receiving waters (surface watercourses or groundwaters or both) will need to be considered when assessing the most appropriate highway runoff treatment. For surface waters, the river flow determines the extent of the dilution which is available to the discharged runoff with 1:8/1:9 being widely adopted as the threshold minimum dilution standard. A critical time occurs in the summer months, not only because of the ‘first flush’ phenomenon, but also because the river flows are at their lowest. Although there are few instances of groundwaters being been adversely affected by highway runoff, the consequences of any pollution incident could be severe as remedial measures will be very difficult to achieve. Therefore, a precautionary approach should be adopted when designing systems to protect discharges to ground.

The availability of land can be a significant factor affecting the choice of a treatment system. For new road schemes, the optimum drainage systems should be identified taking into account water quantity and quality considerations. If land acquisition is deemed necessary this may be supported by the achievement of a better scheme in terms of the landscape, visual and ecological benefits. For improvement schemes, land availability may be limited, and it may be a requirement to design the treatment system to fit into the road corridor, using land within interchanges where this is suitably located.

In determining the degree of flow attenuation required from a particular outfall, both the climate and associated rainfall characteristics need to be considered. A 1:100 rainfall intensity is frequently taken as the design standard although many highways have been constructed to lower 1:30 or 1:50 standards. Whether there are likely to be long dry periods with occasional intense storms or whether a higher and more uniform rainfall can be expected needs to considered together with the local catchment hydrology to determine the extent of attenuation needed. The climate variations may require large balancing ponds, or infiltration basins as opposed to a series of smaller containment devices, such as swales, located at the top of the drainage system. Climatic considerations may also influence the choice of treatment system if a base flow is required e.g. for irrigation where wetland vegetation is present.

The permeability of the natural subsoil can influence the suitability of swales, grassed channels and infiltration basins/trenches as potentially effective treatment solutions. However, consideration must also be given to the percolation of water to ground and to the effects of the possible transmission of pollutants to the underlying subsoil, particularly in areas of existing contamination. A minimum percolation rate of 13-15 mm/hour are is the frequently applied standard. The use of impermeable membranes may be necessary in some circumstances to prevent seepage to ground. They may also be necessary to maintain the quality of the treatment system. Where proposed sites for drainage systems are situated above aquifers the vulnerability of the ground water should be fully assessed including consideration of the minimum travel times to the nearest abstraction points. Where the attenuating properties of the subsoil in respect of highway runoff pollutants cannot be firmly established, it is recommended that a high factor of safety be used when designing and constructing systems above vulnerable groundwaters. Appropriate protection measures may include placing thicker membranes or imported impermeable material (possibly a waste product from elsewhere on site), to provide an impermeable barrier above the vulnerable strata.

Soils can also be important in determining the stability of a treatment system with soils consisting of a gravel, sand and clay mixture being more erosion resistant than fine sands and silts. In the latter situation, low flow velocities will be required and it may be necessary to incorporate front-end rip-rap channels, sheet spreaders and/or concrete aprons to prevent scour. These are more likely to be needed for swales and grassed channels compared to ponds and basins.

The design of treatment systems should be carefully integrated into the landscape taking into account the topography. In flat areas, with little or no gradients, larger systems such as wetlands or ponds may be appropriate whereas in undulating areas, smaller and more frequent treatment and attenuation systems will be preferable for blending into the landscape.

Although there are many factors which can influence the choice of treatment systems for use in drainage systems, there may be several solutions at some locations. In other situations only certain drainage systems may be appropriate. Also in some circumstances where flood control and spillage containment is required, more than one system may be necessary and appropriate treatment trains may be the best option providing the necessary space is available.

2.2 Guidelines for Swales

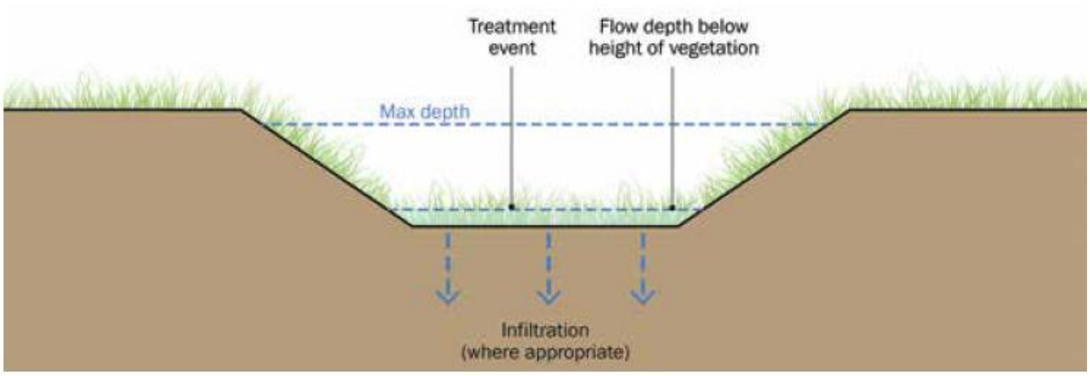
Swales are wide, shallow, flat-bottomed, gently sloping, vegetated depressions, which are designed to convey stormwater such as highway runoff and may operate as the first stage of flow attenuation/pollutant removal in a drainage system. They are appropriate for draining long stretches of road where it is convenient to collect distributed inflows of runoff and there are few buried services alongside or crossing the road. Although they are suitable to areas where the road is on a gently sloping embankment where they can be incorporated into the sloping surface, they are less suitable where roads are located on steeper embankments. This is because, unless they are lined with an impermeable geomembrane (at a depth of at least 0.5 m), infiltrating water could cause stability issues. Where space is available swales can be successfully integrated into the general landscape of the highway, incorporating existing and proposed landscape elements such as trees or hedges as appropriate and contributing to linear eco-corridor development.

Swales can have a variety of profiles, either uniform or non-uniform, but the standard swale channel is broad and shallow (side slopes of 1:10 or less and a maximum 2% gradient unless check dams are present) and covered by vegetation, usually grass, to slow the flow of the water. This facilitates the removal of pollutants through sedimentation, filtration through the root zone and soil matrix, evapotranspiration and infiltration into the underlying soil. Although the effectiveness of swales for removing pollutants will depend upon the detailed design, they typically demonstrate good performance for suspended solids and particulate associated metals (>50%) but lower efficiencies for soluble metals. Coarse to medium sediments and associated pollutants (such as oils/grease and metals) can be removed by filtration through surface vegetation and groundcover. Fine particulates and associated contaminants can be removed by infiltration through the underlying soil and/or filter medium layers. In addition to pollutant removal by filtration, dissolved pollutant removal occurs by sorption of pollutants to the filter medium, and there is also some biological uptake by vegetation and subsoil biota. Organic contaminants can be removed through photolysis and volatilisation.

There are 3 different types of swales known as conveyance swales, dry swales and wet swales. Conveyance swales are shallow vegetated channels which are effective at collecting and conveying runoff from the drained area to another treatment system (see Figure 2.1). In the US and Australia, the former two types are termed swales with wet swales commonly termed bioswales. The dry swale is a vegetated conveyance channel, which incorporates a filter bed of prepared soil overlaying an underdrain system which provides additional treatment and conveyance capacity beneath the base of the swale, and prevents waterlogging. To prevent infiltration, or where groundwater levels are high, a basal liner may be required (see Figure 2.2). Wet swales are specifically designed to deliver wet and/or marshy conditions in the base and are appropriate for use at very flat sites with poorly drained soils where they can provide the amenity or biodiversity requirements of a longitudinal pond/wetland component (see Figure 2.3).

2.2.1. Design aspects

Swales are well suited for conveying and treating runoff from roads because they represent a linear feature which is easily incorporated into the roadside space. As the swale length parallels the road, it should be equal to, or greater than, the contributing roadway length. The length of any section of swale between culverts should be at least 5 m or greater for maintenance access purposes.



(after CIRIA 2015)

Figure 2.1. Schematic diagram showing the cross section of a conveyance swale

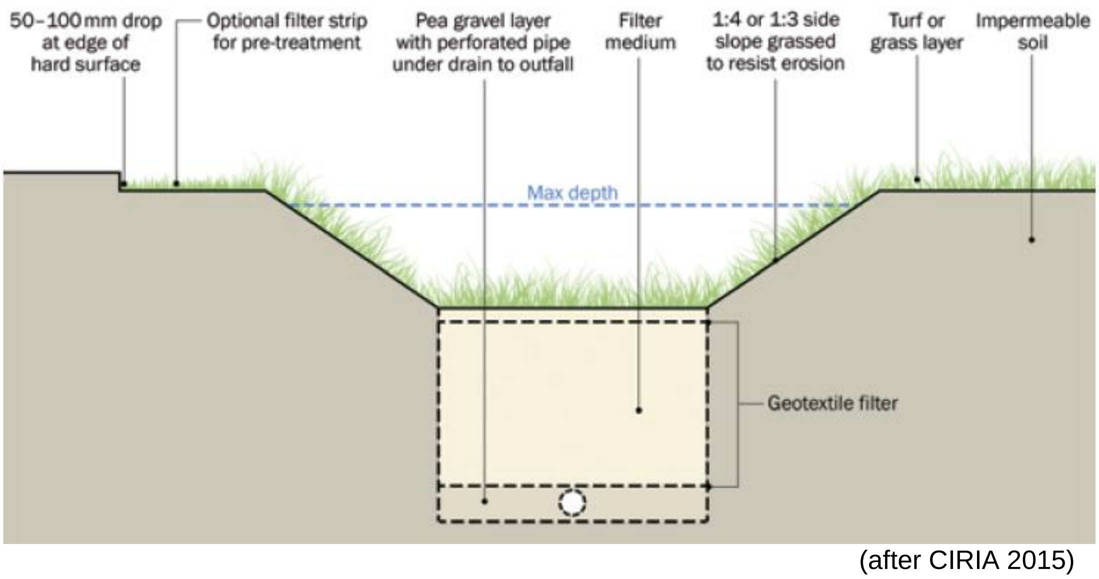


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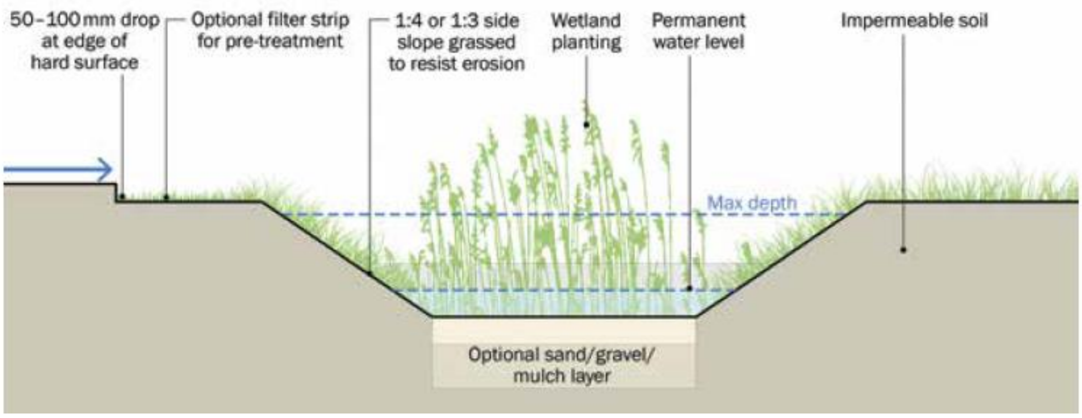
Figure 2.2. Schematic diagram showing the cross-section of a dry swale.



(after CIRIA 2015)

Figure 2.3. Schematic diagram showing the cross-section of a wet swale (or bioswale)

Swales provide the most effective treatment when the speed of the water flow is slow e.g. immediately after it leaves the road for the majority of rainfall events. However, for the flows associated with more intense storms, previously accumulated suspended solids may be released and washed downstream. Swales should be designed with trapezoidal or parabolic cross-sections and a bottom width of 0.5–2.0 m, to accommodate the 5 year 24 hour event, and checked against a 10 year event. The channel velocity should not exceed 0.25 m/s, with the longitudinal slope being in the range of 0.5% to no more than 6%. The flow speed should be less if the swale length is less than 120m, as an 8 - 10 minute residence time within the swale is optimal for maximum effectiveness. The residence time can be extended by increasing flow width and length or by introducing check dams. Additionally, decreasing slope and/or increasing the density of vegetation will also increase the residence time but can result in greater water depths due to increased flow impedance. The design event runoff volumes should half empty within 24 hours. This will help to ensure that storage and treatment volumes are available for subsequent events and, for dry/conveyance swales, should also protect vegetation from damage by saturated conditions.

The side slopes should be as flat as possible to aid pre-treatment of lateral incoming flows by maximising the swale filtering surface, to limit erosion channelling and allow easy access for mowing. For shallow swales and low-speed roads a side slope of 33% is considered acceptable both from a safety and maintenance perspective. For faster roads, side slopes of 25% may be more appropriate to address both safety concerns and maintenance aspects such as accessibility for grass mowing. Where there are concerns regarding risks associated with infiltrating water, swales can be underdrained, which will act as a subsurface drain at the side of the road.

For safety reasons, swales running adjacent to roads should not be very deep and the normal maximum swale depth is 400–600 mm although this will be influenced by the depth of inflow pipework. The installation of deeper swales will involve higher land-take requirements, deeper water and costly excavations. Therefore alternative options should potentially be considered to ensure that the optimum surface water management system is delivered.

The attractiveness of swale design is improved by avoiding abrupt changes in vertical or horizontal directions and this also reduces the risk of erosion and assists in the ease of maintenance. Swales are particularly suited to areas where drainage from the road flows over the edge as sheet flows. Where piped flow is channelled to a swale a flow spreader is recommended to avoid the occurrence of rivulets or channels resulting in a reduction in treatment effectiveness. Ideally, a smooth sheet flow should be designed for to help maintain the stability of the swale channel and avoid the possibility of scour. An even flow of low velocity is assisted by wider or longer channels with rip-rap, concrete aprons and spreaders installed at the outfall of the swale. The installation of check dams also contributes to flow reduction in swales. Although settlement is not a major removal process in swales this is encouraged if there is a small vertical component to the flow, caused by infiltration in areas where the underlying material is permeable and discharge to ground can be permitted. If infiltration is allowed, the maximum likely groundwater level should be at least 1 m below the base of the system.

As swales can act in a conveyancing role, they can obviate the need for a system of gullies and piped drainage by designing the drainage system to allow the swale to discharge to a suitable collection point. In addition, this can provide a significant primary treatment prior to discharging the highway runoff to further treatment in ponds or wetlands. In this way swales can provide a cost effective removal of suspended solids and potentially extend the periods between major maintenance for downstream treatment systems.

2.2.2. Planting regime

A dense and even grass sward is an optimal requirement if a swale is to be effective in retaining suspended solids. The selected species should combine both rapid establishment and recovery, with some salt tolerance and tolerance of both wet conditions and periodic inundation. Possible species to consider are perennial ryegrass (Lolium perenne) and creeping bent (Agrostis stolonifera). Where salt tolerance is a particular requirement, salt tolerant cultivars of fescue species (Festuca spp.) can be selected. Rush species (e.g. Juncus spp.) should also be considered. Vegetation height should be approximately twice the depth of water to be treated and ideally 100-200 mm. Shorter vegetation will not effectively treat the faster flows and taller vegetation will have a tendency to be flattened; very regular close mowing is therefore not to be encouraged.. Geotextiles may be employed to prevent erosion in the early stages of vegetation development or as temporary measures in advance of seeding, but should not be relied on in the long term as they will degrade. Swales should not be located where extensive areas of trees or overhead structures will cause shade conditions that could limit growth of grass (or other vegetation).

2.2.3. Maintenance and management

Details of an appropriate maintenance schedule together with frequencies for the required actions is shown in Table 2.1. Since swales perform most efficiently when the grass sward is dense and between 100 and 200 mm in length, regular mowing down to 100 mm will be required. The frequency will depend both on growth and location and may typically be three or four times a season. Heavy machinery should be avoided and mowing should not be practised when ground conditions are wet and soft as this could compact soils, create ruts and result in erosion. Removal of litter and debris is recommended on a regular basis with swales being checked after major storm events.

The build-up of debris can lead to the formation of channels and a reduction in treatment effectiveness by disrupting the even flow necessary for optimum efficiency.

The potential build-up of sediment should be checked annually particularly in the upstream areas of the swale and also at check dams, where these are present. Long term siltation over the remainder of the swale is unlikely to be a problem, although ‘crusting’ may be observed. This should be removed mechanically and will result in a subsequent need to re-seed. Swales should be inspected annually for structural repairs, especially to the inlet areas and side slopes where erosion may occur. Repair should include infill, reshaping of the slopes and reinforcement if necessary. Bare areas should be re-seeded and fertilised if necessary.

Table 2.1. Details of regular and occasional maintenance and remedial actions recommended for swales

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Remove litter or debris	Monthly or as required
	Cut grass to retain height within specified design range	Monthly (within growing season) or as required
	Remove weeds and unwanted plants	Monthly at start and then as required
	Inspect inlets, outlets and overflows for blockages, and clear if required	Monthly
	Inspect infiltration surfaces for ponding, compaction and silt accumulation	Monthly
	Inspect vegetation coverage	Monthly for first 6 months then half yearly
Occasional maintenance	Re-seed areas of poor vegetation growth	As required
Remedial actions	Repair any damaged areas by re-turfing or re-seeding	As required
	Scarify and spike topsoil layer to improve infiltration, break up silt deposits and to prevent compaction	Annually or as required
	Remove build-up of silt on upstream gravel trench and flow spreader	Annually or as required
	Remove and dispose of oil and petrol residues using safe practices	As required

2.2.4. Spillage containment

Check dams are primarily installed to reduce flows but can also act as a form of automatic spillage containment for less serious accidental spillages. The shallow gradient of most swales makes them unsuitable for the containment of major spillages although it may be possible to surround the lowest part of the swale with a berm fitted with a notched weir outlet. In such situations, it is essential that any spilt liquid cannot percolate to groundwaters, and an impermeable liner may be needed.

2.3. Guidelines for Filter Strips

Filter strips are gently sloping and uniformly graded strips of grass or other dense vegetation that are capable of treating runoff from adjacent impermeable surfaces through sedimentation, filtration and infiltration. At locations where there is a risk of groundwater contamination, infiltration will need to be prevented. Filter strips are particularly well suited for managing runoff from roads because they are a linear feature which can normally be accommodated into roadside spaces. The road/filter strip boundary needs to be carefully designed so that it does not become blocked by sediment or vegetation. Filter strips work best when receiving runoff as overland sheet flow with sufficiently low velocities to enable the treatment processes to take place effectively. Filter strips do not provide a significant attenuation or reduction of peak flows or runoff volumes.

Filter strips are easy to construct and represent low cost systems which are particularly suited to use as a pre-treatment option especially for non-urban highways. Therefore they are often (but not always) employed at the upstream end of a drainage system to reduce the loads of sediment reaching swales, ponds and trenches.

In addition to infiltration (where permitted), filter strips treat runoff by vegetative filtering and promoting the settlement of particulate pollutants. The vegetation traps organic and mineral particles that are then incorporated into the soil, while the vegetation takes up any nutrients. Soluble pollutants can be removed where infiltration is acceptable with filter strips able to provide an effective contribution to interception during the more regular small rainfall events. Based on the 75 percentile pollutant concentrations in urban runoff of 114 mg/L for TSS, 0.6 µg/L for total cadmium, 22 µg/L for total copper, 112 µg/L for total zinc and 8 µg/L for total nickel, filter strips can demonstrate removal efficiencies of 69%, 50%, 45%, 53% and 50% respectively (CIRIA, 2015).

2.3.1. Design aspects

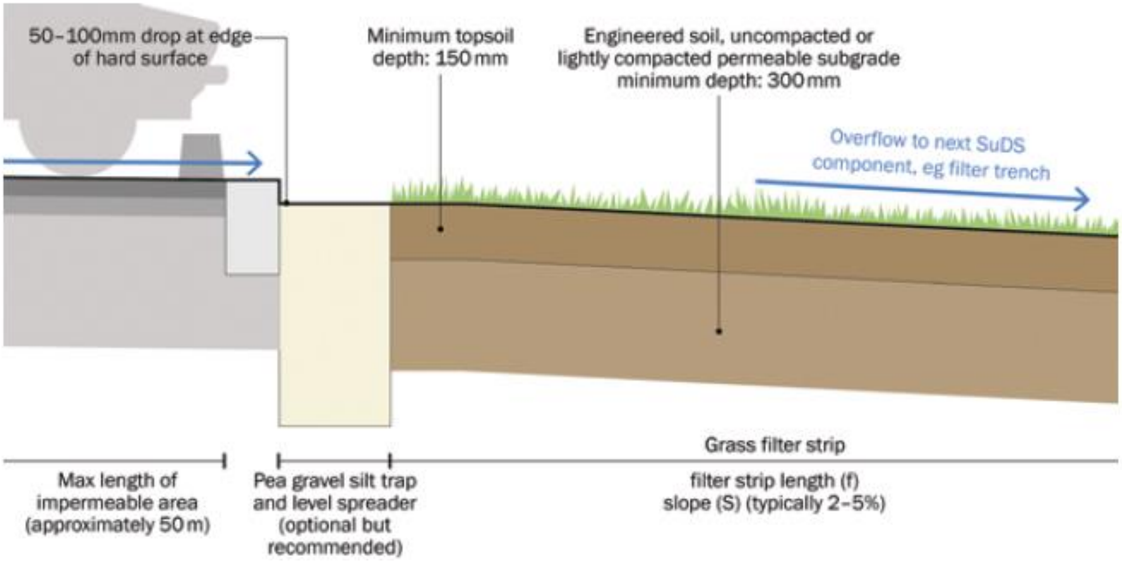
A schematic diagram showing a typical design for a filter strip is provided in Figure 2.4. The contributing impervious area should possess a shallow slope falling towards the filter strip with drainage along the entire length to encourage sheet flow.

2.3.1.1. Inlet

Prior to a filter strip, a flow spreading device can be used to ensure that a consistent lateral flow is delivered along its full length. Examples of flow spreading devices include pervious pavement strips, stabilised turf strips, slotted curbing, gravel filled trenches and concrete sills. There should always be a drop of at least 50 mm from the pavement edge (as shown in Figure 2.4) to the filter strip to prevent the formation of a sediment lip.

2.3.1.2. Pre-treatment

Filter strips are themselves sometimes used as pre-treatment systems and are not normally equipped with their own pre-treatment. However, the drop between the level of the impervious surface and the filter strip may provide some pre-treatment in terms of sediment trapping and also aids oxygenation of the sheet flow.



(after CIRIA 2015)

Figure 2.4. Schematic diagram showing a typical design for a filter strip

2.3.1.3. Main system

Filter strips should be designed with a minimum longitudinal slope of 1% (to prevent ponding) and a maximum slope of 5% (to prevent channelling). If possible the slopes at the top and bottom of the flow path should be at the lower end of the range to reduce the risk of erosion as a consequence of elevated flows. The maximum flow velocities across the filter strip should not exceed 1.5 m/s. Lower flow velocities than this are recommended to facilitate effective treatment (see below). There is no recommended limit to the length of impervious area draining to a filter strip providing that sheet flow is maintained for the design storm. If it is required to control the sheet flow rate across the filter strip this is possible by constructing an impermeable berm across the top of the slope with piped outlets to regulate flows. However, this additional component will introduce an extra maintenance requirement in terms of regular inspection for pipe blockages.

The density of the vegetation is an important factor for a good pollutant removal performance which is required for all runoff events up to and including 1:1 year events. The duration of an event is the relevant critical duration of the filter strip flow rate and for road drainage 15 minutes is considered appropriate. For this water quality design event the flow depth should not exceed the height of the vegetation with a depth of 100 mm considered able to maintain good levels of filtration. The peak flow velocity should be less than 0.3 m/s to promote efficient sedimentation and the time of travel of runoff across the filter strip (residence time) should be at least 9 minutes.

The top soil beneath a filter strip should drain well and be capable of supporting the growth of dense vegetation, mainly mixed grasses, but also other plants to promote biodiversity and to enhance the aesthetic appearance. If the underlying soils are compacted, a 300 mm depth of soil should be removed and replaced with a blend of top soil and sand to promote grass/plant growth and also to promote infiltration. The selected grasses/plants will need to tolerate the alternating wet and dry conditions to which the filter strip will be subjected. In addition, the grasses/plants need to be able to grow efficiently through silt deposits which will be present. Salt tolerance is important where filter strips are located adjacent to roads. Ideally the vegetation should be dense and deep rooted and maintained at lengths of 75-150 mm to ensure effective filtration. Planting from seed should be during spring and early summer to allow a full growing season for establishment. The objective should be to achieve 90% vegetation cover with reseeding/replanting if necessary. If turfs are used these should be planted with the seams lying at right angles to the flow to reduce erosion damage. Fertilising should be avoided, if possible, to prevent damage to sensitive receiving waters. A newly constructed filter strip should be protected from surface water flows until the vegetation has become established e.g. by diverting runoff during this period.

Where infiltration is supported, the level of infiltration occurring from a filter strip will be relatively low and providing the underlying soils have an appropriate organic and clay content there should not be a pollution risk to groundwater. The groundwater level should always be at least 1 m below the lowest level of the filter strip. Where highly sensitive groundwaters are present, an impermeable geomembrane liner can be installed at a depth of 0.5 m subject to waterlogging considerations. Where the underlying soils have some capacity to store runoff it is possible that in the case of very shallow slopes there will be interception during small runoff events. It is expected that a filter strip will be able to dispose of the first 5 mm rainfall depth falling over the contributing impervious area. With regard to exceedance flows these are normally allowed to pass across the filter strip and any damage repaired. However, if protection is specifically needed for downstream components, a bypass can be considered. The amount of infiltration during large storms is not sufficient to contribute to volume reductions.

2.3.1.4. Outlet

In most cases the outflow from a filter strip will be directed to further treatment via a conveyance component such as a swale and therefore an outlet mechanism is not required.

2.3.2. <u>Integration into landscape</u>

Although not suitable for steep sites, filter strips can be readily integrated into the local landscape and are appropriate for incorporation into road verges. They are able to contribute to both amenity and ecological potential with, for example, the introduction of local wild grass and flower species providing visual interest and a beneficial wildlife habitat and contributing to the development of eco-corridors. Filter strips should not be located in shaded areas, such as close to trees, as this may impede efficient grass growth. Where filter strips are located adjacent to roads consideration should be given to the installation of low level inconspicuous barriers to prevent unauthorised vehicular access. Appropriate signage identifying the location of filter strips should be provided as their function as part of the surface water management system is not always obvious.

2.3.3. <u>Maintenance and management</u>

The efficient operation of filter strips is dependent on the different schedules and frequencies of maintenance shown in Table 2.2. The major maintenance requirement is

Table 2.2. Operation and maintenance requirements for filter strips

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Remove litter and debris	Monthly (or as required)
	Cut the vegetation to maintain height within specified range	Monthly during growing season
	Remove weeds and nuisance plants	Monthly (at start, then as required)
	Inspect for evidence of erosion, poor growth, compaction, ponding, sedimentation, contamination (e.g. oils)	Monthly (at start, then half yearly)
	Check gradients in filter strip and flow spreader	Monthly (at start, then half yearly)
	Inspect gravel flow spreader (if installed) for clogging	Monthly (at start, then half yearly)
	Identify any silt accumulation on filter strip and establish required removal frequency	Monthly (at start, then half yearly)
Occasional maintenance	Reseed areas of poor vegetation growth, alter plant types to better suit condition. If required	As required or if bare soil is exposed in >10% of filter strip area
Remedial actions	Repair erosion or other damage by re-seeding or re-turfing	As required
	Scarify and spike topsoil layer to improve infiltration capability, break up silt deposits and prevent compaction of soil surface	As required
	Remove build-up of sediment on upstream flow spreader or on top of filter strip	As required
	Remove and dispose of oils or petrol residues using appropriate safe practices	As required

mowing to retain grass lengths of 75-150 mm across the entire surface to facilitate the filtering of sediments and associated pollutants. This also limits the risk of flattening during runoff events although this is not believed to inhibit the pollutant removal process. Grass clippings should be collected and removed off-site to safely dispose of filtered sediments and pollutants. When deposited sediments exceed 25 mm in depth they should be removed and, where the received drainage is from busy roads, tested for toxicity to determine the appropriate method of disposal. If the process of sediment removal results in any damage to the surface of the filter strip the affected area should be repaired and immediately re-seeded or planted.

2.3.4. Spillage containment

Filter strips can provide a sacrificial spillage containment role, such as trapping oil in the road environment, but will then require extensive remedial action as described in Table 2.2. In cold climate regions, filter strips can act as snow pack containment areas adjacent to highways such that during snow melt any salt-laden sediment can be slowly transferred to an appropriate treatment system (e.g. infiltration trench, swale, filter drain etc.).

2.4. Guidelines for Filter Drains

A filter drain is a shallow trench lined with a geotextile and filled with stones, gravel or rubble which receives either lateral inflow directly from the drained surface or via a pipe system. They are limited to use in relatively small catchments but can be easily sited adjacent and parallel to roads to directly receive the surface drainage. Filter drains provide temporary sub-surface storage for the attenuation, conveyance and filtration of surface water runoff. Some of the received run-off passes through the geotextile membrane and soaks away into the surrounding soil thus reducing the rate of downstream discharge through a perforated pipe in the base of the trench. The presence of a high level perforated pipe can act as an overflow for extreme flows and where a network of filter drains exist these pipes can be used to transfer excess water around the system.

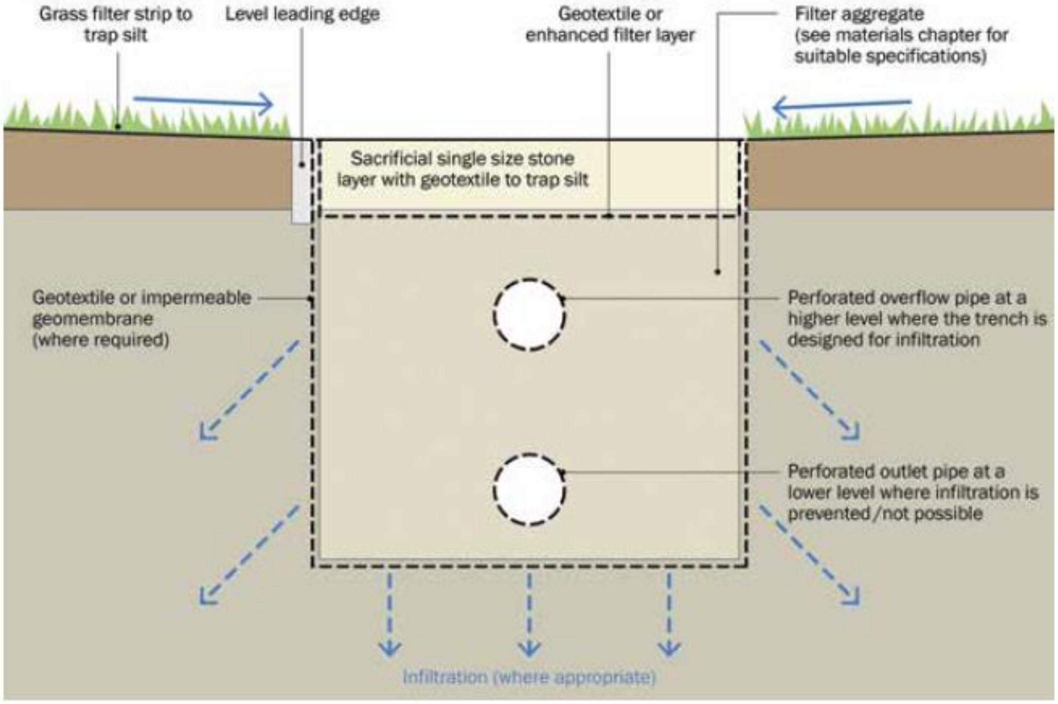
The gravel/stone fill in the filter drain provides some filtering of the runoff thereby trapping sediment, adsorption processes can remove soluble pollutants and organic matter and oil residues can eventually be broken down by bacterial action due to microorganism populations which become established on the gravel substrate. This process is assisted by the intermittent flows which filter drains receive as this allows them to drain and re-aerate between storm events. In addition to the use of gravel/stone as the fill material there are a number of different synthetic media available for which improved enhancement of water quality have been claimed. If infiltration is allowed, further pollutant load reduction occurs through losses to the surrounding soil. Flows should be captured by the filter drain and then flow towards the outfall at low rates to maximise contact time with the gravel. For road drainage a drain flow duration of the order of 15 minutes is recommended for the 1:1 year event. Performance efficiencies for gravel filters of greater than 90% for TSS and between 60 and 80% for metals have been reported but this has to be balanced by the potential for clogging and the need for cleaning. It is not recommended that filter drains are used for sediment capture. Although not routine design practice, it is possible to introduce an additional filter layer such as sand, granular activated carbon, leaf compost or pea gravel. The different types of media possess different pollutant removal potentials with sand being efficient at TSS removal whereas organic materials are better for metal removal.

2.4.1. Design aspects

Because filter drains are on-line treatment systems it is important that their design fully considers the inflow rates and volumes which may be associated with high return period storm events by ensuring that the system is adequately protected from damage and excess flows can be conveyed safely downstream. Under normal operating conditions their ability to act as conveyance systems means that filter drains can work well as part of a treatment train.

2.4.1.1. Inlet

When designed to receive road drainage, filter drains normally receive runoff by lateral flow directly onto the surface of a filter drain situated either in the verges or central reservation adjacent to the low edges of pavements. It is also possible for filter drains to receive piped inflows with the runoff distributed through perforated pipes located just below the surface.



(after CIRIA 2015)

Figure 2.5. Schematic cross-section of a typical filter drain

2.4.1.2 Pre-treatment

A high clogging potential exists for filter drains in the absence of effective pre-treatment particularly for sites, such as highways, which can deliver high sediment loads. Blockages are difficult to observe and may lead to an increased risk of surface water flooding and the possibility of water ingress into the road pavement structure. Given the high cost of replacing the filter material should blockage occur, it is preferable to install an appropriate pretreatment system. The most effective option for filter drains receiving incoming sheet flow from an adjacent impermeable surface is a small filter strip between the edge of the drained area and the drain. A 0.5 to 1 m wide strip of grass can remove a significant amount of silt and prolong the time interval between cleaning/rehabilitation. The presence of a filter strip can also alleviate the problems associated with stone scatter (see Section 1.2). Where point inflows exist, filter drains should be installed downstream of a sediment forebay or silt trap or other

SuDS system (such as a swale) to prevent clogging and failure. If no pretreatment is possible, a geotextile layer should be inserted just below the filter drain surface where it can be regularly removed and cleaned or replaced.

2.4.1.3. Main device

Filter drains may be designed to allow or not to allow infiltration depending on the suitability of the surrounding soil and the vulnerability of the underlying groundwater. Where infiltration is allowed the maximum groundwater level should be at least 1 m below the base of the drain. Where infiltration is practised the trench incorporating the filter drain can be lined with a geotextile whereas a geomembrane or other impermeable liner or a concrete trough can be utilised to prevent infiltration. The volumetric runoff reduction in filter drains will mainly occur by infiltration where this is allowed. In addition, some water will soak into the filter medium and will be removed by evapotranspiration. Filter drains contribute to the reduction of peak flows by limiting the rates of conveyance through the filter medium and by providing attenuation storage which fills when the rate of flow at the outlet is controlled.

Filter drain depths should be between 1 m and 2 m, with a minimum depth of fill material of 0.5 m through which the incoming runoff is required to pass. Filter drain widths will be governed by the flows to be accommodated but minimum widths will be determined by any embedded pipes with bedding surround being at least equivalent to the pipe diameter e.g. 450 mm for a 150 mm pipe. The perforated drainage pipes in the base of filter drains can be rigid pipes of vitrified clay or precast concrete or flexible pipes of uPVC, polyethylene or polypropylene with diameters of between 100 mm and 700 mm. They should be buried at depths of between 0.6m and 2.0m. Where perforated pipes exceed 10 m in length, access sumps should be installed to enable cleaning by jetting or rodding.

The longitudinal slope of the ground in which filter drains are located should not exceed 2% to ensure relatively low flow velocities for stable conveyance through the filter medium and to allow time for pollutant removal processes to occur. The voids ratio and permeability of the granular fill should be sufficiently high to allow adequate percolation and to minimise the risk of blockage. Where the emphasis is on flow attenuation as opposed to pollutant removal, geocellular products can replace stone/gravel as the fill material as they possess a higher void ratio providing higher storage capacity for high return period flow events

2.4.1.4. Outlet

In the absence of infiltration, the drainage from each filter drain will be collected by a perforated pipe near the base of the system (Figure 2.5). As the flows through filter drains are designed to be low, erosion protection is not normally required at the final low-level outfall. However, this can be fitted with an appropriate flow control device to contribute to controlling the storage capacity within the filter drain. In the event of overfilling, appropriate overflow facilities should be in place so that excess flows can be conveyed safely downstream. Figure 2.5 shows the use of a high level perforated pipe to fulfil this function.

2.4.2. Integration into the landscape

Filter drains can be effectively incorporated into site landscaping, require minimal land take and fit well beside roads. They should not be sited on unstable ground and are restricted to sites without significant slopes unless they can be placed parallel to contours. They generally have a low amenity potential but can be designed creatively to provide attractive boundary lines or edging. In landscaped areas, filter drains can be protected with a geotextile, covered with top soil and planted with grass. The overlying grass can contribute to reducing the clogging of the trench surface. However, it is essential that maintenance practices are not overlooked.

2.4.3. Maintenance and management

Regular inspection and maintenance, as described in Table 2.3, is important for the continued effective operation of filter drains to design performance standards. Sediments removed from upstream pre-treatment devices that receive runoff from heavily trafficked roads may require testing for toxic/hazardous characteristics to determine its classification before choosing appropriate disposal methods. In the event of serious clogging occurring it may be necessary to remove and clean the stone/gravel fill material or to initiate a full replacement. A common cause of damage to filter drains occurs as a result of vehicles leaving the carriageway and scattering the surface filter material. This can be prevented by the installation of a ‘hard surface cover/cap’ which directs surface flow to a slotted drain which then empties into the underlying trench.

Table 2.3. Details of regular and occasional maintenance recommended for filter drains.

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Remove litter and debris from filter drain surface and pre-treatment devices	Monthly (or as required)
	Inspect filter drain surface and inlet/outlet systems for blockages, clogging, standing water and structural damage	Monthly
	Inspect pre-treatment systems, inlets and perforated pipework for silt accumulation, and establish appropriate silt removal frequencies	Six monthly
	Remove sediment from pre-treatment devices	Six monthly (or as required)
Occasional maintenance	At locations with high pollution loads, remove surface geotextile and replace, and wash or replace overlying filter medium	Five yearly (or as required)
	Clear perforated pipework of blockages	As required

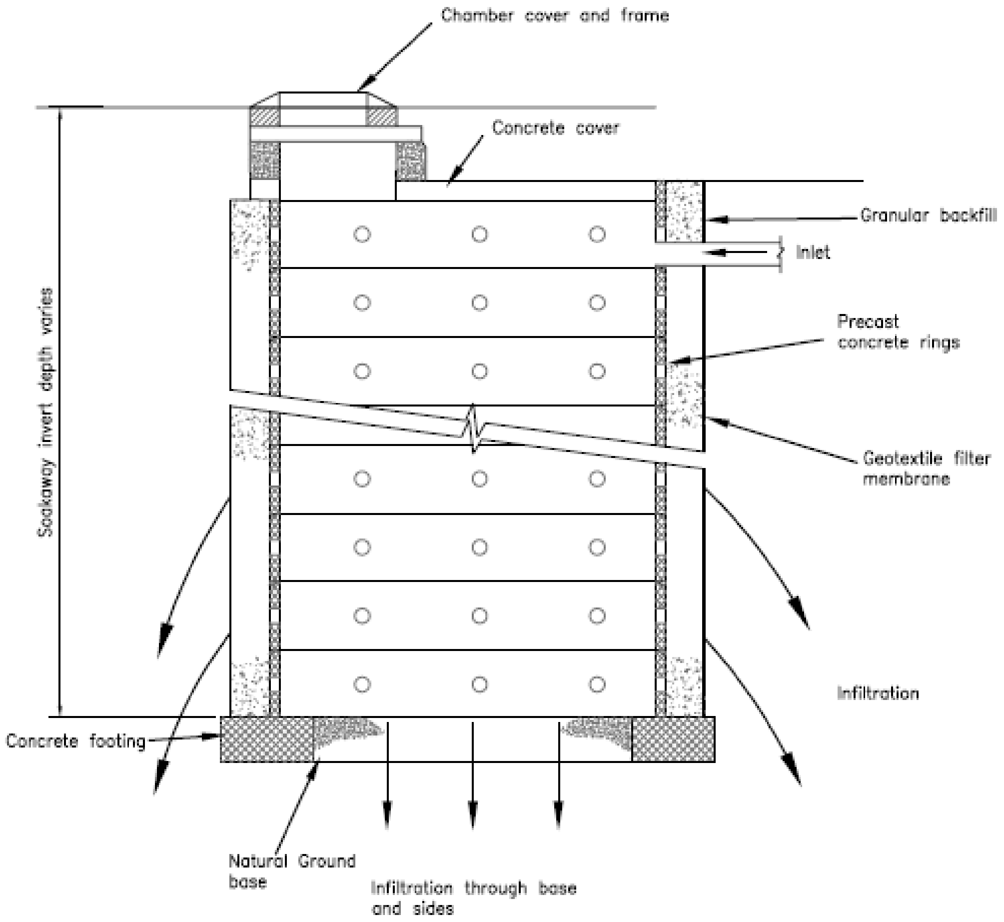
2.5. Guidelines for Soakaways and Infiltration Trenches

Soakaways and infiltration trenches have the ability to reduce peak runoff rates and volumes and to remove pollutant levels through infiltration processes depending on the permeability of the surrounding soils. This can also contribute to both baseflow and groundwater recharge. To prevent any possible contamination of groundwater it is preferable if the runoff has been pre-treated before entering the infiltration system. This is particularly important in the case of silt and sediments which could rapidly lead to clogging and subsequent failure of the system. These systems should not be sited above vulnerable groundwaters.

Infiltration systems provide storage for runoff in an underground chamber, lined with a porous membrane and filled with a suitable aggregate material such as coarse crushed rock. They enhance the natural ability of the soil to drain the water through the provision of a large surface area in contact with the surrounding soil, through which the water can pass. The rate of water disposal by a soakaway is dependent on the infiltration potential of the surrounding soil. Most national highway authorities specify a minimum 13 – 15 mm/hour percolation rate although many US states require a higher level in the order of 20 -25 mm/hour. The size of the device and the bulk density of any fill material determine the storage capacity. Pollutant removal within infiltration systems occurs by physical filtration, adsorption to the aggregate material and biochemical transformations involving micro-organisms growing on the fill or in the soil. The level of treatment depends on the size of the media and the length of the flow path through the system, which controls the time it takes the runoff to pass into the surrounding soil. The in-ground attenuation of pollutants is assisted by the slow movement of the runoff through the soil which is the opposite of what is required for the efficient disposal of runoff to avoid surface flooding. Therefore, there is a compromise to be reached between the quality and quantity benefits to be gained in terms of the surrounding soil porosity and permeability.

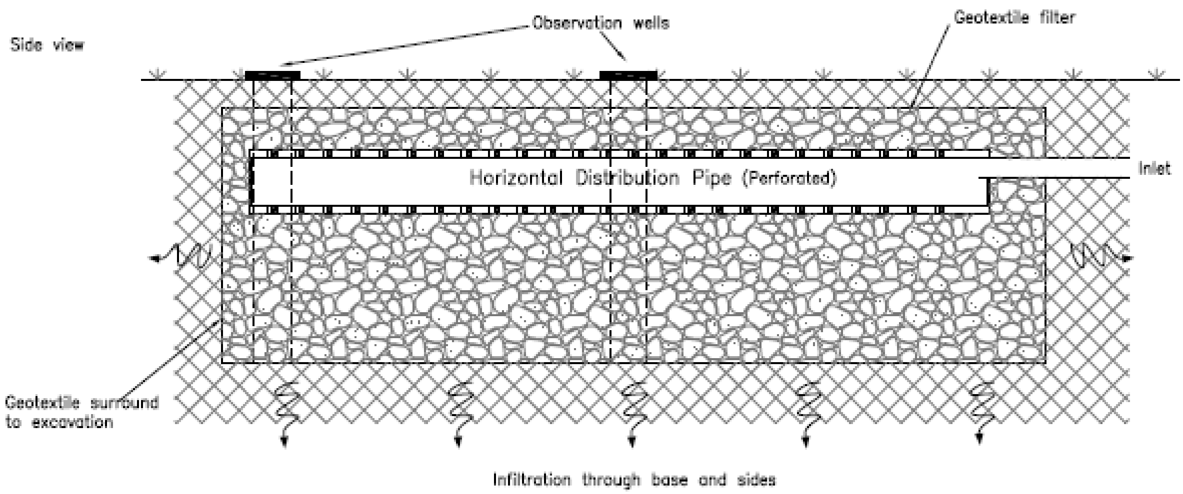
Soakaways are typically square or circular excavations which provide storage for runoff before it discharges to ground. A commonly used design because of its simplicity of construction and ease of installation is the pre-cast perforated concrete ring type of soakaway (see Figure 2.6). Following an excavation to the required depth, a concrete footing is formed and then segments lowered one on top of the other until the hole is filled. The area between the outside of the rings and the excavation can be backfilled with aggregate. Where they are required to drain larger areas, such as highways, it may be desirable to group several soakaways together.

An alternative type of soakaway is the trench type soakaway which is shown schematically in Figure 2.7. This diagram shows the location of inspection tubes spaced at regular intervals and the underground inlet pipe feeding into a horizontal perforated or porous distributor pipe which is laid in the top of the granular fill along the length of the trench. Trenches are usually constructed with a horizontal base and the volume between the structure and the excavation is backfilled with granular material. Typically a minimum trench width of 300mm is considered to be appropriate. This type of soakaway tends to require a lower volume of excavation and granular fill material for a given discharge capacity than a soakaway with a conventional profile. The narrower and longer the trench, the more efficient it is in terms of outflow performance and construction cost as well as being compatible with installation parallel to a road surface.



(after DMRB, 2006)

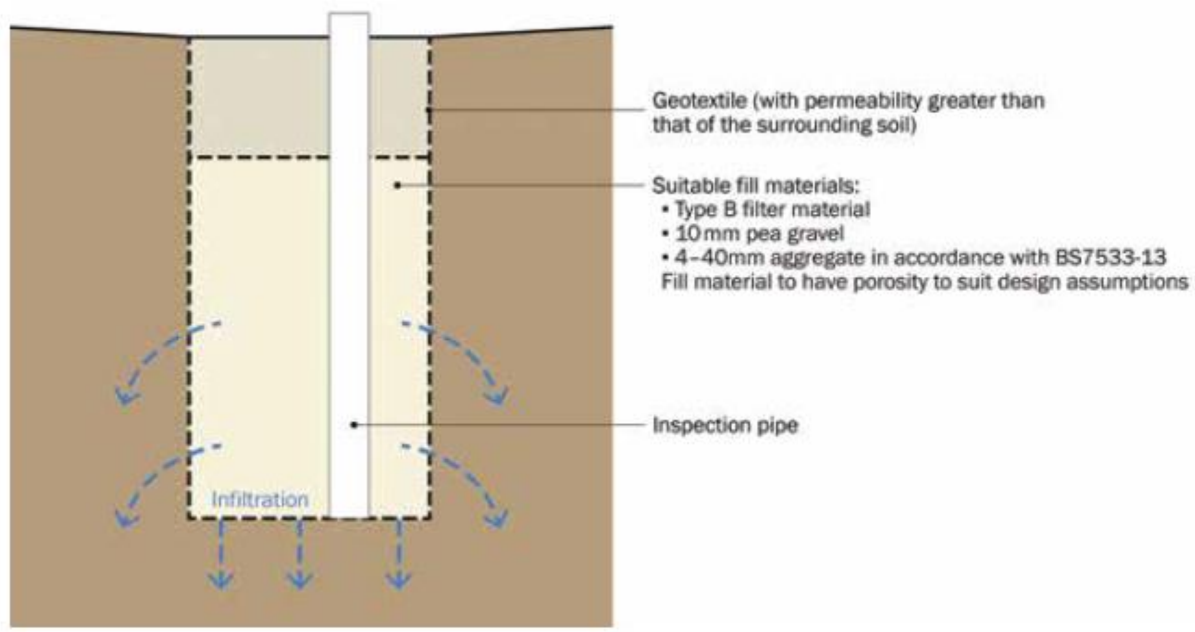
Figure 2.6. Schematic diagram of a pre-cast perforated concrete ring type soakaway



(after DMRB, 2006)

Figure 2.7. Schematic side view of a trench type soakaway with horizontal distributor pipe

Infiltration trenches are similar to trench type soakaways in that they are shallow, excavated trenches that have been lined with a geotextile and backfilled with rubble or stone to create an underground reservoir (Figure 2.8). This acts as a temporary subsurface storage for runoff and allows exfiltration into the surrounding soils from the bottom and sides of the trench. However, they differ in that the stone fill material is exposed at the surface and the discharged water can be introduced on to it either directly from the drained area or via a filter strip. Alternatively the runoff can be delivered through a perforated pipe bedded in the fill material. Infiltration trenches usually serve small catchment areas up to 2-3 hectares and the closer they are to the source of the runoff the more effective they will be.



(after CIRIA 2015)

Figure 2.8. Schematic cross-sectional diagram of an infiltration trench

2.5.1. Design aspects

An important hydraulic consideration with respect to roads is the need to allow the removal of storm runoff from the carriageway quickly and effectively and therefore infiltration systems are required to provide sufficient storage capacity to cope with peak runoff volumes (and potential follow-on storm volumes). Where this is not feasible it may be necessary to incorporate an additional storage facility, such as a detention basin, upstream of the infiltration system to temporarily store the water discharging from the road. It is important that this requirement to provide effective drainage does not override the legal necessity of protecting the groundwater. Infiltration systems are not be sited above vulnerable groundwaters particularly where there is the potential for highly polluted incoming runoff.

Prior to the installation of soakaways a field investigation should be carried out to determine the soil infiltration rate. This should be conducted along the length of a road as there may be considerable differences in ground conditions along the route necessitating changes in the design of the infiltration system. In low lying areas, e.g. near rivers, there may be less unsaturated zone available requiring an infiltration system which is broader and flatter in configuration whereas on high ground, the depth of the unsaturated zone may be large enough for smaller deeper structures needing less land take.

Soakaways are not suitable for poor draining soils. In determining the suitability of installing an infiltration system the stability of the ground should be assessed in terms of potential subsidence or slope instability as a consequence of infiltration. Similarly, possibility of causing groundwater flooding and leakage into adjacent underground pipes should be considered.

Both types of soakaways are designed to have the incoming runoff delivered by an underground pipe from the drained area (Figures 2.6 and 2.7). In contrast, infiltration trenches normally receive lateral inflow directly from an adjacent impermeable surface which allows an even distribution of the runoff across the granular surface of the trench.

2.5.1.1. Pre-treatment

Pre-treatment is recommended to limit the susceptibility of infiltration systems to failure due to potential clogging by sediments and silts. Where practical upstream treatment systems such as swales should be installed. In the case of roads draining to an infiltration system it is highly recommended that contributing surfaces are swept regularly to prevent the ingress of sediment/silt and thereby reduce maintenance requirements.

The long term performance of infiltration systems depends on maintaining the initial storage volume by keeping the pores clear within the granular fill. Any material that is likely to clog the pores of the drainage material or seal the interface between the storage and the adjacent soil should be intercepted before reaching the infiltration system. This will also contribute to maximising its effective life between cleaning. Where it is deemed necessary, sediment traps and/or oil interceptors may be installed to treat the surface water prior to discharge to the infiltration system

2.5.1.2. Main device

When selecting an infiltration system for a specific highway location it is important to consider the topography and the shape of the area available adjacent to the road so that the selected design matches the site dimensions. Infiltration systems should not be located within 3-6m of a building structure e.g. a bridge. Infiltration systems should not normally be deeper than 3 to 4 m so that a vertical distance between the base of the device and the groundwater of at least 1 m exists. The base of infiltration devices should be flat to facilitate even downward infiltration of the runoff. The road sub-base needs to remain unsaturated when the infiltration system is operating at its maximum design capacity. There should be no downgradient groundwater emergence and no groundwater surcharging leading to harmful waterlogging or exacerbating groundwater flooding.

The infiltration capacity is determined by the ability of water to penetrate the unsaturated zone, which is in turn dependent on the physical properties of the ground and the surface area in contact with the infiltration system. The ability to transmit water will be influenced by the number and size of drainage ports, the amount of sediment allowed to settle and remain in the chamber and the degree of choking that occurs immediately outside the chamber in the surrounding ground. The manhole rings available from precast concrete suppliers for soakaways have sufficient outlets to allow the water to infiltrate efficiently into the ground.

The depth of the unsaturated zone below an infiltration device needs to be maximised to ensure that the maximum attenuation of pollutants can occur. To achieve this it may be necessary to vary the depth and size of the systems' chambers so that in areas where the unsaturated depth is lower, a number of shallow interconnected devices may be used to provide sufficient short-term storage, whilst maximising the depth of unsaturated zone. In areas with a deeper unsaturated zone the infiltration systems may consist of fewer deeper devices, so requiring less land, whilst still maintaining sufficient attenuation capacity. The selected configuration may result in the need for additional land to enable access and maintenance.

Infiltration systems should be designed to at least the 1:30 year storm with an emphasis on being able to manage the 1:100 year event (together with a climate change adjustment) where it is essential to avoid the occurrence of surface flooding. An infiltration device designed to manage 1:10 or 1:30 year storms should be capable of emptying from full to half-full status within 24 hours to allow subsequent rainfall events to be treated. This condition may be difficult for the greater than 1:30 events requiring larger storage requirements balanced against allowing longer emptying times. In terms of interception it should be feasible to capture the first 5 mm of any rainfall event even where infiltration rates are low.

The drainage system must provide a balance between sufficient infiltration rate and storage capacity to allow the fast and efficient removal of water from the surface of the road. The storage capacity must be designed to cope with peak runoff from the maximum design storm event, for no flooding of the road surface without the drainage network backing up. Additional storage is thus essential where the discharge rate from the road exceeds the infiltration capacity of the infiltration system.

Infiltration systems should be lined with a geotextile material to prevent the migration of fine particulate materials. Geotextiles should be selected according to the nature of the surrounding soil particle size and permeability. They are specifically used to separate granular backfill materials from ground material in the walls of excavated areas and to prevent fines within the infiltration system from migrating outwards into granular surround materials hence reducing the potential clogging of those materials.

Perforated, precast concrete ring soakaways should be installed in a square pit with side dimensions of double the soakaway diameter. The void area around the concreate soakaway should be filled with a suitable permeable aggregate material such as Type B filler material, pea gravel or 4/40 aggregate. An alternative is to use synthetic media such as porous synthetic aggregate which, although more expensive, provides both potential volume and quality benefits. Many soakaways are now filled with geocellular units, pre-wrapped in geotextile, which provide good overall storage capacity.

2.5.1.3. Outlet

The minimum depth of unsaturated material below the soakaway or infiltration trench should be 1 m to reduce the risk of groundwater rising into it and restricting the available storage volume. In addition, a sufficient depth of unsaturated material contributes to protecting the groundwater from contamination in the runoff. Therefore shallow infiltration structures are preferable and geotextile layers can be incorporated within them to trap surface water runoff particulates and hydrocarbons. The best protection for the underlying groundwater exists where the unsaturated soils do not possess high permeabilities (e.g. clean gravels) and do not contain rapid flow fracture routes (e.g. preferably with some organic and clay content).

2.5.2. Integration into the landscape

Because of their subsurface design infiltration systems require a minimal net land take and can be easily integrated into a site. However, they offer very little in the way of amenity or biodiversity value as they are usually completely underground and water should not appear on the surface. They do, however, increase soil moisture content and help to recharge groundwater, thereby helping to mitigate problems of low river flows. Infiltration trenches fit well beside roads. Soakaways can be designed in such a way as to allow the overlying surface to be part of an alternative amenity use.

2.5.3. Maintenance and management

The useful life and effective operation of an infiltration system is highly dependent on the frequency of maintenance and the risk of sediment being introduced into the system (see Section 1.1.2). Therefore it is recommended that soakaways and infiltration trenches should be designed with monitoring points to enable the water level within the system to be measured e.g. via an inspection well or cover. For larger installations it is recommended that the inspection access should provide a clear view of the infiltration surface. The build-up of pollution is more difficult to see in infiltration trenches and for this reason they tend to have high historic failure rates due to poor maintenance, wrong siting or high debris input. A reduction to a maximum of 3% water content is normally required in the trapped sediment and it may have to be disposed of according to hazardous waste regulations.

The types of operational and maintenance requirements that are appropriate for infiltration trenches and soakaways are identified in Table 2.4. Normally manual maintenance will be appropriate but for larger systems a suction tanker may be necessary to remove accumulated sediment. Failure to regularly remove any built-up sediment can result in this becoming hard packed making removal more difficult. If the system becomes completely blocked with silt, replacement of the aggregate and geotextile will be required.

Table 2.4. Operation and maintenance requirements for soakaways and infiltration trenches

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Inspect for sediment build up in any pretreatment component and base of inspection tube or chamber and inside of concrete manhole rings	Annually
Occasional maintenance	Remove any sediment in any pretreatment component and base of inspection tube or chamber and inside of concrete manhole rings	As required based on inspection
Remedial actions	Reconstruct soakaway and/or replace or clean void fill, if performance deteriorates or failure occurs	As required
	Replacement of clogged geotextile	As required
Monitoring	Inspect and note rate of any sediment accumulation	Monthly in the first year and then annually
	Check to ensure emptying is occurring efficiently	Annually

2.5.4. Spillage containment

It is important to prevent gross pollution, such as may occur following an accidental spillage from entering an infiltration system. Therefore, measures to control and contain spillages should be installed where there is a combination of a high probability of occurrence and the risk to the receiving waters is sufficient to justify them. Appropriate control systems include notched weirs or penstocks or boomed forebays, to prevent drainage water that is highly contaminated from moving down the drainage system. Such measures will enable polluting material to be intercepted before it reaches the infiltration system, providing sufficient time for emergency spill responses to be implemented.

2.6. Guidelines for Detention Basins

Detention basins are landscaped depressions that are normally dry except during and immediately following storm events. They can be designed as on-line components where the surface runoff deriving from rainfall events is directed through the basin which fills as a consequence of a restricted outlet providing storage of the runoff and flow attenuation. Detention basins are typically designed to empty within 6 to 12 hours following the end of a storm whereas extended detention basins are designed to lengthen the storage time, for example, to between 24 and 48 hours. In an off-line configuration the runoff would be stored once the flows have reached a specified threshold.

Where the detention basin is vegetated a degree of treatment will be provided. In contrast hard landscaped storage areas are normally designed as off-line components and will not provide any treatment. These systems are unlikely to be used to receive runoff deriving specifically from roads. In vegetated basins infiltration is possible through the soil such that for small rainfall events total interception is possible. This assumes that the small amounts of infiltration do not pose a risk to groundwater. The principal water quality benefits of vegetated detention basins are associated with the removal of sediment and floating materials, but levels of nutrients, heavy metals, toxic materials and oxygen-demanding materials may also be significantly reduced. The water quality benefits of a vegetated detention basin increase as the detention time for an event becomes longer. Although when designed appropriately, some or all of the basin area can be used as a recreational or other amenity when dry, this is not normally the case for road drainage where the basin is likely to be sited on private property.

Pollutant removal efficiencies based on the upper 75 percentile concentration values monitored at the inlets and outlets to detention basins have been found to be 59%, 33%, 45%, 48% and 50% for total suspended solids, total cadmium, total copper, total zinc and total nickel, respectively.

2.6.1. Design Aspects

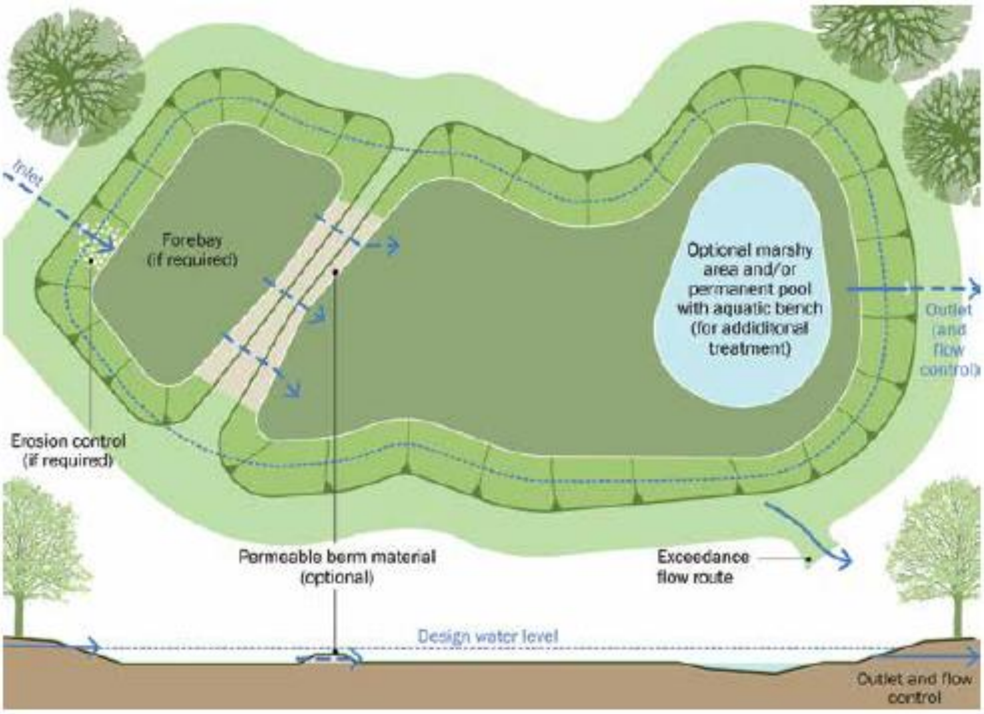
A schematic diagram showing a typical design for a detention basin is provided in Figure 2.9 and details of the individual components are given in the following sections.

2.6.1.1. Inlet

Where it is considered necessary, the energy of the incoming flows should be dissipated to minimise the risk of scouring and erosion. This can be achieved by stabilising inflow channels using rip-rap or other erosion control systems. Ideally the incoming flows should be distributed across the full width of the basin as this will maximise the potential vegetated filtration area and enhance the pollutant removal effectiveness within the detention basin.

2.6.1.2. Pre-treatment

Where there is no upstream pre-treatment, on-line detention basins should be preceded by a forebay to reduce the sediment loads reaching the vegetated area. This will improve the water quality performance of the detention basin and also reduce long-term maintenance requirements. The forebay, which should occupy at least 10% of the total basin area, can be created by building an earth berm, stone or rock-filled gabion or rip-rap across the upstream portion of the basin. The forebay should be



(after CIRIA 2015)

Figure 2.9. Schematic diagram showing plan view and profile of a typical detention basin.

accessible and easily maintained. The presence of a fixed sediment depth marker to measure sediment deposition with time will assist with the development of appropriate maintenance schedules.

2.6.1.3. Main basin

The inlets and outlets to a detention basin should be positioned to maximise the flow path with the recommended length/width ratio for on-line vegetated detention basins being between 3:1 and 5:1. The base of a basin should be fairly flat with a gentle slope of no more than 1 in 100 towards the outlet. This will maximise contact of runoff with the vegetation and prevent standing water conditions from developing. The base of the basin can also be provided with a layer of engineered soil or underdrains to maintain a firm and dry surface. Areas above the normal high water elevations of the basin should also be sloped towards the basin to allow effective drainage. The side slopes should not usually exceed 1 in 3 unless special site and/or safety arrangements allow for steeper slopes (e.g. steeper slopes may be acceptable for very shallow basins). Slopes should be no steeper than 1 in 3 wherever mowing is required, to reduce the risks associated with maintenance activities. Flatter slopes tend to improve the aesthetics, at the expense of extra land-take.

Detention basins reduce the flow rates from a site by controlling the discharge rate and allowing the basin storage to fill during storm events. The required peak flow control and storage volume can be determined using standard hydraulic assessment. Detention basins can be sized to provide flood attenuation for all events up to the 1:100 year event with discharges being constrained to the equivalent greenfield site rate. For the most extreme design event the maximum depth of water in the basin should not normally exceed 2 m and may be less where safety considerations are important. For the smaller rainfall events, vegetated detention basins can provide interception. The absence of runoff is due to water soaking into the basin topsoil layer and being removed by evapotranspiration as well as by small amounts of infiltration (where this is allowed). Where a detention basin is designed to facilitate infiltration, it should be possible for the disposal of 5 mm rainfall depth over the contributing catchment area. Overall, the extent of volumetric reduction of runoff to surface receiving waters will depend on the infiltration rate of the surrounding soil, the catchment area, the area and depth of the system, the type of vegetation and the climate. It is important that the storage capacity of the detention basin is retained and not influenced by extended periods of high groundwater levels.

To accommodate those rainfall events which exceed the design capacity of a detention basin it is important that an exceedance flow route is provided. This can be achieved by installing an overflow pipe, channel or weir/overflow structure above the design water storage level to convey excess flows downstream. Exceedance flow structures should be located as close to the inlet as possible to minimise the flow path length for above-capacity flows, thus reducing the risk of scouring. The overflow should not impede access to any inlet/outlet/control structure that manages more frequent flows.

Detention basins primarily treat incoming runoff through the gravitational settling of particulate pollutants supplemented by some filtration through the basal vegetation and the underlying soils. There is also the potential for biodegradation and photolytic breakdown of hydrocarbons during the drying processes between runoff events. The pollutant removal performance should be maintained for all runoff events including those with a 1:1 year return period event. For these frequent storms the treatment efficiency of a vegetated detention basin will be improved where the depth of flow is maintained below the height of vegetation (i.e. usually < 100 mm), where the maximum flow velocity in the basin is 0.3 m/s to ensure adequate runoff filtration and the time of travel of runoff from inlet to outlet within the basin is at least 15 to 20 minutes.

2.6.1.4. Outlet

The control of the rate of discharge at the outlet from a detention basin can be by means of a small diameter pipe, an orifice or a notched flow control device. The outfall design can be such that different discharge rates can be applied for storm events of various probabilities. However, a target outfall rate of 2 to 5 L/s/ha is frequently applied to achieve satisfactory detention times. Trash screens are not recommended as grilles have a tendency for clogging rapidly, triggering more regular maintenance requirements and potentially affecting hydraulic performance.

A small permanent pool at the outlet to vegetated detention basins helps to prevent resuspension of sediment particles by high intensity storms and provides enhanced water quality treatment for frequent events. Where a micropool is installed at the outlet, the soil below the pool area should be sufficiently impermeable to maintain the permanent pool, unless a continuous baseflow or high groundwater table is present. In highly permeable strata, a liner may be required to prevent the pool from drying out in the summer months. The presence of a pool at the outlet can provide biodiversity benefits but requires careful design of minimum depths and planting strategies to avoid the establishment of unattractive elements.

2.6.2. Integration into landscape

To facilitate the ability of vegetated detention basins to blend into the highway landscape they should possess edges with curves and undulations to produce an aesthetically interesting and natural-looking feature. Roundabouts and junctions can often provide the necessary suitable space for detention basins and on the motorway and trunk road network there is often the availability of suitable sites in adjacent open countryside. Where the aesthetic aspects are less important it is also possible to incorporate as linear detention cells in series.

2.6.3. Planting regime

Detention basins are typically grassed structures, although the presence of additional vegetation can enhance the appearance and amenity value of the basin, stabilise side slopes and prevent erosion, and serve as a wildlife habitat. Soil depths will vary for different planting proposals, so although 100 mm of subsoil may be suitable for supporting a wildflower meadow, 150 mm topsoil is required for amenity grass and 450 mm will be necessary for planted areas. Where small pools are included as a feature of the basin, they are normally planted with wetland vegetation species. Common reed (Phragmites australis), reed canary grass (Phalaris arundinacea) and amphibious bistort (Persicaria amphibian) are particularly appropriate for use where there are intermittent periods of inundation. Where inundation is infrequent, creeping bent and rush species may be more appropriate.

2.6.4. Maintenance and management

Details of an appropriate maintenance schedule together with frequencies for the required actions is shown in Table 2.5. The major maintenance requirement for detention basins is usually the mowing of those areas which cannot be managed as ‘meadow’. All vegetation management activities should take account of the need to prevent the spread of invasive species. Mowing should ideally retain grass lengths of 75–150 mm across the main treatment surface to assist in filtering pollutants and retaining sediments and to reduce the risk of flattening during runoff events. Grass clippings should be disposed of outside the detention basin area to remove nutrients and pollutants. Where a detention basin has a small permanent pool at the outlet, any submerged and emergent aquatic vegetation should be managed as for ponds or wetlands. Plant management should be carried out to achieve the desired habitat effect.

Sediment will need to be removed, typically once deposits exceed 25 mm in depth. Sediments excavated from a detention basin that receives runoff from local roads will not generally be toxic/hazardous and can therefore be safely disposed of by either land application or landfilling. However, where incoming runoff is from busy trunk roads and motorways, sediment testing should be carried out to determine its classification and the need for appropriate disposal methods. Following sediment removal any damage should be repaired and immediately reseeded or planted. This will also apply to any erosion and/or scour resulting from repeated filling and emptying during storm events.

Table 2.5. Details of regular and occasional maintenance and remedial actions recommended for detention basins

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Remove litter and debris	Monthly
	Cut grass in and around basin to maintain grass length at design level	Monthly (during growing season) or as required
	Inspect inlets, outlets and overflows for blockages, and clear if required	Monthly
	Inspect banksides, structures, pipework etc. for damage	Monthly
	Remove sediment from inlets, outlet and forebay	Annually or as required
	Manage vegetation in basin and plants in outlet pool (if provided)	Annually or as required
Occasional maintenance	Re-seed areas of poor vegetation growth	As required
	Prune any trees and remove cuttings	Every 2 years or as required
Remedial actions	Repair erosion or other damage by re-seeding or re-turfing	As required
	Repair/rehabilitation of inlets, outlets and overflows	As required

2.7. Guidelines for Retention Ponds

Retention ponds are depressions designed to temporarily store surface water above permanently wet pools that permit settlement of suspended solids and biological removal of pollutants. Retention ponds are also known as flood storage ponds particularly when the major function is peak flow control rather than water quality considerations. Well-designed and maintained permanent water bodies can offer important aesthetic, amenity and wildlife benefits. They can be created by using an existing natural depression, by excavating a new depression, or by constructing embankments but should possess shallow, grassed side slopes. An important aspect of the design should be that the natural hydrology of a catchment area is not affected by large quickly-drained areas of highway. The most effective retention pond designs will involve consultations between engineers, hydrologists, ecologists and landscape architects.

A flow control system at the outfall controls the rate of discharge for a range of water levels and allows the pond to fill during storm events with the attenuation storage volume being provided above the permanent pool. The runoff from each rainfall event is detained and treated in the pool, with the volume of the pool influencing the efficiency with which particulate pollutants settle out. Larger volumes provide longer periods of time for sedimentation to occur, and greater opportunities for biodegradation and biological uptake mechanisms (where vegetation is present). Ideally, they should be designed to efficiently remove the finest particles (<63 μm) as these take longer to settle out, but may carry more than 50% of the pollution load of metals and hydrocarbons. Removal rates based on the upper 75 percentile concentration values monitored at the inlets and outlets to retention ponds have been found to be 75%, 33%, 68%, 65% and 25% for total suspended solids, total cadmium, total copper, total zinc and total nickel, respectively.

2.7.1. Design Aspects

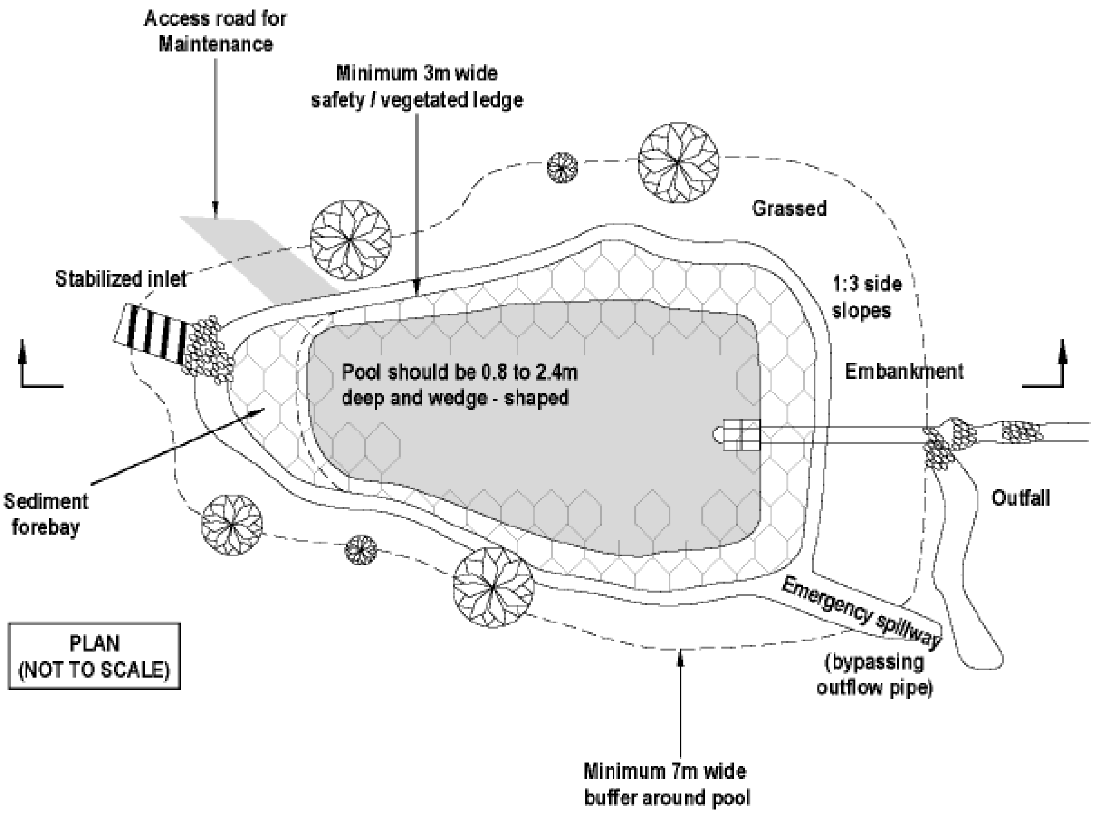
A schematic diagram (not to scale) showing a typical layout for a retention pond is shown in Figure 2.10.

2.7.1.1. Inlet

At the pond inlet, it is advisable to dissipate the energy of the incoming flows to minimise the risk of scouring and erosion, and to prevent disturbance to the permanent pool volume. This can be achieved by stabilising inflow channels using rip-rap or other erosion control systems, or by partially or fully submerging the inlet pipe. The scale of the erosion mitigation system should be physically and aesthetically proportionate to the size of the pond. It may be appropriate to have an inlet device which diverts the flow away from the pond once it is full enabling the required area of the pond to be less, as it will only need to be sized to treat runoff from the first 5 - 10 mm of rain (i.e. the first flush).

2.7.1.2. Pre-treatment

The integration of a separate sediment forebay into the design of a retention pond encourages the deposition of coarse sediments as well as preventing the main open water body from becoming unsightly and odorous. An alternative approach is to install a sediment trap/gross pollutant trap which provide a more efficient front-end removal of contaminated sediments. In both cases, the risk of rapid accumulation of silt within the main pool is reduced saving on the difficulty and costs of removal. The installation of a fixed sediment depth marker in the forebay allows the temporal sediment build-up to be monitored and informs the required frequency of future maintenance schedules in both the forebay and in the main pool. To facilitate sediment removal in the forebay the base can be reinforced. In the event that a membrane liner is used without protection, great care should be taken during sediment removal operations. Sediments excavated from forebays that receive runoff from roads should be safely disposed of in accordance with current waste management legislation. It is recommended that the surface area of the sedimentation forebay should be at least 10% of the total retention pond area.



(after DMRB, 2006)

Figure 2.10. Schematic diagram showing the typical layout for a retention pond

2.7.1.3. Main pond

Retention ponds should be designed so that flow enters the pond and gradually spreads out, avoiding the creation of dead zones caused by corners, and optimising the sedimentation process through maximising the flow paths. Inlets and outlets should be placed to maximise the flow path through the facility. The ratio of flow path length to width should be at least 3:1 to avoid hydraulic short-circuiting and ideally 4:1 or 5:1. Baffles, pond shaping and islands can be added within the permanent pool to increase the flow path length and improve water quality treatment effectiveness. In general, wet pond facilities function best when surface water entering the pond moves through the pond as a single wave or unit, fully displacing the existing wet pond volume through a phenomena known as plug flow. By preventing short-circuiting occurring, this flow pattern maximises the hydraulic retention time, which enhances particulate and particle-bound sediment settlement. In addition to avoiding dead zones, care must be taken not to cause the flow speed to increase in localised areas, as this would reduce the effectiveness of sedimentation as well as increasing the risk of particle re-suspension during intense storms.

Flow attenuation within a retention pond should normally be able to retain a storm event with an annual probability of 1% (although designs to accommodate 1:30/50 storms are common alternatives) for the catchment and to discharge the water into the downstream watercourse at a rate that would occur in those rainfall conditions if no road were present. This will reduce the risk of damage to habitats and species caused by the rapid discharge of runoff into sensitive receiving waters. In the event that a rainfall event exceeds the design capacity of the pond or an outlet blockage occurs, an exceedance flow route will be required to convey excess flows. This can be achieved by installing an overflow pipe or weir/overflow/spillway structure above the design water storage level to convey the excess flows downstream. They should be designed to prevent over-topping of any embankment which might cause structural damage. For small ponds, a simple grass channel integrated into the landscape is usually suitable as an exceedance route. A freeboard of 300 mm for the design event should ideally be sufficient for larger ponds. The exceedance flow structure should be located as close to the inlet as possible to minimise the flow path length for above-capacity flows (thus reducing the risk of scouring).

Treatment efficiency will be increased the longer the residence time of the retained water allowing the opportunity for smaller particles to settle. The volume of the permanent pool is the primary factor determining the treatment efficiency of a retention pond. The optimum pond size in terms of treatment performance equates to double the mean annual storm volume and does not significantly improve above this. The maximum depth of the permanent pool should not exceed 2 m to avoid stratification and anoxic conditions and normally should not exceed 1.2 m to comply with safety considerations. Keeping the permanent water at or below this depth allows oxygen to reach the bottom of the pond, enabling the biodegradation of oils by natural organisms. Alternatively, very shallow ponds may be at risk of algal blooms and high biological activity during summer months. If ponds have to be > 1.5 m in depth, it is recommended that some form of recirculation is provided in the summer months, such as a fountain or aerator, to prevent stagnation and low dissolved oxygen conditions. The existence of a small amount of base flow will help to maintain circulation and reduce the potential for low oxygen conditions during late summer. The maximum depth of temporary storage above the permanent pool should be limited to 0.5 m for small to medium-sized ponds, but increased depths may be suitable for larger systems. In larger ponds, sub-division into separate cells can enhance volume attenuation and improve treatment through the existence of longer pollutant removal pathways and higher surface area-to-volume ratios. These systems also facilitate a more environmentally effective maintenance programme through staggered application to each zone and an enhanced biodiversity with lower zones tending to comprise cleaner water.

The soil below a retention pond should be sufficiently impermeable to maintain the water levels within the permanent pool at the required level. In permeable strata, a liner (or other impermeable material such as puddled clay) will be required to prevent leakage and potential of the pond drying out. Prior soil investigations including permeability tests should be carried out. Where there is a sensitive underlying groundwater zone a hydrogeological risk assessment should be conducted to determine an appropriate separation distance between the bottom of the pond and the elevation of the annual maximum water table unless a liner is proposed.

The incorporation of vegetation into the pond design can enhance the treatment potential. Plants will normally be introduced in the shallow water around the edge of the permanent pool where they will act as biological filters and additionally provide ecology, amenity and safety benefits. The presence of a flat safety bench around the perimeter of the pond allows a site for planting as well as providing a suitable distance before open water discouraging direct access and facilitating maintenance. A suitable width for a safety bench is 3.5 m, with a slope of less than 1 in 15, although this will be dependent on land availability. Side slopes to retention ponds are recommended not to exceed 1 in 3 for public safety reasons and to facilitate mowing. Steeper bank slopes should be reinforced e.g. by gabions.

2.7.1.4. Outlet

Maximum discharge rates may be stipulated as a consent condition relating to the construction of an outfall. Control of the rate of discharge from a retention pond could be by a non-clogging structure and may involve the use of a small diameter pipe, a protected orifice or a notched flow control device. The outfall design can be such that different discharge rates can be applied for storm events of various probabilities. The presence of an outlet with variable control allows the first inflows to be retained for the longest period whilst allowing subsequent inflows (when the level of the pond is higher) to flow out at a quicker rate. In this way the runoff from most rainfall events will be retained for the maximum period. Trash screens are not recommended due to potential blockage and flow restriction. The presence of a controlled discharge maximises the dilution potential of the receiving waters and reduces the polluting impact. Ideally the outlet area should be adjacent to the deepest waters to provide final settling and to prevent sediment re-entrainment.

2.7.2. Integration into the landscape

Retention ponds should aim to reflect the overall character, shape and scale of the prevailing topography and be located within the highway land providing appropriate access for maintenance. Curvilinear or indented shapes will blend in more effectively with adjoining contours and create more interesting and attractive features. It may be possible to locate the pond within a roundabout or junction, or if a linear pond is necessary, this could run parallel to the road. The existence of long and relatively narrow ponds increases the flow path helping to promote efficient sedimentation. Retention ponds are used extensively on the motorway and trunk road network, where there is space in open countryside.

2.7.3. Planting regime

Vegetation can be allowed to develop in the marginal areas at the edges of the pond thereby encouraging the presence of wildlife. Suitable marginal plants include reed mace (Typha latifolia), common reed (Phragmites australis) and branched bur-reed (Sparganium erectum). If planting is required in the deeper parts of the retention pond (>0.5 m), spiked milfoil (Myriophyllum spicatum), pond weeds (Potamogeton natans and P. pectinatus) and common club-rush (Schoenoplectus lacustris) are appropriate. These aquatic species can perform a limited role in uptake of soluble metals, but importantly can contribute to oxygenation of the water and enhance the processes of precipitation and biodegradation of organic material.

2.7.4. Maintenance/management

In order to preserve treatment performance and to ensure continuing operation to design standards, ponds will require regular maintenance. Therefore, detailed specifications and frequencies for the required maintenance activities should be provided within a maintenance plan. A summary of the required procedures together with their frequency is provided in Table 2.6. Any invasive maintenance work such as silt removal is only required intermittently, but it should be planned to be sympathetic to the requirements of wildlife in a pond. An appropriate time period for this is considered to be every ten years although this may double where effective pre-treatment is provided. Where nature conservation is particularly important, care should be taken to avoid disturbance to nesting birds during the breeding season and habitats of target species (e.g. great crested newt and water voles) at critical times. Invasive silt and vegetation removal should only be carried out within limited areas (25–30% of the pond area) at any one time on one occasion each year to minimise the impact on biodiversity.

Where the growth of vegetation has been permitted this will occasionally require cutback and removal to ensure the preservation of a permanent pool of open water and to prevent excessive build-up of organic detritus and nutrients. The removal of vegetation should only be necessary at approximately 5 year intervals and should be confined to the removal of roots and/or rhizomes in small patches to promote new root/rhizome growth. No more than one third of the vegetation should be removed on each occasion in order to allow its treatment capacity to be maintained. Contaminated material (vegetation and /sediment/sludge) may need to be dewatered on site prior to special disposal. This requires appropriate space and steps must be taken to prevent any chance of drain-back into the pond. If willow, alder and birch have become established around the pond margins they may need to be removed to prevent shading of the treatment vegetation.

The inlet and outlet structures as well as other exposed elements should be frequently inspected and repairs undertaken as required. The fluctuating water levels can lead to an aggressive environment causing greater deterioration than expected. Areas of erosion should be filled, compacted and reseeded as soon as possible. Eroded areas near inlets and outlets may require rip-rap fill to prevent further erosion.

2.7.5. Spillage Containment

Retention ponds can act as effective forms of spillage containment if the outlet is designed so that the smaller flows typical of spillages are retained until they can be pumped out. This may be achieved automatically by a siphon so that the outflow only operates when a certain water level is reached, or manually by a penstock. Where risk of spillage is not high (an annual probability of less than 1%), it may be more appropriate to use controls such as sandbags or a notched weir. The design must allow easy access and straightforward use of the specified spillage control device. In emergencies, the quicker such devices can be used, the lower will be the risk of pollution. There is a risk that devices such as penstocks may be more susceptible to vandalism and they may deteriorate over time due to prolonged periods without use.

Table 2.6. Operation and maintenance requirements for retention ponds

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Remove litter and debris	Monthly
	Cut grass	Half yearly (monthly during growing season)
	Inspect marginal and bankside vegetation and remove nuisance plants	Monthly at start and then as required
	Inspect inlets, outlets, banksides, structures, pipework etc. for blockages or physical damage	Monthly
	Inspect for evidence of excessive silt accumulation; test any built-up sediment for contamination to inform disposal route	Half yearly
	Inspect water body for signs of poor water quality	Monthly (May to October)
Occasional maintenance	Remove sediment from main body of pond when build up reduces pond volume by 20%	With effective pre-treatment this should only be required every 20-25 years
	Selectively remove flora to preserve required diversity where plant growth has been allowed within pool area	Every 5 years
Remedial actions	Repair erosion or other damage	As required
	Re-align rip-rap or repair other damage	As reqyuired
	Aerate pond when signs of eutrophication are detected	As required
	Repair/rehabilitate inlets, outlets overflows	As required

2.8. Guidelines for Constructed Wetlands

Wetlands can be defined as areas that are permanently (or periodically) saturated by surface water or groundwater so that they are able to support aquatic and/or semi-aquatic (emergent) vegetation. Natural wetlands are generally of high nature conservation value and therefore should not be used to treat highway runoff. As a consequence, wetlands required to reduce the flooding and pollution risk associated with highway runoff will normally be of the constructed type. A plan view of a typical constructed wetland is shown in Figure 2.11. Constructed wetlands are categorised according to the predominant flow pathway of water through the system with the primary flow in Surface Flow (SF) wetlands being across or close to the surface of the growing medium and through the above ground parts of the plants (see Figure 2.12) whereas in Sub-Surface Flow (SSF) wetlands the flow is directed primarily through the growing media and plant root zone (see Figure 2.13). The principal physical, chemical and biological removal mechanisms include sedimentation, adsorption, precipitation and dissolution, filtration, bacterial and biochemical interactions, volatilisation and infiltration.

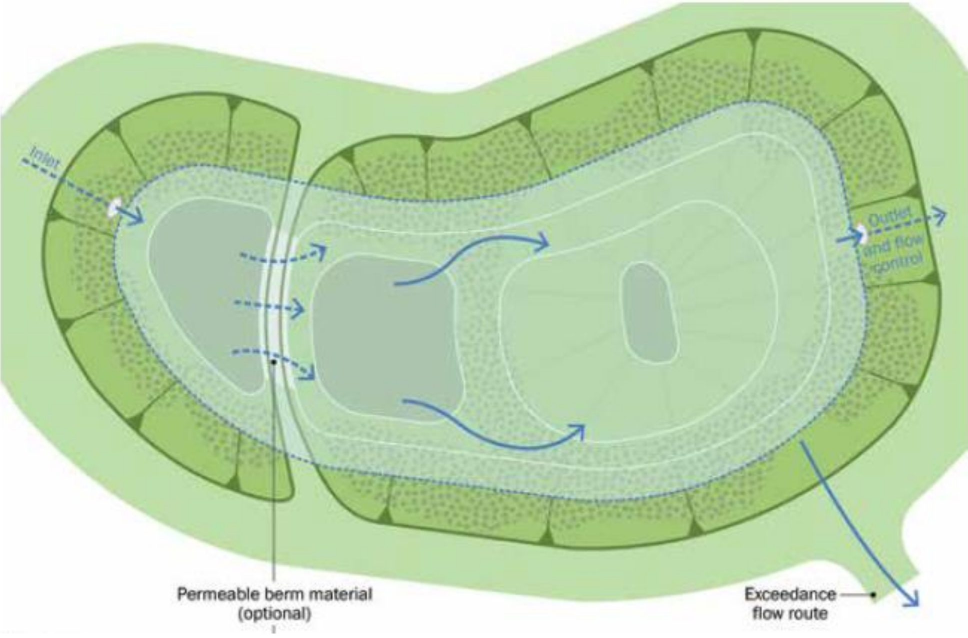


Figure 2.11. Plan view showing the design of a typical constructed wetland

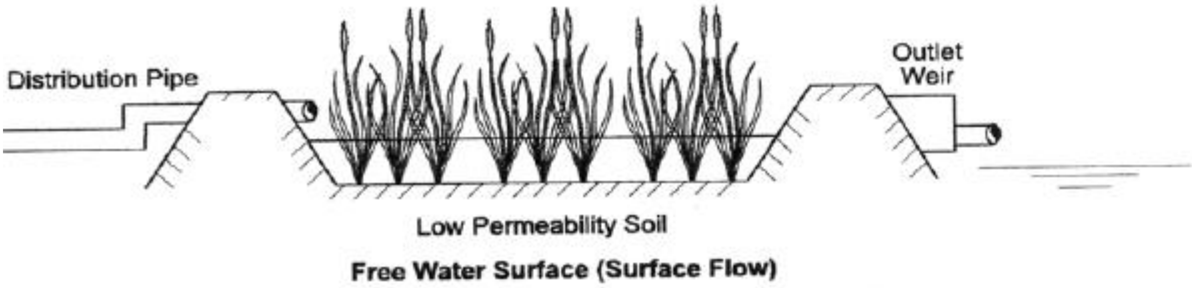


Figure 2.12. Cross-sectional view of a surface flow (SF) constructed wetland

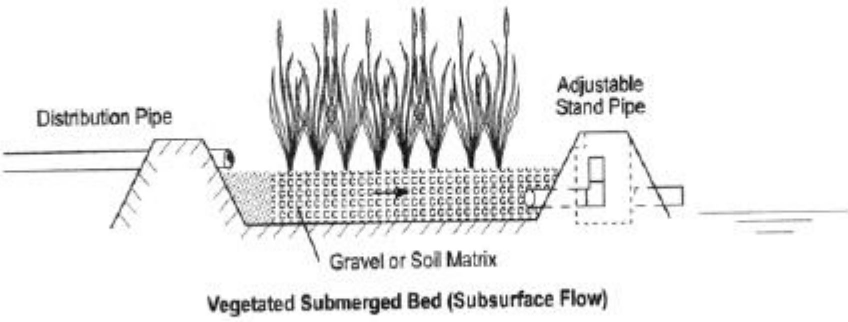


Figure 2.13. Cross-sectional view of a subsurface flow (SSF) constructed wetland

SSF wetlands can be constructed in two different configurations depending on the flow pattern through them. The most widely used system for surface water drainage is the horizontal flow system in which water is fed in at the inlet and flows slowly through the substrate (normally gravel) under the surface of the bed to the outlet zone (Figure 2.13). The alternative configuration supports vertical flow through a graded gravel/rock substrate. The sand covered surface of the bed is intermittently dosed by flooding the surface and the effluent then drains vertically down through the bed to be collected at the base. These systems are similar in design and operation to conventional percolating filters and require more operational input than horizontal flow systems.

SSF wetlands are essentially basins filled with non-soil substrates (e.g. rock/gravel) which are either saturated with water or have a shallow, intermittent or seasonal water cover. The water flows through the substrate at an appropriate water level, and is usually planted with common reed vegetation. This type of wetland supports the removal of pollutants through biological and chemical processes in the supporting porous media and the root zone. Provided there is a relatively long residence time (24 hours or more), the hydraulic resistance and large surface area provided by the media and the vegetation promote pollutant removal through adsorption, microbial degradation and biological uptake (particularly of metals). Because of these removal mechanisms, SSF wetlands can efficiently remove soluble metals and provide a high level of protection for sensitive receiving waters. However, the effectiveness of these systems is dependent on the porous medium being kept saturated (which may be a problem during extended dry periods) and there may be a requirement to provide secondary flows through the system. They are more costly to build and require a higher maintenance input than other vegetated systems.

SF wetlands are permanently saturated open ended or closed basins in which the growing medium material (usually soil) is kept at the saturation and inundation level appropriate for the type of vegetation established. The influent passes as free-surface flow at shallow depths and at low velocities above the soil substrate. They are effective in the removal of suspended solids and associated heavy metals through the physical processes of settlement and filtration. Provided there is a relatively long residence time (24 hours or more), adsorption and microbial degradation and biological uptake of metals and nutrients can occur. SF wetlands are suited to treatment of highway runoff as they are able to deal with the high suspended solid loads but need to be designed so that they remain sufficiently wet in the summer months. Their effectiveness in removing pollutants is dependent on how they cope with peak storm flows, particularly as suspended solids can remobilise near to the outfall structure.

2.8.1. Design Aspects

2.8.1.1. Inlet

The inlet pipe to wetland systems should be constructed in such a way that influent flow velocities do not exceed 0.3 to 0.5 m/s and provide an even distribution across the width of the bed (to minimise the risk of scour). The reduced velocity can be achieved using a stone trench (rip-rap or gabion zone) to dissipate high water flows and enable effective sedimentation to be achieved and to prevent physical damage to the plants, particularly during the establishment stage. To spread the influent flow evenly a level spreader device (serrated weir plate, hard aprons etc.) is effective particularly if combined with a grassed filter strip prior to entry into the wetland cell.

As constructed wetlands typically take 1-3 years to mature and achieve optimal pollutant removal potential it is important to protect the young plants during their early growing stage. Therefore it is advisable to install oil separators and sedimentation ponds (see Section 1.1.2) prior to the discharge of runoff into a constructed wetland. The presence of a sedimentation pond is particularly important at the front end of a SSF wetland to reduce the clogging of the pores in the substrate by suspended solids.

2.8.1.2. Pre-treatment

The trapping of sediments and associated pollutants by a front-end sediment forebay or pre-settlement pond provides the potential for the treatment of the (the more frequent) small runoff events and more effective treatment of the first flush. The recommended sizing of the sediment pre-treatment pool should be equivalent to between 10 to 15% of the total wetland cell volume. The discharge from the forebay into the main wetland cell can be by a filter strip or a gabion wall.

2.8.1.3. Main basin

An important factor influencing the treatment mechanism function of wetlands is the hydraulic retention time. Wetlands should have a minimum retention time of at least 10 - 15 hours for the design storm event (typically a 1:50 event) or alternatively retain the average annual storm volume for a minimum of 5 - 10 hours to achieve a high level of pollutant removal efficiency. The hydraulic retention time is expressed as the ratio of the mean wetland volume to mean outflow (or inflow) rate and therefore when calculating this for a SSF wetland, the wetted volume within the substrate that is occupied by free (drainable) water has to be determined. This is represented by the porosity (or void fraction) of the substrate, with higher porosity values indicating a greater retention volume of water per unit volume of media. However, excessive porosity can lead to scour in the bed causing breakdown of the substrate. Other factors which can influence the retention time include the aspect ratio (width : length), the vegetation, depth of water, and the slope of the bed. For SSF wetlands the recommended aspect ratio is 1:4 with a slope for the wetland bed of 0.5 - 1%. The same bed slope is recommended for SF wetlands with a minimum dry weather flow aspect ratio of 2:1. Short-circuiting should be minimised by careful construction with intermediate open-water zones for flow distribution and the use, where possible, of baffles and islands.

A hydraulic loading rate of 0.2 m^3/m^2/day is considered appropriate to wetlands to achieve maximum treatment efficiency. However loading rates as high as 1m^3/m^2/day have been proposed given the provision of a void storage capacity of 50m^3 and 100m^3 per impervious hectare respectively for 5mm and 10mm effective runoff volume. The most cost-effective wetland stormwater storage volumes for water quality treatment are between 50 and 75 m^3/ha although this is for residential and commercial/industrial catchments. A wetland sized to capture such volumes will also retain the first-flush of larger storms. Oversizing the wetland basin will only result in the more frequent events (which carry most of the total annual pollution load), receiving less treatment and thus providing a poorer overall removal efficiency. It has been suggested that an arbitrary hydraulic rate loading break-point is of the order of 2.7 ha catchment area/1000 m^3 storage volume/day, with wetlands having a larger area per unit flow (a lower loading rate) being normally SF systems and whereas smaller areas (with higher loadings) are typically associated with SSF systems.

In the absence of financial constraints and land availability, the constructed wetland should be designed to treat storms with a return period of 10 years, although the attenuation design could be up to the 100 year return period. If a compromise is necessary requiring a design based on a shorter return period, the system should be capable of treating the polluted first flush of any storm event. SF wetlands should be capable of treating the first 10mm of runoff without overtopping. They should be surrounded by berms with slopes of 20% or less, which are at least 0.5m above the permanent water level. The depth of water should be between 0.15 and 0.3m. The existence of a variable wetting-drying cycle due to changes in depth helps to encourage different habitats and macrophyte growth/diversity which improves the treatment potential. SF wetlands utilise a natural soil substrate to provide the organics and nutrients to maintain plant growth.

In SSF wetlands the influent flows below the surface of the substrate which can be a combination of organic and clay based soils, sand, gravels and stones to provide support for the plants. Purification occurs during contact with the plant roots and the substrate surfaces, which as well as providing adsorption sites also provide attachment surfaces for microbes which directly or indirectly utilise pollutants. Because the substrate is thermally insulated by the overlying vegetation and litter layer the wetland performance is not significantly reduced during cold weather. The nature of the substrate used will have an important influence on its hydraulic conductivity which should be between 10^{-3} m/s and 10^{-2} m/s to enable the runoff to flow at a sufficient rate for treatment without backing up and causing overland flow. It is recommended that the minimum substrate bed depth should be 0.6 m.

2.8.1.4. Outlet

To help prevent the drying out of SF wetlands and to maintain the required water level the outlet can be a weir or appropriately positioned high level pipe. In a SSF wetland it is recommended that the lowest level should be 300mm below the substrate surface although this will also be dependent on plant types. For both types of wetland, an additional source of water may be needed to supply the reedbeds during extended dry periods. In situations where groundwater levels are high it may be possible to utilise ground water flows to keep the wetland moist. This would have to be subject to preventing any possibility of contamination of the aquifer by pollutants from the wetland.

Ideally the outlet structure should incorporate control measures which allow the water level in the bed to be varied to promote biodiversity (see Section 1.1.3) and to allow periodic raising of the water level for weed control and bed oxidation. Where there has been temporary storage of stormwater it needs to be released slowly to prevent downstream flooding in extreme events. This can be satisfied by fitting wetland basins with adjustable outlet controls to maintain outflow rates and volumes compatible with a sustainable receiving water regime. At the outlet an additional rip-rap (or gabion) zone can be introduced to prevent weed growth and resuspension of reedbed substrates. Outlet structures are particularly prone to debris accumulation and a gabion zone (or debris screen/fence) will help to alleviate this problem. If high flood conditions at the site are anticipated, there should be appropriate provision such as emergency overflow spillways or by-passes, to facilitate through-flow and prevent disturbance and flushing of the wetland substrates.

Subject to land is availability it may be possible to install a final settlement tank with a minimum capacity of 50 m^3 extending across the width of the wetland. This is particularly desirable in the case of sensitive receiving waters which will benefit from protection from fine sediment which may otherwise be washed out of the wetland. An alternative, more ecologically appropriate form of tertiary treatment would be a final micropool or settlement pond.

2.8.2. Integration into the landscape

The presence of vegetation in constructed wetlands provides an attractive feature which together with their shape and layout should aim to reflect the overall pattern and scale of the surrounding landscape. Use should be made of natural dips and hollows, which will reflect the likely position for a reedbed. Geometric shapes and steep uniform banks should be avoided with side slopes generally being no steeper than 1 in 3. Smoothly flowing curved shapes will assist in giving the constructed wetland a natural appearance and the creation of bays will provide appropriate sites for aquatic birds. The avoidance of monocultures by the use of additional plant species, especially in the margins of a wetland, promotes the visual appearance and enhances the wildlife interest of the wetland. The planting of trees near a wetland should be avoided to prevent shading, invasion of roots and damage to any wetland liner.

2.8.3. Planting regime

The dominant feature of a constructed wetland is the macrophyte zone containing emergent and/or floating vegetation. It is normal practice to use the native plant species commonly found in local water bodies and watercourses, as these are generally pollutant tolerant and known to thrive in nutrient-rich situations. The selection of plants for stormwater wetland treatment systems should be based on the following criteria:

- easy to propagate, ability to establish quickly and exhibit a strong relatively constant growth rate
- possess high biomass and attractive appearance combined with substantial root density and depth
- good capacity to absorb or transform pollutants
- high tolerance of eutrophic conditions
- easy to harvest
- provision of ecological value

Plant species fulfilling these criteria which have been used in wastewater treatment wetlands include the common reed (*Phragmites australis*), reedmace (*Typha latifolia* and *Typha angustifolia*) as well as flag iris (*Iris pseudacorus*), bulrush (*Schoenoplectus* spp.) and sedges (*Carex* spp.). The most frequently used plant in SSF wetlands in the UK is *Phragmites australis*. In SF wetlands, the choice of plant is dependent on the depth of water cover and its periodicity. For permanently full or partly inundated wetlands, *Typha latifolia* is recommended together with branched bur-reed (*Sparganium erectum*), pond weeds (*Potamogeton spp.*) and flote-grass (*Glyceria fluitans*). In seasonally wet parts *Phragmites australis*, reed canary grass and amphibious bistort are considered appropriate. In drier parts rush species should be considered. Establishment of aquatic and emergent species should be from planted rhizome/root stock in the spring. The grass and rush component can be sown, ideally in late summer. The extent of planting should be designed so there is vegetation across the entire flow path.

Attention needs to be paid to water levels throughout the first growing season as young plants can be killed off by even shallow flooding. Nutrients may be a limiting factor of initial plant growth in highway runoff treatment wetlands and a supplementary source of nutrients from slow release pellets may be required. Long term maintenance of water levels is also important to prevent stress on the plants, especially *Typha latifolia* (see Section 1.4)

2.8.4. Maintenance and management

The establishment of a site specific maintenance regime for constructed wetland is essential if their proper and continued function is to be guaranteed. The required operation and maintenance procedures together with their frequencies are summarised in Table 2.7. The problems that are most likely to occur are blockages of inlets/outlets, flow regulating devices, siltation of storage areas, algal growth and plant dieback. Regular inspection (e.g. monthly) of the inflow and outflow within SSF wetlands will determine the level of hydraulic conductivity in the substrate. The elevated levels of silt and oil/grease which can occur in highway runoff can create a substrate clogging problem particularly if the installed pre-treatment system needs cleaning/emptying. When the efficiency of the pre-treatment system is preserved, the design life of constructed SSF wetlands used to treat highway runoff is estimated to be between 15 to 20 years. After this time, the substrate may need to be replaced. Cores should be taken to establish the overall state of the substrate and to identify clogged or severely contaminated areas. Where the need for bed replacement (and re-planting) is determined this should be undertaken in sections starting at the front end closest to the inlet. If possible the capability for on-site dewatering of contaminated sludge/vegetation should be provided in the form of a fenced off restricted access disposal area.

The vigour of the reed vegetation and any surface litter build-up should be regularly reviewed and harvesting conducted as required. It is recommended that cutting is by hand and not machine to avoid damage to the substrate and its porosity. To preserve operational efficiency only a section of the bed (no more than half) should be cut at a time.

The maintenance and inspection of SF wetlands is less onerous than for SSF wetlands with inspections recommended on a quarterly basis to ensure the integrity of the system. It is anticipated that accumulated silts within SF wetlands may need to be removed by dredging after more than 10 years, depending on size and level of inputs. This should be undertaken on a cyclic basis involving only a third or a half of the system at a time to ensure the continued presence of mature vegetation to promote sedimentation while the newly planted areas are becoming established. Where sediment removal is undertaken, the area would be replanted. In this type of system it is anticipated that the vegetation would not be cut.

Table 2.7. Operation and maintenance requirements for constructed wetlands

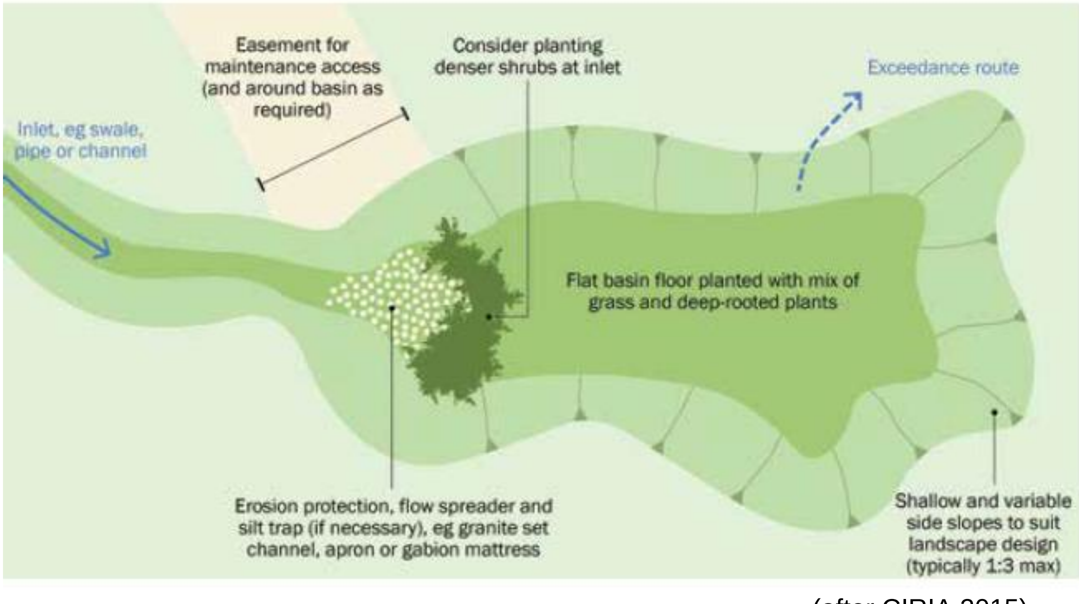
Maintenance schedule	Required action	Typical frequency
Regular maintenance	Remove of gross litter/solids; clean any surfaces where solids and floatables have accumulated	Monthly
	Cut grass in surrounding areas	Half yearly (monthly during growing season)
	Inspect marginal and bankside vegetation and remove nuisance plants	Monthly at start and then as required
	Check inlet and outlet structures and clean by jetting if necessary	Monthly
	Check sediment accumulation levels in wetland and remove sediment if required; test removed sediment for contamination to inform disposal route	Half yearly
	Check weir settings and ensure maintenance of water levels	Half yearly
	Cut submerged and emergent aquatic plants (at 0.1 m above pond level; include approximately 25% of pond surface)	Annually
	Remove all dead plant material before start of growing season	Annually
Occasional maintenance	Maintain the appearance and status of the wetland vegetation including replacing, harvesting and weed control as necessary	Every 5 years
	Check substrate porosity in SSF wetlands and instigate maintenance procedures if necessary	Every 10 years
Remedial actions	Repair erosion or other damage	As required
	Re-plant where necessary	As required
	Repair/rehabilitate inlets, outlets overflows	As required

2.8.5. Spillage containment

SF wetlands can act as effective spillage containment facilities providing outfalls are appropriately designed through mechanical devices (e.g. penstocks or similar) or by physical means (e.g. using sandbags or booms to block a suitable channel). Although the wetland may need to be thoroughly renovated following a serious spillage, this is considered acceptable for events where the estimated probability is less than 1% annually. For higher probability events, the cost of providing separate containment should be balanced against the cost of renovating the wetland following a spillage, also taking into account the value and vulnerability of the receiving waters.

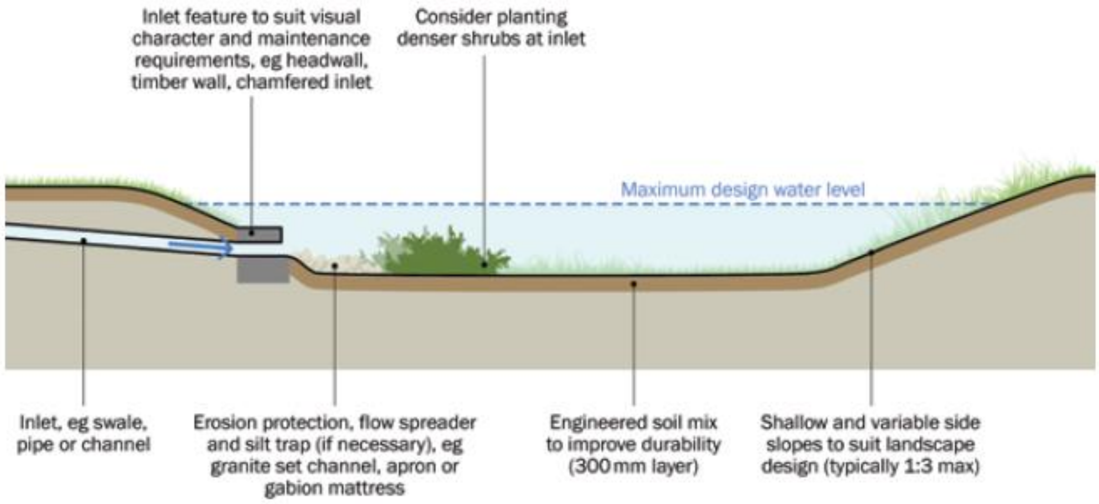
2.9. Guidelines for Infiltration Basins

Infiltration basins have the ability to both store and treat road runoff and hence protect the downstream receiving water environment from flooding and pollution. They are designed to retain storm water flows and allow the water to percolate through a filter layer which may typically comprise porous material, such as gravel. The water may then be directed to a surface water outfall, or it may continue to percolate through to groundwater thereby supporting baseflow and groundwater recharge processes. The rate at which water can be infiltrated depends on the infiltration capacity (permeability) of the surrounding soils. Infiltration basins are flat-bottomed, shallow landscape depressions that store runoff (allowing pollutants to settle and filter out) before infiltration into the subsurface soils (Figures 2.14 and 2.15).



(after CIRIA 2015)

Figure 2.14. Schematic plan view of an infiltration basin.



(after CIRIA 2015)

Figure 2.15. Schematic side view of an infiltration basin.

Although the process of infiltration is the main pollutant removal process operating in infiltration basins, it can be assisted by other processes in the case of specific types of pollutants such as sedimentation for suspended solids. Sedimentation is also relevant for particulate associated metals and organics although where high rates of sedimentation occur there is the possibility of more rapid clogging of the infiltration surface. Additional processes contributing to the removal of metals in infiltration basins are adsorption and plant uptake. Adsorption is also relevant to the removal of organics together with biodegradation and volatilisation. Infiltration basins are considered to provide good removal potentials for suspended solids and particulate associated pollutants but are less effective for soluble pollutants. Their overall effectiveness is dependent on their design for storm flows, particularly as suspended solids are prone to remobilisation, leading to the possibility of high sediment and associated metal loads being discharged.

2.9.1. Design aspects

2.9.1.1. Inlet

In well-designed basins, inlet flows should be low but where necessary inlet channels should be stabilised using appropriate erosion control, such as rip-rap. A level spreader at the inlet to the infiltration basin will also reduce the risks of erosion and, in addition, promote shallow sheet flow which will maximise pollutant removal opportunities.

2.9.1.2. Pre-treatment

Clogging is a potential problem for any infiltration system and therefore to avoid high failure rates effective pre-treatment is recommended to remove as much suspended solids and fine silts (< 6 mm diameter) from the incoming runoff as possible. Therefore, where possible pre-treatment practices such as swales, sediment basins and filter strips should be incorporated into the overall design either singly or in series upstream of the infiltration basin to minimise clogging risks.

2.9.1.3. Main basin

The bottom of the infiltration basin should be flat to provide a uniform distribution of incoming runoff across the surface thereby maximising infiltration. The tolerance on the base levels should be a maximum level difference of 10 mm in 3 m. The side slopes of infiltration basins should normally be no steeper than 1 in 3 to allow for vegetative stabilisation, mowing, access and for public safety reasons. Stepped or benched slopes also offer a range of habitats that can survive fluctuating water levels and wet to dry soil conditions. The shallow side-slopes and benching will help mitigate safety risks and also provide for biodiversity and habitat creation.

A minimum distance of 1.5 m between the base of the infiltration system and the maximum likely groundwater level should always be adopted. This is to minimise the risk of unwanted exchanges between surface and ground water. Otherwise there is the possibility of groundwater rising into the infiltration component and reducing the available storage volume. The minimum 1.5 m depth of unsaturated material facilitates the protection of the groundwater from any contamination in the runoff. The performance of the infiltration basin design, from a groundwater protection perspective, will depend on the extent of the likely runoff contamination and site and ground characteristics. Unsaturated soils/clean gravels through which the runoff percolates efficiently and which are not fractured deposits with rapid flow routes (preferably with some organic and clay content) are known to provide good protection to underlying groundwater.

The size of an infiltration basin will be governed by the catchment area, which should ideally be between 2 and 10 ha. The basin should be sufficiently large to accommodate the first 10mm of a storm (the 'first flush') without overtopping. In the event of overflow occurring, excess surface water runoff from a basin can be controlled by a weir overflow. Infiltration basins serving smaller catchments may be designed with a narrow trench-like shape. The shape of the basin will be determined by prevailing environmental considerations, with the aim being to fit the basin into the surrounding landscape to achieve the most natural appearance. The slopes and shape of the basin should reflect those that occur locally. Where possible, local materials should be used for engineering features and boundary treatments.

Following a storm event, the basin should completely empty within 72 hours and in many cases it is recommended that the infiltration component should discharge more rapidly e.g. from full to half-full within 24 hours when designed to manage the 1:10 year or 1:30 year event. For more extreme events, designing to half empty in 24 hours can result in very large storage requirements. Where there is the possibility of subsequent storms scouring retained suspended solids and releasing them to receiving waters by overtopping, an appropriate option may be to isolate the first flush in a smaller basin and use a second basin for attenuation if required.

The filter layer should consist of a free draining granular material to permit ready dispersal of the incoming runoff and a 10 - 15% sand composition will assist the effective treatment of the water. Top soils or engineered soils (root zone or amended soils) used in infiltration basins should be sufficiently permeable. Geotextiles should be used to prevent contamination of the filter layer from either the subgrade or topsoil.

The design should allow for occasional removal and replacement of the filter material. This could either be at predetermined major maintenance intervals or following an accidental spillage.

The depths and rate of rise of the temporarily stored water in infiltration basins should be sufficiently low in order to minimise the risks posed for site users and operators, who may not be accustomed to these fluctuations. A risk assessment should be undertaken to establish the frequency and rate of flooding to a range of inundation depths in order that public safety is not put at risk. Flatter slopes tend to improve the aesthetics but at the expense of extra land-take. Appropriate access to the infiltration basin should always be provided for maintenance activities such as grass cutting and rehabilitation of the infiltration surface.

Because of the possible occurrence of high sediment loadings in runoff from disturbed ground, construction of infiltration basins should take place after the site has been stabilised in order to minimise the risk of premature system failure. If this is not possible, initial excavations should be carried out to within 450 mm of the basin floor, and final excavation delayed until after site stabilisation. All excavation and levelling should be performed by equipment with tracks that exert very light pressures, to prevent compaction of the basin floor, which may reduce infiltration capacity. Topsoil should not be laid in basins when the ground or the topsoil is saturated. The base of the basin should be carefully prepared to an even grade with no significant undulations. After final grading, the basin floor should be tilled to a depth of 150 mm to provide a well-aerated, porous surface texture. The topsoils used to finish the side slopes need to be suitably fertile, porous and of sufficient depth to ensure healthy vegetation growth. Immediately following basin construction, the base and side slopes should be stabilised with a dense coverage of water-tolerant grass.

2.9.1.4. Outlet

If the incoming water cannot all be successfully infiltrated an overflow route for the excess surface water needs to be provided via either a piped outlet or a weir overflow. The overflow should not impede access to the inlet control structure that manages more frequent flows.

2.9.2. Integration into landscape

In order to fit an infiltration basin into the surrounding landscape and achieve the most natural appearance, the slopes and shape of the basin should reflect those that occur locally. In undulating countryside, infiltration systems may have to be increased in number and reduced in size to blend successfully into the landscape. If it is considered that a basin may become an unattractive component of the landscape, carefully designed low mounds, combined with planting can provide screening from passing motorists.

2.9.3. Planting regime

Typically, infiltration basins are constructed with grassed surfaces, but the presence of additional vegetation can enhance the appearance of the basin, contribute to stabilising side slopes and preventing erosion, and encouraging the establishment of a wildlife habitat (e.g. the use of wild flower meadow mixes). Planting regimes should be able to cope with the occurrence of alternating wet and dry conditions. Native plants and vegetation may be preferable and more able to survive expected fluctuations in soil water levels. Vegetation also increases the effectiveness of infiltration by slowing the flows across the basin and by maintaining or enhancing the pore space in the underlying soils via deeper rooting systems. Very vigorous root intrusion into subsurface systems caused by the presence of large shrubs and trees should be kept to a minimum as this can lead to the occupation of a significant proportion of the void space required for runoff attenuation and can also cause structural damage. If trees are present they should not prevent access or hinder future maintenance practices.

Since standing water will only be present for short periods in infiltration basins, appropriate vegetation types are creeping bent (Agrostis stolonifera) and rush species (Juncus spp.). If the design of the infiltration basin is such that standing water persists for longer than 24 hours, wetland species such as common reed (Phragmites australis), reed canary grass (Phalaris arundinacea) and amphibious bistort (Persicaria amphibia) may be considered.

2.9.4. Maintenance and management

The use of infiltration basins as amenity features needs to be balanced against the increased maintenance requirements this can cause. If the basin is purely aesthetic or biodiverse and is not used as an active or passive recreation space then there is no real increase in maintenance. In this situation the typically required operation and maintenance procedures together with their frequencies are summarised in Table 2.8. However, if the surface is going to be used by pedestrians or used for playing informal sports, this can cause the surface to become compacted and require more frequent maintenance to maintain the infiltration capacity which should not be less than 13 – 15 mm/hour.

Quarterly inspections of inflows and outfalls are recommended and to examine for the presence of debris/rubbish, which needs to be removed to allow infiltration basins to continue operating efficiently. Litter and sediment removal will be needed twice a year. If there is the possibility of leaf fall, this should be cleared away in late autumn to prevent the system becoming less effective. Signs of ponding will indicate inefficient infiltration and that cleaning out of the filter is needed. Slopes and spillways should be checked twice annually to ensure there is no erosion, settlement, slope failure, unwanted tree growth, wildlife damage or vehicular damage.

During the establishment phase, the addition of fertiliser and the application of herbicides within an infiltration system should be avoided to minimise the risk of pollutants and nutrients entering the groundwater. Regular mowing in and around infiltration basins is required and may need to accommodate specific sward mixes where these have been used. Vegetation management activities should take account of the need to maximise biosecurity and prevent the spread of invasive species.

Table 2.8. Operation and maintenance requirements for infiltration basins

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Remove litter and debris	Twice a year
	Cut grass in and around basin	Monthly (during growing season) or as required
Occasional maintenance	Re-seed area of poor vegetation growth	Annually or as required
	Remove sediment from pre-treatment system when 50% full	As required
Remedial actions	Repair erosion or other damage by re-seeding or re-turfing	As required
	Repair/rehabilitate inlets, outlets and overflows	As required
	Rehabilitate infiltration surface using scarifying/spiking techniques if performance deteriorates	As required
	Re-level uneven surfaces and re-instate design levels	As required
Monitoring	Inspect inlets, outlets and overflows for blockages and clear if necessary	Quarterly
	Inspect banksides, structures and pipework for evidence of physical damage	Twice a year
	Inspect infiltration surfaces for compaction and ponding	Monthly

Any sediments which accumulate on the surface of infiltration basins should be removed to maintain the viability of the treatment system and to prevent human exposure where the basin is being used as an open space. It may be advisable to test the hazardous nature of the removed material so that the appropriate waste disposal route can be followed. This is particularly important where the infiltration basin receives runoff from a busy road.

2.9.5. Spillage Containment

Because infiltration basins can be highly vulnerable to damage resulting from major accidental spillages, they should preferably be avoided where the spillage risk is high. If this is not possible, available options are to use two basins with a control system to divert the spillage into the second basin, or else to protect the infiltration basin by using a separate containment area together with an oil interceptor.

2.10. Guidelines for Porous Surfacing

Porous surfaces are able to provide a pavement suitable for pedestrian and/or traffic use while allowing surface water to pass through the surface into the underlying structural layers where it may be temporarily stored, allowed to infiltrate to ground or gradually discharged downstream. This provides an efficient way of managing runoff close to its source and involves interception, reduction of the frequency and volume of discharged water and pollutant removal potential. Pervious pavement drainage has decreased concentrations of metals, oil and grease, and sediment when compared to impermeable surface drainage. The pollutant removal processes include filtration (particulates and attached pollutants which are mainly trapped within the top 30 mm), biodegradation of organic pollutants (through the action of naturally occurring microbes), adsorption of pollutants (through binding to aggregate surfaces) and settlement and retention of solids. These processes occur within the subsurface aggregate, the geotextile layers and the underlying soil (if infiltration is allowed). Based on the 75 percentile pollutant concentrations in urban runoff of 114 mg/L for TSS, 0.6 µg/L for total cadmium, 22 µg/L for total copper, 112 µg/L for total zinc and 8 µg/L for total nickel, porous pavements can demonstrate removal efficiencies of 61%, 17%, 50%, 74% and 63% respectively (CIRIA, 2015).

Pervious surfaces conform to two main types identified as either porous pavements or permeable pavements. Permeable pavements consist of impervious materials, such as block paving, laid in such a way as to create void spaces through which the surface water can pass into the sub-base. Concrete is the most common material used in block paving although clay and natural stone may also be used. The water passes through widened joints which are filled with sand or grit. Typical uses are in pedestrian areas, driveways, car parks and lightly trafficked roads. The same uses are also appropriate for grass reinforcement systems in which grass or gravel act as the infill in between concrete or plastic grids laid on a free-draining structural sub-base layer. Porous pavements allow water to infiltrate across their entire surface and examples include porous asphalt, porous concrete or resin bound aggregate, laid on a recommended sub-base of free-draining granular material. These systems are able to remain free-draining provided regular surface maintenance limits the deposit of debris in the surface void spaces. Typical uses are for public, engineered surfaces carrying high volumes of heavy and/or light vehicles. Because this type of pavement is appropriate for highway use it is particularly relevant for consideration within the PROPER project. Since the current context is with regard to UK guidelines, the emphasis within this section will be on porous asphalt surfaces which have been widely used in the UK.

There have also been claims for noise reduction properties for porous asphalt as well as reductions in the amount of spray produced. Open asphalt concrete or whisper concrete applied as a top layer on motorways substantially reduces splash/spray as well as noise and lane rutting. It contains up to 20% hollow space with relatively little fine components in the sub-base and is said to encourage downward filtration. However, it is more costly and typically needs replacing every 10 – 12 years.

2.10.1. Design aspects

Porous pavements are increasingly used in the construction of estate roads and car parks because of their ability to allow surface water to infiltrate into the sub-grade or to be captured for controlled release off site. These pavements are constructed with porous asphalt surfacing overlying a thick gap-graded sub-base, which can temporarily store water. Where infiltration directly into the sub-grade is permitted, no special collection system will be required however as with all proposed infiltration, the risks to the ground water regime should be carefully assessed. Traffic levels on motorways and trunk roads require strong pavements for which porous asphalt may be used as a departure from standard practice in the UK. However, current UK practice is to use it for highways with low traffic volumes, low axle loads and speeds of less than 30 mph. However, porous asphalt can be capable of supporting HGV traffic and it has been used on major highways in The Netherlands for over 10 years. However, there are concerns that frequent vehicle braking and turning can cause the surface to rut and porous asphalt to spall and it is recommended that geotechnical and pavement engineers should be fully consulted regarding its suitability for use on busy highways. Ideally a stiff layer of asphalt, asphalt concrete, concrete or hydraulically bound coarse graded aggregate should be located beneath the bedding layer.

2.10.1.1. Inlet

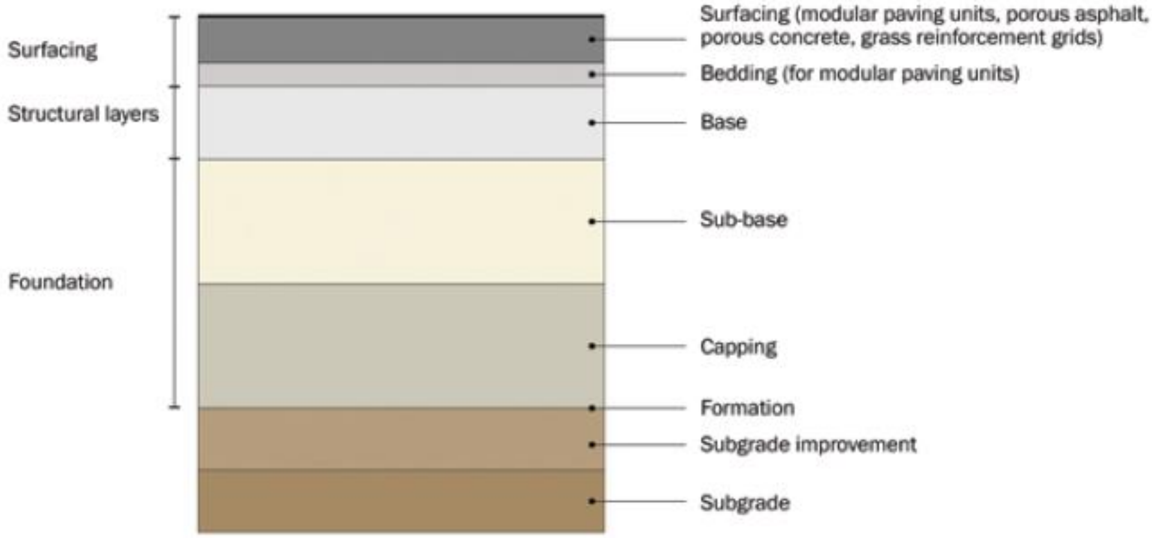
Normally rainfall arrives directly on to the pervious pavement surface and infiltrates into the lower levels. If there is sufficient hydraulic capacity it is feasible for runoff from adjacent impermeable areas to be directed on to the porous surface. However, it is important that the flow of water from such an additional source is distributed along the edge of the permeable area and not channelled to a discrete point as this could lead to clogging of the surface.

2.10.1.2. Pre-treatment

Pre-treatment is not commonly practiced as porous pavements combine both the runoff source and the treatment system. If pre-treatment were to be feasible it would be beneficial to reduce the suspended solid content of the runoff to inhibit the clogging potential in the porous surface.

2.10.1.3. Main system

The different layers which typically constitute the structure of a road pavement are shown in Figure 2.16. These layers are required to efficiently distribute the concentrated loads from the wheels of vehicles to a level that the soil (subgrade) can support without failure or excessive deformation. The surfacing layers are subjected to the highest wheel pressures and therefore need to be of high quality materials such as asphalt, concrete or block paving to prevent cracking or excessive rutting under the influence of traffic use. Pervious surfaces allow water into them and therefore the design should be such that they can support traffic while facilitating the free flow of water through them. The pressure decreases with depth allowing weaker materials to be used in the sub-base and capping layers. These layers also serve to prevent groundwater reaching the bound upper layers. The sub-base material needs to contain a large proportion of interconnected voids to allow water to freely flow through it. Therefore it requires to exhibit sufficient permeability (minimum of 6×10^{-2} m/s) and porosity (at least 30%) whilst retaining strength and resistance to abrasion. The aggregates used in the sub-base are required to carry the surface loading through point-to-point contact between them. 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) fulfil these requirements. When the sub-base is being laid this should be done in 100-150 mm layers and compacted to ensure the achievement of maximum density without crushing the individual particles or reducing the porosity below the design value.

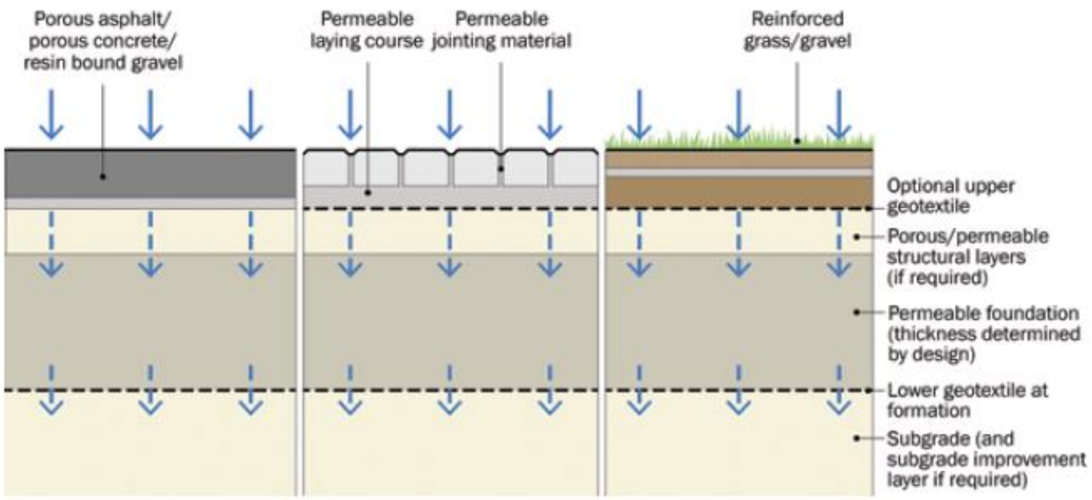


(after CIRIA 2015)

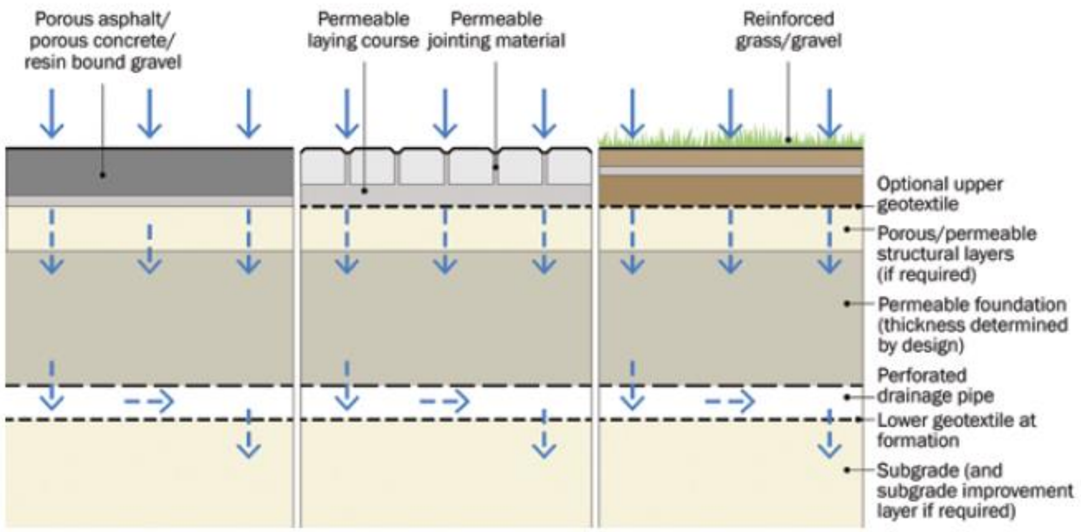
Figure 2.16. The different layers which typically constitute a road pavement structure.

The management of water below porous pavements is dependent on the level of infiltration which is permissible into the ground. Schematic diagrams of three possible systems are shown in Figure 2.17. Where total infiltration is allowed (Figure 2.17a) there will be no discharge to a sewer or watercourse although an overflow may be necessary to cater for events in excess of the design event or in situations where the infiltration rate becomes restricted. Where there is only partial infiltration, because the amount of rainfall exceeds the infiltration capacity, the excess water needs to be transported away using, for example, perforated pipes which provide a large surface area for the water to flow into (Figure 2.17b). If infiltration is not practicable (low soil permeability) or not feasible (sensitive groundwater; water table within 1 m of the sub-base) an impermeable, flexible membrane can be positioned above the subgrade and the water collected in a perforated pipe for conveyance to an outfall (Figure 2.17c). Impermeable membranes need to be durable and robust, resistant to puncture and movement strains, and unaffected by potential pollutants. High density polyethylene, polypropylene and ethylene propylene diene monomer rubber fulfil these conditions.

Porous pavements need to be able to effectively capture the design storm event and discharge it in a controlled way to the subgrade or drainage system thereby reducing peak flows to watercourses and the risk of downstream flooding. The infiltration of rainwater through the porous surface must exceed the design rainfall intensity to avoid surface ponding. A minimum value of 2500 mm/hour is considered appropriate for a pavement surface. This will decrease over time and safety factor of 10 is generally applied to all porous surface types to allow for clogging which may affect the proportion of porous surface area over the surface design life. The required capacity of the sub-base will depend on rainfall characteristics, design return period, infiltration potential into the subgrade and discharge constraints. In addition to its volume, the available



(a)



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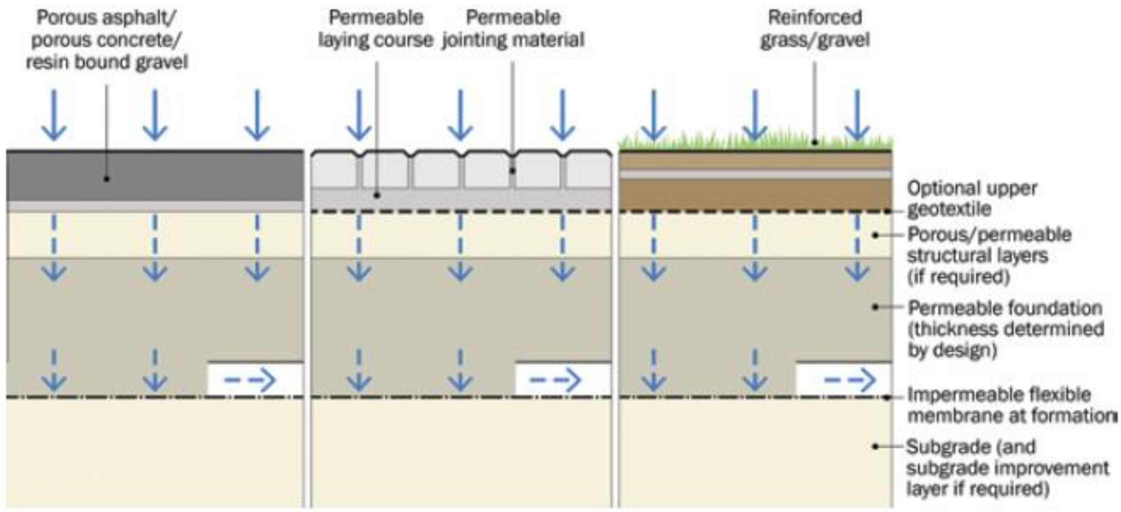


(c)

(after CIRIA 2015)

Figure 2.17. Schematic diagrams of different porous pavement designs involving (a) total infiltration (b) partial infiltration and (c) no infiltration.

storage in the sub-base will be determined by the usable voids (voids that are freely draining) within the aggregate with a porosity of 30% being typical for coarse-graded aggregates.

2.10.1.4. Outlet

Where perforated pipes are located in the sub-base, water will be removed via an outlet. In order to ensure effective use of storage in the sub-base, a flow control may be installed. This is usually small orifice plates in a control chamber. The size can be small (minimum 20 mm) because the water has been filtered. It is possible to install an observation well, consisting of a 150 mm perforated pipe, prior to the outlet to enable the emptying times of the pavement system to be observed and to observe changes over time. Overflows may be constructed to ensure the surfaces remain free of water at all times.

2.10.2. Integration into landscape

Pervious pavements can be used in most ground conditions but may require a liner where infiltrating water can result in slope instability such as at the top of cuttings or embankments. Only a small head difference from the runoff surface to the outfall is required facilitating their use on relatively flat terrain. Porous pavements effectively permit the dual use of space, so no additional land take is required. Another consequence of this is good community acceptability.

2.10.3. Maintenance and management

Where accessibility for maintenance purposes exists, the design life of porous pavements should be of the order of 20 years. However, porous asphalt tends to lose strength and begins to fatigue due to oxidation of the binder and so the design life may be reduced slightly.

Regular inspection and maintenance is important for the effective operation of porous pavements as they are known to be prone to clogging. A summary of the required procedures together with their frequency is provided in Table 2.9. It is advisable to check the operation after particularly heavy rainfall and to identify any signs of ponding. Regular sweeping using a brush and suction cleaner helps to preserve the surface infiltration capacity by removing silt and other sediments. An alternative cleaning process is to use lightweight rotating brush cleaners combined with power spraying using hot water. If the porous asphalt surface becomes clogged then more specialist cleaning using both oscillating and rotating brushes combined with water jetting may be required to restore the surface infiltration rate to an acceptable level. Material removed from the voids may contain pollutants that need to be disposed of as controlled waste and therefore sediment testing is recommended.

Table 2.9. Operation and maintenance requirements for porous pavements

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Brushing and vacuuming over whole surface	Once a year, preferably after autumn leaf fall. Reduced frequency may be feasible if observations indicate good porosity
Occasional maintenance	Removal of weeds using permitted herbicide from an applicator (as opposed to spraying)	As required
Remedial actions	Remedial action on any depressions or rutting considered detrimental to operation and safety	As required
	Rehabilitation of surface and upper substructure by remedial sweeping	Every 10 to 15 years or as required (if infiltration inhibited by clogging)
Monitoring	Monitor inspection chambers	Annually

3. International Guidance for Highway Treatment Systems

3.1. Introduction

Appendix 1 lists guidance manuals and best practice approaches for the control and management of highway runoff that have been issued by various non-UK authorities and organisations and which have been consulted in working up this Deliverable. There is a substantial international literature available although many manuals and documents adopt or refer to available guidance criteria and design/operational recommendations that have been developed for generic urban stormwater runoff rather than representing guidance specifically resulting from studies of highway situations and conditions.

All of the French documentation for example (see Appendix 1), refers to sustainable 'alternative durable' stormwater (ruisellement) drainage in the context of urban development with no specific reference to either urban or rural autoroutes/motorways. French drainage authorities in general have been implementing "blue-green" approaches to stormwater runoff since the early 1990s (Foncier Conseil, 1992; Valiron and Tabuchi, 1992; Bergure and Ruperd, 1994) and French highway drainage has conventionally assimilated this best practice into their road drainage design.

The Dutch framework for road runoff control essentially relies on the application of porous surfacing (ZOAB) to the highway backed up by 'over-the-shoulder' verge infiltration (Van Grinsven, 2014). Where soil percolation rates are low, infiltration ditches and retention ponds are permissible to prevent as far as possible any overflows to receiving waters. This strategic approach is not directed at any conscious 'blue-green' philosophy but reflects working experience. The fundamental expectation is that the large majority of emitted highway pollutants will be deposited on, retained in and degraded on or within the porous surfacing (Van Grinsven, 2014).

A full detailed review of European best management practices (BMPs) for the sustainable control and management of highway and urban stormwater runoff can be obtained from Revitt et al. (2003). A recent international review (Sage et al., 2015) concluded that flow rate and volume limitations remained the principal global criteria for the assessment of stormwater drainage controls. Administrative, institutional, legal and management criteria were considered to be the principal drivers for the final choice of specific BMPs and strongly influenced whether 'blue-green' infrastructure was adopted into the drainage design. However, this international review was developed exclusively in the context of generic urban runoff control rather than from the perspective of highway drainage.

By far the most extensive and well established guidance is that available from the United States where multi-lane interstate and other expressways count for nearly 20% of the total 4 million miles (6.5 M km) of highways with 77% being in rural environments. A distinction is generally made in the US guidance manuals between non-urban highways assumed to have open drainage such as verges, ditches and swales whereas urban highways are dominated by piped systems to accommodate kerbs, gutters or other 'hard' roadside infiltration-type drainage systems. The following sections of this Deliverable firstly consider the voluminous US guidance material in terms of the pan-state adoption of a generally consistent process-based selection approach and a common structural framework for a phased and criteria-based Best Management Practice (BMP) design and implementation procedure. A review then follows of selection criteria and procedures for quality control of highway runoff adopted in climatically different conditions to those encountered in the UK. The southern US states and Australia are considered as representative of semi-tropical biomes whilst Sweden and Canada are taken as cold climate representatives. There has been a tacit acknowledgement that urban drainage in cold climates poses very specific problems in terms of approaches to and design of sustainable control and management (Maksimovic, 2000), particularly in respect of BMP performance during winter highway snowmelt runoff.

3.2. US Highway SuDS/BMP Guidance

3.2.1. US BMP Practice

The classic US baseline guidance document is that published under the auspices of the Federal Highway Administration (Dorman et al., 1988). This still forms core material for many of the numerous state and municipality guidance documents. However, increased attention is now being paid to the more recent Best Management Practice (BMP) guidance published by the National Academy of Sciences, Engineering and Medicine (2006) as part of a national evaluation of highway BMP control approaches and which utilises the extensive national BMP public domain database which can be accessed at www.bmpdatabase.org.

A full listing of individual state Department of Transportation (DOT) websites for which stormwater drainage guidance can be accessed is given on the US Environmental Protection Agency website (see Nonpoint Discharge Elimination System: NPDES website platform under ‘Stormwater Discharges from Transportation Sources’). Similar guidance and hyperlinks to state drainage manuals is given in AASHTO (2010 and 2014) where operational highway drainage practice is linked to wider green infrastructure approaches or Low Impact Development (LID) practice. These manuals were essentially developed to assist state DOTs and their contractors in complying with local, state and/or federal stormwater management regulations. Typically they include design and construction specifications in addition to BMP selection criteria and guidance. An extensive introduction is given on the main NPDES website window to innovative materials, good practice and both structural and non-structural approaches for Best Management Practice (BMP) design, construction, installation, post-construction and strategic planning for highway stormwater quality control and management.

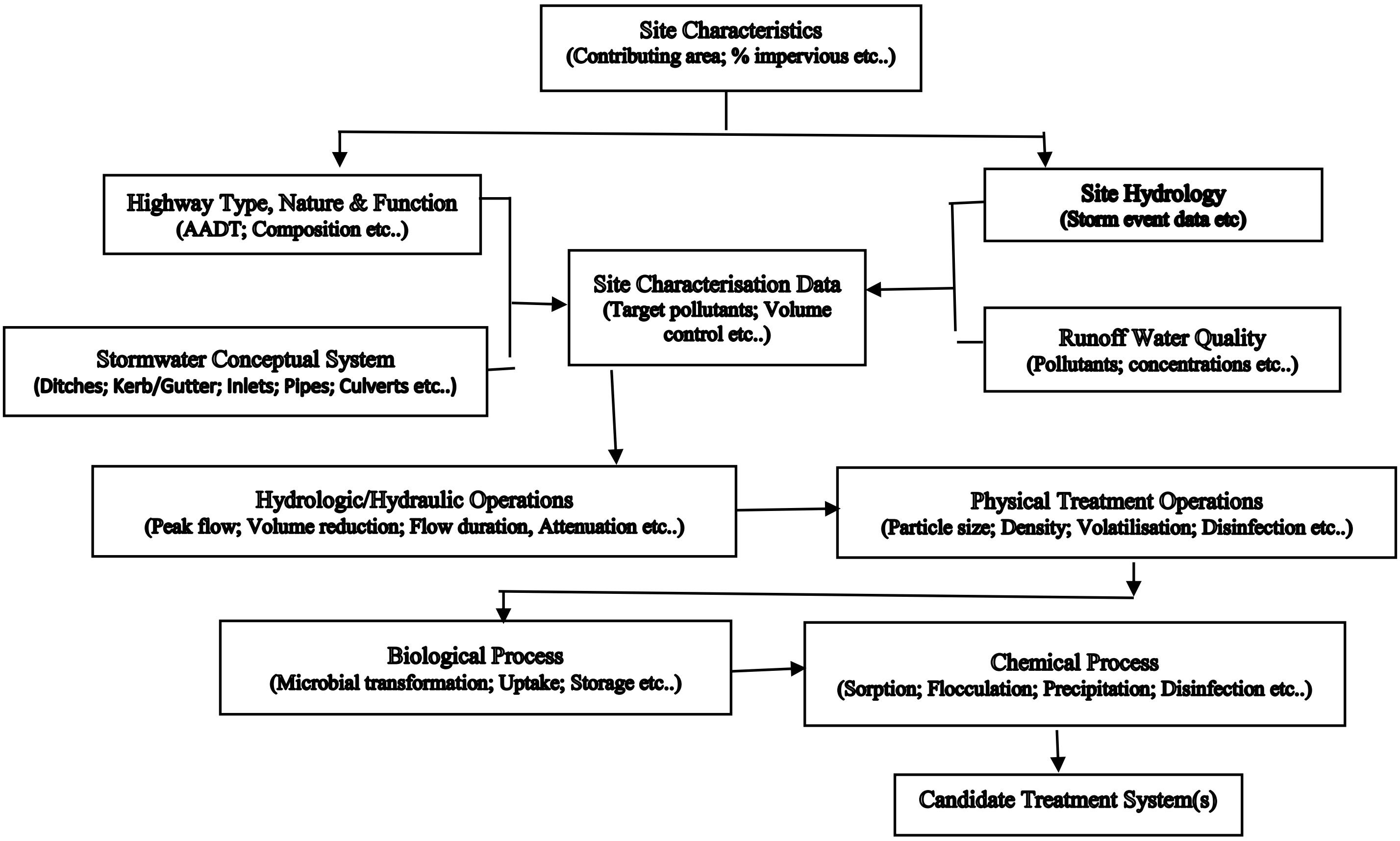
The principal emphasis and focus in the US guidance criteria undoubtedly remains flow control (especially peak flow control) rather than quality control. However, pollution mitigation and ‘blue-green’ drainage infrastructure has become a major issue for all US highway (and urban) authorities following the major legislation contained in the 1972 and more recent revisions of the Clean Water Act (CWA) and the 1990 (Phase I) and 1992 (Phase II) NPDES regulations. Under this legislation, (as well as individual state Stormwater Management Acts), highway authorities and municipalities must employ BMPs to protect and maintain receiving water quality. The CWA legislation requires that stormwater drainage to receiving waterbodies must meet both numeric standards for quantifiable chemical properties and narrative criteria based on biomonitoring. State water quality management plans must also identify priority non-point problem locations together with appropriate mitigating measures. However, as the drainage system has become more sophisticated with regard to managing both the quantity and quality of stormwater runoff, the funding and administrative resources required, as well as jurisdictional overlaps in terms of highway responsibilities, have also grown in a commensurate manner. It is this expanding and increasingly stringent regulatory framework which is leading to a growing concern and stress over the future management of the stormwater infrastructure for state highways in the US. This concern is shared by many highway authorities across the UK, Europe, Canada, Australasia, Japan and elsewhere. There remains a generally perceived risk associated with the adoption of 'softer' blue-green approaches for stormwater drainage management and a particular aversion to be involved in holistic catchment-wide management strategies. The lack of institutional capacity and technical expertise may be significant impediments in this regard.

3.2.2. <u>Selection of BMPs for Highway Drainage in the US</u>

The primary 'blue-green' measures for highway runoff pollution mitigation in the US are vegetative controls mainly because they represent a relatively low-cost and performance effective drainage option (as judged by the national BMP database) and are widely applicable for non-urban highway situations. Grass verges and filter strips and/or grassed bioswales combined with wet detention or wetland cells (often with sediment forebays) represent common hybrid highway BMP control options especially in areas having high groundwater conditions. Infiltration measures are only recommended after sediment pre-treatment and where site-specific conditions (such as soil infiltration rate) can ensure an effective quality control. Such 'special case' consideration for infiltration and soakaway systems is thus somewhat different to highway drainage policy in the UK or Slovenia where such facilities are common first default options for highway runoff control as advocated for example in the UK SUDS Manual (CIRIA, 2015).

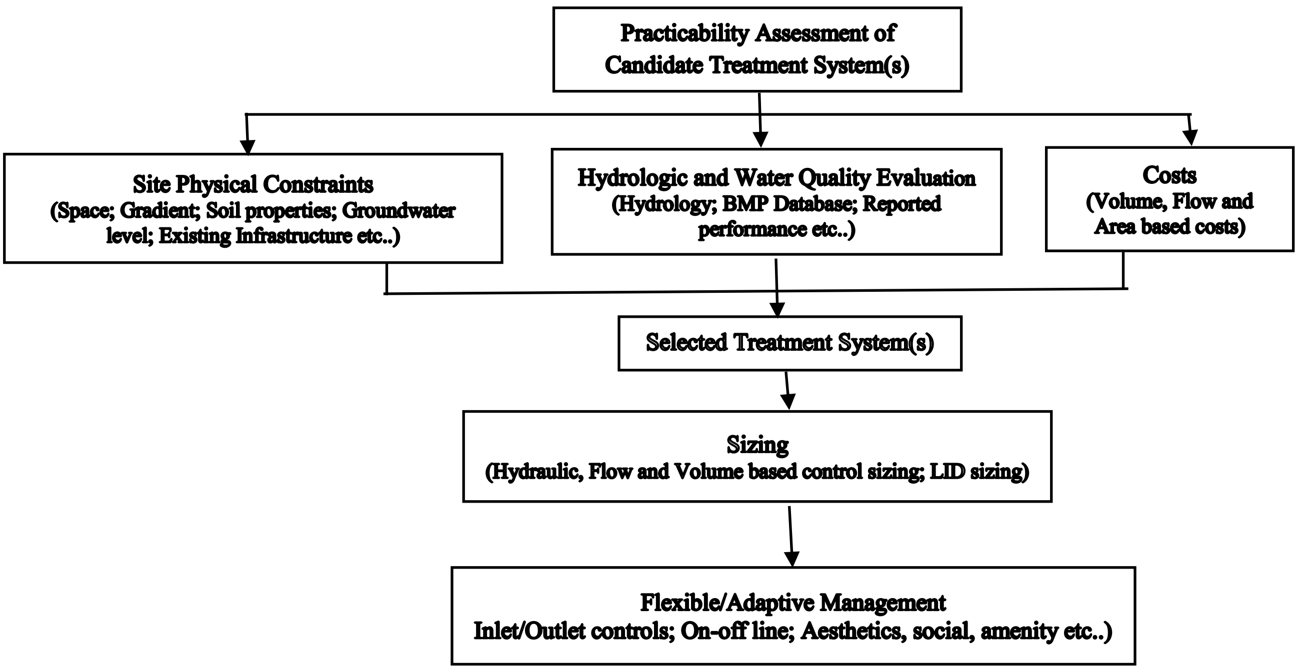
Figure 3.1 illustrates the conceptual design sequence for a typical highway BMP system as set out in the 2006 US National Academy of Sciences, Engineering & Medicine report which is based on a fundamental unit operating process (UOP) methodology. Pollutants of concern are quantitatively ranked on a scale according to their potential reduction by the various UOPs. Once the relevant UOP matching the runoff management objectives (e.g. reductions in flow volume, TSS, metals or hydrocarbons) have been identified, individual drainage BMP controls and other related 'blue-green' functions and facilities can be considered. It is clearly important that the user has a fundamental understanding of the relationship between the BMP design and the UOP in order to select appropriate candidate site controls. The practicability of each potential candidate BMP must then be assessed in terms of site design feasibility, installation and implementation.

Figure 3.2 outlines the structural procedural framework by which such a practicability assessment can be made. The UOP procedure (when linked to the national BMP database) presumes a first choice, if standalone BMPs are only being considered, of a preferred sequential choice led by vegetated control measures, followed by detention/retention storage, infiltration systems and finally wetlands. Most state highway drainage guidance recommends that multiple cell (or treatment train)



(after National Academy of Sciences, Engineering & Medicine, 2006)

Figure 3.1. Conceptual highway runoff treatment system design



(after National Academy of Sciences. Engineering & Medicine, 2006)

Figure 3.2. Practicability assessment for selected BMP treatment system(s)

approaches are also given prime consideration in the design with particular emphasis on the introduction of a front-end sediment catchpit or forebay.

The DOT manuals generally develop a series of BMP selection matrices frequently involving a 3-step filtering procedure to determine the most appropriate BMP or group of BMPs for a particular site location. These descriptive and narrative matrices usually cover initial physical feasibility criteria (e.g. site conditions, contributing area, soils, gradient, depth to water table etc.). Step 2 considers stormwater treatment suitability typically following a UOP decision-making framework based on performance effectiveness (using data obtained from the national BMP database), to ensure that both water quantity and quality control benefits are considered. The final third step would consider other environmental and community criteria including operation and maintenance (O&M), ecology, amenity, community acceptance etc.). The US EPA has developed a generic ArcGIS BMP siting tool to support this drainage infrastructure selection process although it is primarily intended for the management of general stormwater runoff rather than being highway specific (www. epa.gov/water-research/best-management-practices-bmps-siting-tool).

3.2.3. Highway Drainage in the US Southern States

Many of the US southern states are classified as having a humid subtropical climatic regime although there is a considerable diversity particularly between the coastal Gulf states (Texas, Luisiana, Mississippi and Florida) and the inland states (Arkansas, Tennessee and Georgia). This diversity results from a range of weather patterns that affect the region including dominant frontal systems during autumn/winter and convective systems which dominate during spring/summer. In addition, late summer is frequently dominated by extreme tropical cyclonic systems which can result in severe flooding. Since 1980, these southern states have experienced more billion-dollar flood disasters than any other region of the United States and, as a result, frequent non-compliance of receiving waterbody standards. Many of the coastal and river/estuarine valley areas are low lying (often below 2 m above sea level) and with climate change and sea level rise are subject to increased flood risk especially as soil storage capacity has been substantially reduced. The base courses of many coastal highways can also become saturated causing premature failure. Therefore adequate and effective drainage systems are crucial to maintain the integrity of highway drainage infrastructure in the region. In such coastal regions, state DOTs may be forced to fallback on conventional sewers for stormwater runoff management with tight fitting pipework, minimal infiltration allowances and frequent pumping stations. In addition, state DOTs would be required to provide treatment prior to permitted discharge to receiving waterbodies.

State DOT guidance currently relies heavily on ‘over-the-shoulder’ side verge drainage and on exfiltration (French) drains but such systems can become submerged during wet weather conditions. The coastal states have considered the introduction of infiltration ‘galleries’ and gravity injection wells to divert excess highway runoff to local pumping stations for potential treatment and discharge to receiving waterbodies. However, it is estimated that such systems could cost more than $1M per lane-mile with no guarantee that the final discharge would be able to meet NPDES permitting requirements (Bloetscher et al., 2012). The highway BMP selection procedure largely follows the OUP and matrix filter methodology outlined in Section 2 above. When

candidate BMPs have been identified from this methodology the final decision-making step is concerned with the prime functional objectives of the control device(s).
Figure 3.3 illustrates a general template for the decision-making process for this final selection procedure which has been adopted in some form or other by the majority of southern states and which seeks to maximise both flow and quality performance and benefits. State DOT treatment requirements commonly target a minimum 75% reduction in TSS to be achieved in any BMP implementation which normally would involve some form of extended detention storage. Very little use is made of proprietary devices such as swirl concentrators for highway runoff control outside ultra-urban locations.

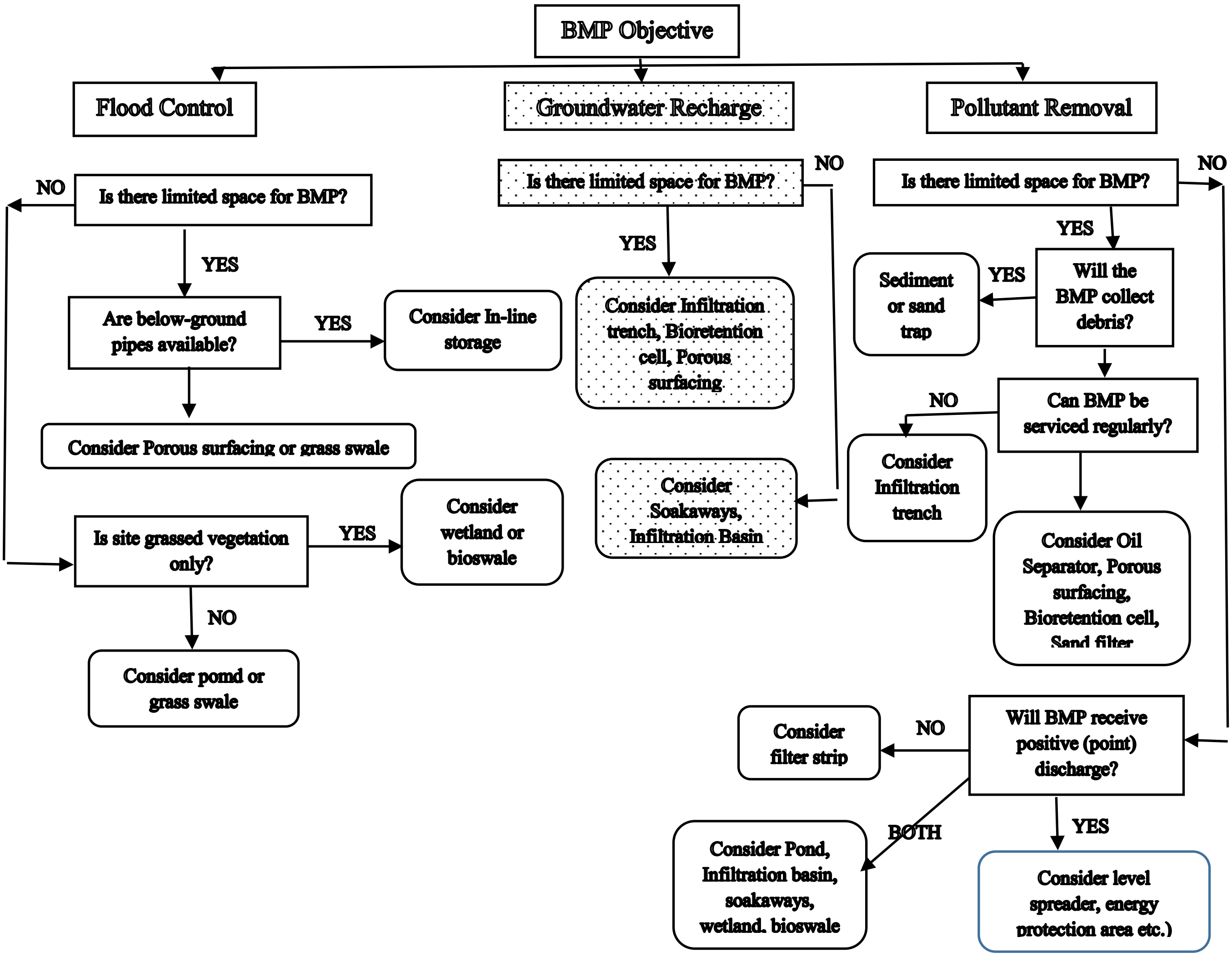


Figure 3.3. Highway BMP selection flow chart

There is a widespread recognition in the southern states that the majority of their non-urban highways are located in areas having substantial adjacent green space. There have been a variety of studies attempting to quantify how much runoff reduction and pollutant abatement might be provided by such spaces (Caltrans, 2018). Utilising such ‘blue-green’ opportunities as functional stormwater controls could clearly have a substantial impact on highway runoff management strategies for transportation authorities. Buffer filter strips and roadside grassed swales have been the most frequently tested and implemented BMP drainage controls, using WinSLAMM to model outcome performance predictions. It should be noted however, that most DOTs regard these two BMPs as representing pre-treatment practices rather than effective standalone BMP drainage controls. The majority of these studies point to infiltration rate as being the key criterion for effective operation of such options.

The majority of DOTs acknowledge that participation in water-smart multi-functional landscaping together with bioengineering approaches and rainwater conservation on site, local and regional scales could yield environmental as well as social and ecological benefits. The LID approach treats stormwater as an on-site resource and would enable DOTs to achieve enhanced ‘greenway’ and ‘parkway’ hubs and corridors. In this respect there is a fundamental need for close integrated working between the highway authorities and the local community planning structures and processes. However, only Florida DOT is anywhere near moving towards a more holistic approach to highway drainage infrastructure possessing well developed documentary BMP guidance and integrated LID advice (see for example Escobia County, 2016). In general this generic Green Infrastructure (GI) approach still remains to be achieved throughout the southern states.

There is however, a growing national awareness that BMPs can be regarded as comprising component elements in a wider Low Impact Development (LID) stormwater management strategy (or design with nature approach) rather than simply being viewed as an end control objective in themselves. Florida DOT (FDOT) is now working more closely with local community districts to form various partnerships (such as with golf and resort complexes to supply irrigation sources) in order to defray operational costs (Stormwater Management Academy, 2015). Local municipalities and the FDOT have collaborated in producing guidance manuals and specifications for implementation of LID infrastructure (Escobia County, 2016), but this nevertheless largely remains a conceptual and contextual exercise for the FDOT as for all other southern state DOTs.

All states continue to undertake highway BMP drainage provision on a site-by-site needs basis. Most state DOTs regard such LID guidance as being essentially (if not exclusively) applicable to urban and ultra-urban development situations. In addition, most DOTs regard highway BMPs as essentially comprising structural forms with little regard for non-structural concepts. It is perhaps significant that nearly all state DOTs retain the term BMP in favour of stormwater runoff control rather than adopting the alternative stormwater control measure (SCM) terminology which has been increasingly favoured for general US urban stormwater management. The latter terminology in the US has become closely associated with LID practice and a general ‘blue-green’ GI approach to urban stormwater drainage infrastructure.

3.3. Highway Drainage in Australia

Australia has been an international leader in the development and introduction of ‘blue-green’ approaches and associated best management practices for highway stormwater runoff as demonstrated in the national Austroads guidance manual published nearly two decades ago (McRobert and Sheridan, 2000). These early guidelines were focussed on embedding highway infrastructure provision within an ecological framework to minimise hydrologic and biodiversity impacts on receiving waters. The focus was regarded as being essential to effectively mitigate erosion and sediment impacts on receiving stream morphology and ecology as well as alleviating flood risk. The potential effects of highway construction and operational drainage on roadside reserve space, adjacent corridors and displacements of local water tables were identified as major issues from an early stage. Such considerations introduced integrated water sensitive urban design (WSUD) approaches as a basis to achieve effective stormwater and ecological resource management. Such best practice guidelines have now become institutionalised within Australian state transportation authority requirements and are now termed as Water Sensitive Road Design (WSRD). The concepts and working principles of WSUD/WSRD in respect of highway drainage were already fleshed out in a preceding study (Wong et al.,1998) and thus were available to underpin the national philosophical approach. These baseline studies introduced matrix-type flow charts to help guide practitioners in the WSRD selection decision-making process. The 'blue-green' WSRD approach was reinforced by the guidance included in follow-on documentation such as that of Wong et al. (2000) and Austroads (2003 and 2013). Figure 3.4 illustrates the filter steps involved in this integrated WSRD process which focus on the assessment of site vulnerability, impacts and mitigation strategies. The upper section of the diagram is concerned with the characteristics and evaluation of site sensitivity whilst the lower section considers how mitigation controls (both structural and non-structural) will be assessed. The user is referred to national/state source regulations and published best practice guidelines for specific detailed BMP design and constructional guidelines.

A flow chart for pollutant control and treatment for both constructional and operational phases as recommended by Austroads (2013) is illustrated in Figure 3.5. Wherever possible, the management design for highway stormwater runoff encourages overland sheet flow from the pavement over the adjacent open verge shoulders rather than any hard roadside kerb, gutter and inlet controls. However, there is still open discussion in most guidance manuals about the relative merits of at-source versus in-transit versus end-of-pipe controls. Irrespective of the final choice made, a treatment train and catchment-wide holistic approach is encouraged. This needs to be incorporated at the initial scoping and design stages if best practice objectives are to be met in a practicable, feasible and cost-effective manner.

Unfortunately this does not appear to be consistently achieved across states. The key element of WSRD is that highway runoff should be regarded as a resource and the focus of control practice should be the protection of the receiving water ecosystem. The performance criteria include a 75% - 80% minimum reduction in TSS and 45% reduction in nutrients with the MUSIC model being commonly used to predict mitigation outcomes. It is clear that the philosophical WSRD approach is firmly based on identifying mitigating measures to protect the surrounding environment and achieve integrated flow and quality control combined with consideration of additional added-value opportunities such as amenity and local water resource use.

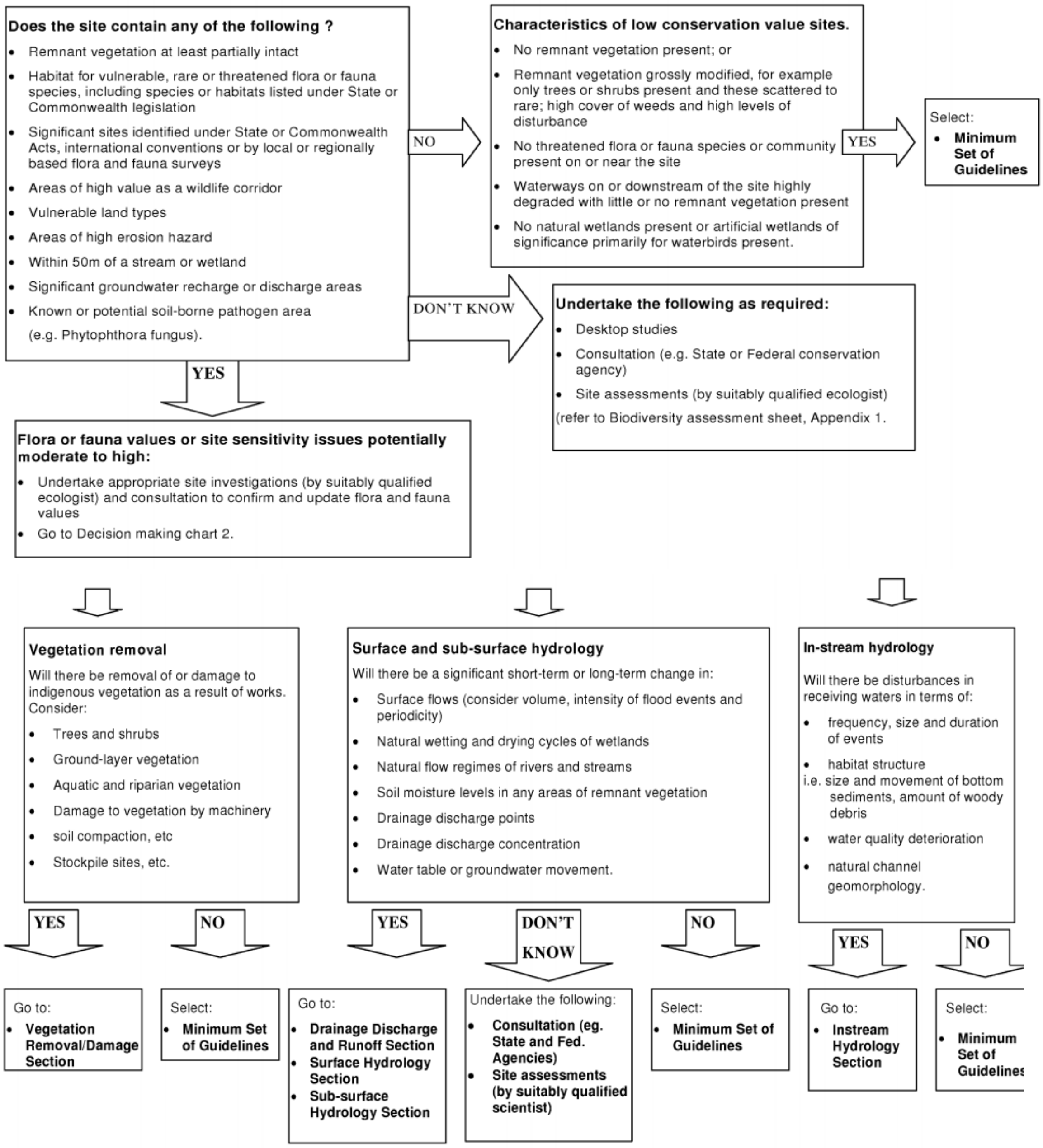


Figure 3.4. Assessment of site sensitivity, impacts and mitigation strategies

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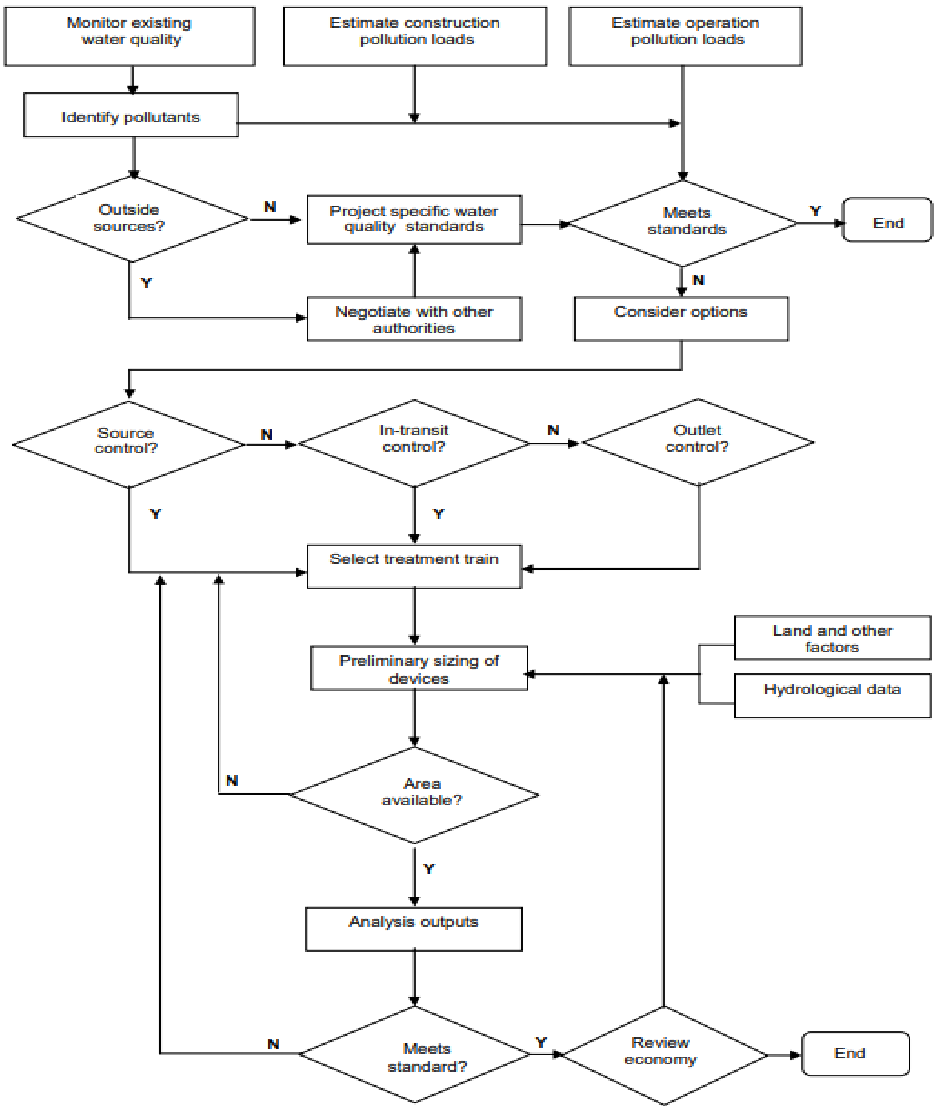

(from Austroads. 2013)

Figure 3.5. Flow chart for highway pollution treatment and control.

Individual state highway drainage manuals cross-reference to the Austroads (2013) guidance with all requiring compliance with the target pollutant threshold levels recommended in the national manual. All state manuals acknowledge the importance of recognising transport processes and pathways in site design which would help to focus design on the basis of UOP conditions; this is especially emphasised where wetland controls are to be considered.

Combined hybrid systems are normally advocated in the state manuals although preference is rarely given to multiple treatment train cells against standalone outlet control approaches. The standard selection criteria are based on consideration of traffic volumes, site gradient, soil and water table, available space, hydraulic head and peak flow volumes, O&M and habitat enhancement. Candidate WSRD controls must then be assessed against these screening factors with guidance as given in the example below (Figure 3.6) taken from the Queensland state transport drainage manual (State of Queensland, 2015). The largely narrative benchmarks set for the

Pollutant control device	Area served (ha)	Slope	Head requirement	Soil type	Capital cost	Maintenance cost	General configuration
Oil grit separators	<1	Note 1	Low	NA	Moderate	Moderate	
Open gross pollutant trap	>2 >40	Note 1	High	NA	High	Moderate High	
Closed gross pollutant traps	<15		Low	NA	High	Moderate	
Trash rack	<20 40	Note 1	Low Moderate	NA	Moderate	Low Moderate	
Downward inclined screen		Note 1	High	NA	Moderate High	Low Moderate	
Extended detention basin (see Chapter 12 for design)	>5	Note 1	Low	All	High	Moderate High	Outlet structures include weirs or outlet pipes Energy dissipater at both basin inlet and outlet to control velocities
Sand filter (depth of)	<2 can be designed larger	Note 1	High	Generally housed in concrete	High	Moderate High	Min filtration depth of 400 mm on recommended filtration time Energy dissipater at inlet
Filter strips	<2	Note 1	Low	All	Moderate	Low	Requires considerable land Length of strip generally >6 m
Buffer zones		Note 1	Low	All	Moderate	Low	
Grassed swales	<2	<5%	Low	Sand to sandy loam	Moderate	Low	Recommended min length of 30 m Bottom width between 0.6 m to 2.5 m recommended
Constructed wetlands		Note 1	Low Moderate	Loam to clay feasible in sand to sandy loam	High	Moderate	
Water quality ponds	>5	Note 1	Low Moderate		High	Moderate	

(after State of Queensland, 2015)

Figure 3.6. Design factors associated with WSRD treatment controls

criteria serve to narrow the available choice of appropriate BMP mitigating measures. Each candidate control device is then evaluated in terms of its potential pollutant performance (as average EMC removal efficiency) in meeting the designated water quality design criteria.

This evaluated removal rate is then finally factored by the proportion of catchment area treatable by the device. State and city councils have all developed their own (but broadly similar) complementary guidance documentation on WSUD which includes detail on the design and selection of individual integrated controls and these local/regional manuals and best practice notes are frequently referred to in the parent state highway drainage WSRD manuals. Victoria state and city highway drainage guidance for example, is firmly based on the national Austroads (2013) best practice manuals but also refers to WSUD principles in terms of the adoption of a contextual integrated approach (Melbourne Water, 2017). The intention here is to support and reinforce the awareness of an integrated holistic 'blue-green' approach to drainage infrastructure and to highlight the overlapping interest and concerns of highway and urban authorities in developing and implementing an integrated strategic approach to the provision of drainage infrastructure.

3.4. Highway Drainage in Sweden

The north to south extension (with over 15% lying within the Arctic Circle) and higher elevation in the north results in considerable regional differences especially in winter when average temperatures in the north are -10˚ to -12˚C compared to -5˚ to 0˚C in the south. Summer temperatures everywhere average between 12˚ and 15˚C. Annual precipitation averages 600 mm with the north experiencing snowfall between 6 to 8 months of the year. Principal concerns for highway authorities have been road damage caused by continuous freeze-thaw cycles, flooding during intense storm events and contaminated sediment, mainly resulting from heavy winter de-icing operations (Kalantan and Folkeson, 2013). Spring meltwater runoff produces up to 3 – 4 times more TSS, metals and hydrocarbons although a much larger proportion of the toxic micro-pollutant components are particulate-bound when compared to rainfall runoff (Marsalek, 2003).

The first rainfall events of the year can flush the accumulated contaminated solids to the receiving water course and additionally contaminate groundwater by slow infiltration as the frozen ground thaws out (Oberts et al., 2000; Rivett et al., 2016). The snow pack can store up to 50% of the total annual runoff and pollutant load with meltwater rapidly transferring this input to the highway drainage system (Kalantan and Folkeson, 2013).

There are concerns regarding the need for increased discharge capacity, installation of check dams on roadside ditches and swales as well as ditch/culvert de-clogging particularly in the context of future climate change and increased (by up to 10%) rainfall runoff. Issues of pressurised below-ice inflows causing bed scouring and reduced storage volumes as well as chloride-laden runoff from salting applications, have also led to suggestions for specific sizing criteria and multiple treatment approaches to enhance BMP performance effectiveness (Viklander and Marsalek, 2003). Given an extensive impermeable base rock coverage and thin soils, only limited opportunity exists for infiltration drainage systems with effective sustainable design and management for best practice highway drainage still presenting a challenge in the cold Nordic climate of Sweden (Westerlund and Viklander, 2008).

Despite these challenges, the concepts of sustainable urban drainage based on 'blue-green' principles have been developed and applied within Sweden since the late 1980s and are globally showcased in the management of stormwater runoff in the southern city of Malmo (Stahre, 2008). The strategic approach is essentially multi-functional, integrating volume and quality control with aesthetics, amenity and community acceptance. The strategy is forward-planning driven with close, if complex and time consuming, collaboration between urban, drainage and planning authorities and involving public participation at all stages. The development of multiple use eco-corridors helps to address the issue of larger drainage capacity through the provision of linear vegetated buffer strips, swales, detention/retention storage and wetlands.

This approach whilst driven by individual municipalities has more recently embraced the national Swedish highway authority who have produced their own complementary highway stormwater best practice design and management guidance (Trafikverket, 2011, 2014; NSRA, 2018). The national Swedish legislation embodied within the Environmental Code contains no explicit regulations regarding stormwater runoff although it is regarded as constituting a type of wastewater and 'water-based operation' and as such subject to treatment prior to discharge. All final discharges must meet threshold Environmental Quality Standards (EQS) regulations as defined by maximum allowable pollutant concentrations. For all non-municipal highways, the Swedish Transport Administration (Trafikverket) is the sole responsible authority for dealing with highway stormwater runoff control design, management and maintenance.

'Open nature' based best practice solutions are recommended as preferred highway drainage options and Appendix 2 outlines the decision making procedure documented by Trafikverket (2011, 2014). The methodology assumes a non-urban (open) highway situation with relatively modest AADT volumes (3000 – 30,000) and is based on a preceding vulnerability analysis and a presumed lack of any receiving water impact following discharge. Where traffic densities exceed the 30,000 AADT threshold, the final design chart C is recommended to be followed. For low vulnerability conditions, infiltration via the adjacent grass verge and/or filter strip is encouraged with overflows to a roadside ditch/culvert (flow chart A). Positive ditch (bench drain) discharges are to be further treated (as given in flow charts B and C) prior to final receiving water discharge. Medium vulnerability sites can take advantage of any infiltration possibilities if the substrate permeability allows (e.g. on glacial tills), otherwise treatment follows that given in flow chart C. High vulnerability locations require a full suite of detention/retention facilities with sediment traps/forebays and/or further infiltration (or vegetated wetland) treatment prior to discharge. Sedimentation ponds account for some 75% of the total 800 pond facilities operated by Trafikeverket (2014).

This approach based on AADT is fairly recent as Sweden has up till now paid relatively little attention to traffic volume as a factor determining whether and what treatment should be required for a specific highway discharge, recommending only that emergency treatment measures (such as oil interceptors), should be in place for management of accidents, spillages etc., involving hazardous substances. Principal highway BMP design criteria appear to be catchment area, peak runoff volume and pond/area/volume rather than AADT. Appendix 2 procedure therefore represents a recent introduction into the regulatory framework for the management of highway discharges and still needs to be fully ratified and implemented nationally. Prior to this new Trafikverket (2014) methodology, water retention and sedimentation were considered to provide sufficient control and treatment to prevent any negative impacts at high vulnerability sites.

3.5. Highway Drainage in Canada

39% of the Canadian landmass lies within the Arctic Circle although only containing 1% of Canada's population. These subarctic northern and central areas experience severe winters (falling at night to -30˚to 35˚C) with 6 – 9 months of snow cover and possessing very brief summer periods; the central prairie provinces have more moderated average winter temperatures of 3˚ - 5˚C. The short summer periods in the southern and eastern areas can average 26˚ - 30˚C. There is a standing Canadian joke that much of Canada experiences eight months of winter followed by four months of road repairs! Total precipitation remains relatively low (< 250 mm per annum) in the northern districts, occurring mainly in late spring/summer increasing to 400 – 500 mm in the central prairies. Both Pacific and Atlantic coastal areas have milder winter periods (averaging -5˚C to 4/5˚C) rising to 18˚ - 20˚C in summer with precipitation reaching 1000 – 1500 mm per annum but being distributed throughout the year with occasional intense summer thunderstorms and tornadoes.

The fundamental basis of highway drainage management in all Canadian provinces is that of flood control and mitigation as typified in the drainage policy regulations and guidelines published by the Ontario Ministry of Transportation (MTO, 2005) which is responsible for nearly 30% (1766 km) of Canadian controlled-access highways. This policy approach is founded on the original drainage system design criteria contained in the MTO 1997 drainage management manual and which is codified in the Ontario PHY Directive B100 (Ministry of Transportation & Communications, 1980). There is however, a recognition that the operation and management of highway corridor drainage needs to be considered within a wider catchment context and therefore requires a close working liaison with local planning authorities (Ministry of Transportation, 2007). There is also an increasing awareness of the need for quality control of highway runoff and the Ontario authorities demand a minimum 70% TSS removal where discharge is to 'sensitive fishery' receiving waterbodies. This threshold may increase to 80% removal for 'highly sensitive' watercourses and even' 'insensitive receiving waters must have a minimum 60% solids removal rate.

Guidelines also require that potential multiple control objectives should also be considered at the design stages (Austroads, 2013) and the implementation of hybrid 'blue-green' bioretention controls are recommended for forebay sedimentation and extended detention facilities to achieve an effective quality control (frequently defined by a 24 hour detention of 40 m^3/ha volume standard). The use of roadside buffer strips, embankments and grass-lined ditches or swales are also widely advocated for initial water quality pre-treatment following sheet flow discharge from the impermeable highway surface (MTO, 2006). Infiltration systems for highway drainage are not recommended as first-line mitigation controls by the large majority of Canadian provinces largely on the basis of potential clogging, groundwater contamination and winter sub-grade degradation.

There are only minor differences in the guidelines adopted across the Canadian provinces with, for example, Alberta specifying a minimum 85% solids (>70 µm) removal rate prior to outfall discharge (Alberta Transportation, 2007). Most provincial guidelines recommend the use of open, level graded roadside cross-channels (or bioswales) carrying a dense vegetation cover. Such buffer/filter strips are viewed as supporting contemporary LID concepts of ecological green corridor development whilst addressing the immediate problem of peak volume and snowpack control associated with cold climate hydrology. Over 5M tonnes of road salts are applied each year on Canadian highways and the meltwater chloride levels from highway runoff are therefore of major concern to all provincial highway authorities. The implementation of roadside grassed buffers as snowpack containment areas together with ditches and (bio)swales are considered by most to represent best management practices for mitigation and control of both meltwater volumes and pollutant reduction (TAC, 2003).

The majority of Canadian provinces are requiring that future highway drainage design should also incorporate the potential effects of an expected 10% – 13% increase in rainfall-runoff consequent upon predicted climate change by the 2050's. It is argued that the initial 5 mm of runoff should be retained for water quality control (based on a 80 – 95% solids capture) as determined by equivalence to the drained paved area for the 1:100 storm event + climate control upraise. A suggested highway LID retrofit guidance to achieve these conditions is indicated in Table 3.1. For open expressways or arterial highways, the table suggests that bioretention and permeable asphalt surfacing as well as prefabricated proprietary systems might be the most effective retrofits. However, there is little evidence that such manufactured devices offer any performance or cost advantage over structural SUDS controls particularly for non-urban highway conditions.

Table 3.1. Evaluation matrix for highway drainage management alternatives.

Practice		Suitability for Arterial Road Reconstruction	Cost Effective?	Streetscaping Benefits?	Water Balance Benefits? (5 mm)	Water Quality Benefits?	Recommended?
Bioretention	Bioretention planter	HIGH	Moderate	Moderate	YES	HIGH	Maybe – highest potential for local drainage in centre of roundabout
	Curb Extension	Moderate	Moderate	Moderate	YES	HIGH	Maybe- depending on ROW and road design
	Boulevard Bioretention	Low	Yes	Moderate	YES	HIGH	No
Swales	Bioswale	Low	Yes	Moderate	YES	HIGH	No
	Enhanced Grass Swale	Low	Yes	Moderate	YES	HIGH	No
	Perforated Pipe	Low	No	No	Moderate (soil restriction)	Moderate (soil restriction)	No
Permeable hard surface		Moderate (sidewalk and pathway only)	No	No	Moderate (soil restriction)	Moderate (soil restriction)	No
Prefabricated Units	Precast Tree Planters	HIGH	Moderate	HIGH	YES	HIGH	YES
	Soil Support System	HIGH	Moderate	HIGH	YES	HIGH	YES
	Oil Grit Separators	HIGH	Moderate	No	No	HIGH	Maybe- with other measures

(after Young and Van Seters, 2009)

There is some evidence that the virtual blanket restrictions on infiltration systems for the drainage and treatment of highway runoff in Canada is being reconsidered in the light of more recent international research and experience (Young and Van Seters, 2009). It is argued that the introduction of underdrains to infiltration trenches/basins (with adjustable flow restrictors), can provide effective flow and quality controls for even fine-textured soils (having up to 20% clay content) with percolation rates less than the current legal threshold of 13 – 15 mm/hour. Such drainage controls are said to enable complete drainage of water between storm events and reduce the potential for freezing in winter. Irrespective of such arguments, much more research and operational site experience is necessary before national or provincial highway authorities are likely to adopt infiltration (or proprietary) systems on any major scale for open non-urban highway situations.

4. Concluding remarks

This Deliverable has confirmed the availability of a large international literature relating to the treatment of drainage waters from roads. Whilst in many countries highway drainage guidance is derived from knowledge of treatment systems designed for general urban runoff, increasing experience in the treatment of highway runoff has led to the development of highway runoff specific treatment guidelines in a number of countries (e.g. see Appendix 1). Highway authorities are highly aware of international receiving waterbody requirements in terms of legislation and standards (e.g. WFD regulations in Europe and NPDES/TMDL regulations in the US) and these provide the principal drivers for highway runoff control. This invariably leads to 'top-down' decision-making with very limited evidence for collaborative 'bottom-up' community-led approaches which are more frequently found with urban runoff drainage infrastructure development. Highway stormwater quality control, in particular, essentially originates from decisions and actions taken by the responsible regional or national transportation and environmental agencies and is therefore strongly institutionalised in terms of organisational and administrative procedures.

Although there is an awareness of the need to pay attention to wider drainage infrastructure interests (particularly in the US, UK, Australia, Switzerland and Germany) there is still little evidence that highway authorities are actively seeking to implement 'blue-green' approaches in contrast to urban stormwater drainage where multi-party, multi-functional collaborative efforts exist to implement catchment green infrastructure initiatives. However, as this Deliverable explains 'blue-green' controls represent only one possible candidate component amongst a range of alternative treatment options for most highway authorities.

The range of treatment systems which have been used for attenuating flow volumes and improving the quality of highway runoff are supported on an international scale by the comprehensive guidelines outlined in Appendix 1 to this Deliverable. However, it is noticeable that in many countries, the emphasis is on engineering criteria and standards with regard to the factors which influence highway drainage and runoff treatment. For example, in the UK the 'Design Manual for Roads and Bridges (DMRB)' has become established as the guidance document which ensures the adoption of engineering consistency and compliance standards for effective highway drainage. Although this is important there are concerns that such an approach may not guarantee truly sustainable drainage and water management as implied by many of the allocated treatment system descriptions e.g. Sustainable Drainage Systems (SuDS), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Low Impact Development (LID), Green Infrastructure (GI) and 'Blue-Green' Treatment Solutions. Treatment systems should not only resolve site drainage requirements but also contribute towards improving the surrounding environment, the receiving waterbody biodiversity and community amenities although the latter criteria rarely applies to highway situations. It is essential that transportation agencies give serious consideration to landscape planning and ecological status issues in addition to the basic requirements for flood and water quality control.

There is some evidence of a tendency towards the increased use of both on- and near-highway mitigation controls such as the application of porous highway surfacing and open asphalt concrete (whisper concrete) as a front-line preventative control for the management of both volume and water quality. For example, the Netherlands, Australia and some US states have accepted the higher costs associated with the more frequent replacement of such systems against the ability of such approaches, when combined with adjacent filter strips and/or open grassed swales, to provide effective and sufficient drainage protection on non-urban highways for the large majority of storm events (i.e. ≥ 1:100 RI) without the need for any further controls.

The prime objective identified in most international guidance is for highway stormwater control facilities to address maximum allowable flow rates through appropriate detention/attenuation practices as opposed to pollutant removal procedures. An effective solution for water quality management adopted by many global highway authorities is based on peak flow control with final outfall discharge rates of between 2 and 5 l/s/ha being considered appropriate. This may be a reasonable assumption but it is supported by only a limited evidence-base. However, the benefits of multiple treatment are widely accepted particularly where it is important to address the water quality problems associated with highly polluted areas such as heavily trafficked highways. In these circumstances local/national guidance typically recommends additional storage and treatment capacity with the intention being to capture the “first-flush” and achieve peak flow reduction through the detention and attenuation of an appropriate initial discharge volume.

Transportation agencies world-wide represent essentially semi-autonomous administrative organisations and are principally motivated by legislation and regulation which are frequently regarded as being the main driving criteria in terms of engineering design. The step-up to full multi-functional, multi-party involvement will not be easy to achieve as such agencies have little tradition and limited working experience of multi-party collaboration particularly where it involves public participation. However, this is important if sustainable management of the volume and quality of highway drainage is to be achieved in conjunction with the implementation of appropriate landscape and receiving water ecological requirements.

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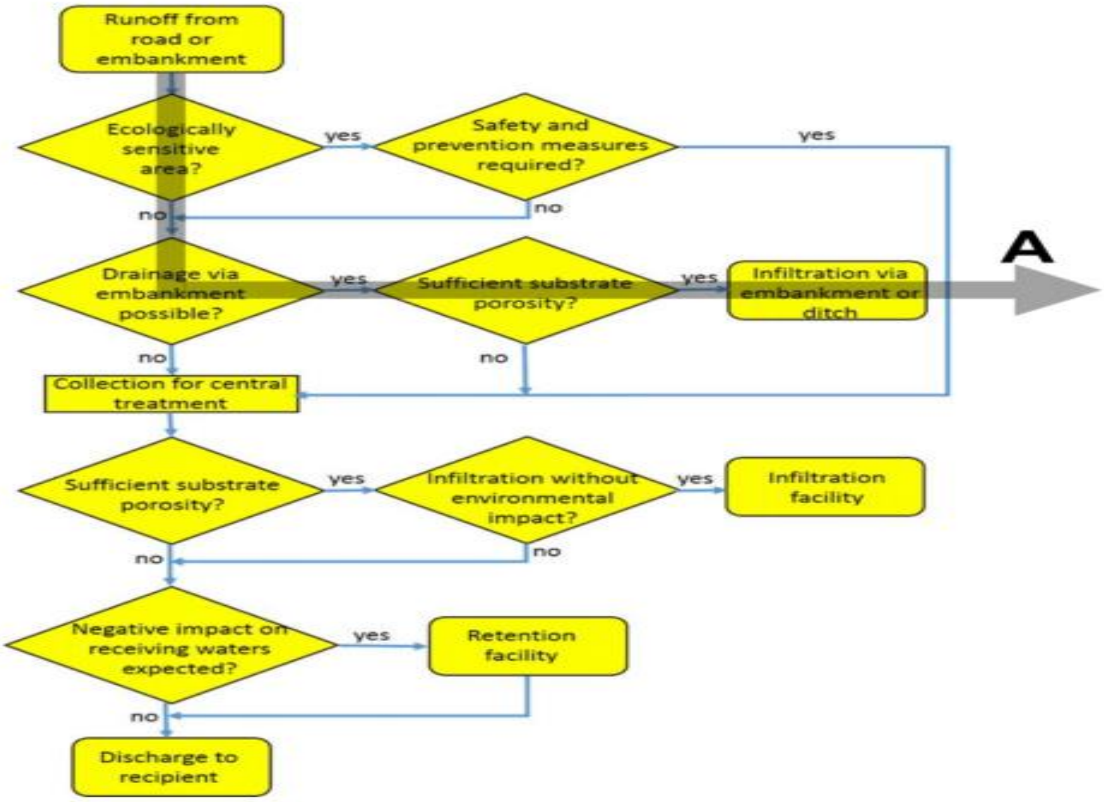
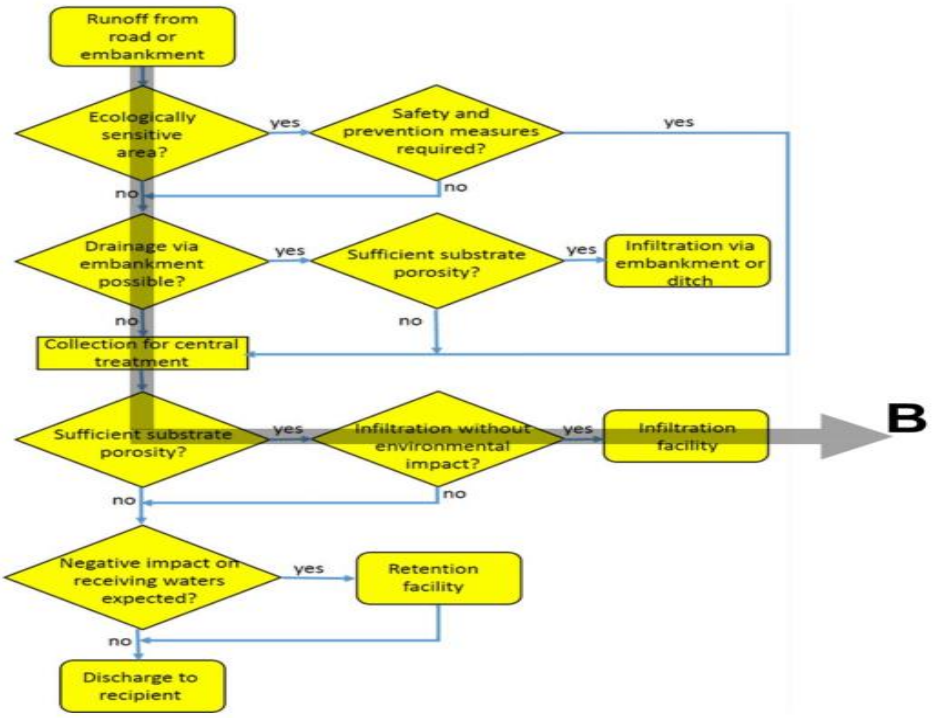
Appendix 2: Swedish Decision Tree Flow Chart for Highway Stormwater Treatment

A. AADT 3000 – 30,000. Low vulnerability and no negative receiving water impact



B. AADT 3000 – 30,000. Medium vulnerability with infiltration opportunities but no negative receiving water impact.



C. AADT 3000 – 30,000. High vulnerability but negative receiving water impacts