European Commission

Natural Water Retention Measures

NWRM

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Individual NWRM

Permeable paving

ACTeon environment research & consultancy

Office International de l'Eau

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Environment

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I. NWRM Description

Permeable paving is designed to allow rainwater to infiltrate through the surface, either into underlying layers (soils and aquifers), or be stored below ground and released at a controlled rate to surface water. Permeable paving is used as a general term, but two types can be distinguished:

- Porous pavements, where water is infiltrated across the entire surface (e.g. reinforced grass or gravel, or porous concrete and cobblestones)
- Permeable pavements, where materials such as bricks are laid to provide void space through to the sub-base, by use of expanded or porous seals (rather than mortar or other fine particles).

It is most commonly used on roads and car parks, but the measure can also apply to broader use of permeable areas to promote greater infiltration. It can be used in most ground conditions and can be sited on waste, uncontrolled or non-engineered fill, providing the degree of compaction of the foundation material is high enough to prevent significant differential settlement. A liner may be required where infiltration is not appropriate, or where soil integrity would be compromised.

CIRIA (2007) and the "Centre des recherches routières" (Road Research Centre) of Brussels (2008) describes three different types of porous/permeable pavements:

A. All rainfall passes through sub-structure and in to soils beneath, with (normally) no surface discharge (i.e. fully infiltrating);
B. Perforated pipes lie between the sub-base and underlying sub-soil, to convey rainfall that exceeds the capacity of the sub-soil to a receiving drainage system (i.e. partially infiltrating);
C. Perforated pipes lie beneath the sub-base, over an impermeable membrane, so all rainfall, after filtering through the sub-base, is conveyed to the receiving drainage system (i.e. no infiltration).

All types provide attenuation of rainfall, and potentially can also store runoff from surrounding areas, if designed and sized appropriately. Types A and B provide infiltration to underlying groundwater, thereby contributing to increased groundwater levels and/or flows, and hence potentially to baseflow. Type C does not interact with groundwater, but stores rainfall (and potentially runoff) and releases it at a controlled rate, hence still contributes to regulating the rate of rainfall-runoff.

II. Illustration

Example of permeable paving in Stamford, UK (photo courtesy of Susdrain)

III. Geographic Applicability

Land Use	Applicability	Evidence
Artificial Surfaces	Yes	Permeable paving is potentially applicable to all artificial surfaces, providing it is suitably engineered for the use it will encounter (e.g. road traffic).
Agricultural Areas	No	Not directly applicable to agricultural land itself, but can be applied to artificial surfaces within agricultural areas, e.g. farmyards.
Forests and Semi-Natural Areas	No	
Wetlands	No	

Region	Applicability	Evidence
Western Europe	Yes	
Mediterranean	Yes	
Baltic Sea	Yes	
Eastern Europe and Danube	Yes	

IV. Scale

	0-0.1km²	0.1-1.0km²	1-10km²	10-100km²	100-1000km²	>1000km²
Upstream Drainage Area/Catchment Area	✓					
Evidence	Permeable paving generally takes runoff only from the permeable area itself. Although they can be designed to accommodate runoff from the surrounding area (CIRIA, 2007), this would only be from a small catchment area.					

V. Biophysical Impacts

Biophysical Impacts		Rating	Evidence
Slowing & Storing Runoff	Store Runoff	Medium	Permeable paving stores rainfall-runoff in the sub-base and either releases it at a controlled rate, or infiltrates to groundwater. Blanc et al (2012) carried out a literature review of the effectiveness of permeable paving for runoff reduction, and found variable results in different situations. Values for runoff reduction varied between 10%-100%, while peak flow reductions of between 12-90% were reported. Effectiveness can decrease significantly over time without sediment management Blanc et al (2012) cite Ilgen (2007), who found new permeable paving to reduce runoff by 98%, while clogged systems achieved only 29-48% reduction. This does not necessarily preclude adequate long-term performance, as long as systems are designed with the expectation of a reduction in effectiveness over time.
	Slow Runoff	Medium	
	Store River Water	None	
	Slow River Water	None	
Reducing Runoff	Increase Evapotranspiration	None	
	Increase Infiltration and/or groundwater recharge	None-Medium	Permeable paving can be designed to allow infiltration, unless local conditions do not allow it (for example where groundwater levels are high or there is soil or aquifer contamination. However where water quality or ground conditions mean that infiltration is not suitable, the base can be lined.
	Increase soil water retention	None	
Reducing Pollution	Reduce pollutant sources	Low	The type of sub-base may be either aggregate or geocellular blocks. Surfaces with aggregate sub-bases can provide good water quality treatment. The treatment processes that occur within the surface structure, the subsurface matrix (including soil layers where infiltration is allowed) and the geotextile layers include: filtration; adsorption; biodegradation; and sedimentation. These can be effective in removing suspended solids and heavy metals, which may be present on paved surfaces. Geocellular block systems provide a higher storage capacity (with >90 per cent voids ratio): although the benefits of treatment within the sub-base aggregate will be lost, they will still allow some settlement of suspended solids (CIRIA, 2007).
	Intercept pollution pathways	Low-medium	

			CIRIA (2009) concluded that "permeable pavements have been researched quite widely…There are differences in performance… but unless there is a large spillage of oil the performance is good for virtually all forms of pollution removal. A high level geotextile is particularly important in terms of hydrocarbon interception and treatment". DTI (2006) presented US data on the effectiveness of porous pavement for suspended solids removal, reported at 82-95%. However this is high compared to the findings of SNIFFER (2004) of 32%. Similarly to hydrological effectiveness, the water quality effectiveness may reduce over time. Where infiltration to groundwater can occur, the potential for pollution to groundwater needs to be considered. However CIRIA (2009) concluded that "the potential for contamination of groundwater from SuDS schemes appears to be low, except from industrial areas. The potential for serious pollution is associated with accidents rather than the continuous background pollution from these areas". This conclusion drew on recent work by SNIFFER (2008) that found "the vast majority of heavy metals, PAHs and petroleum hydrocarbons are retained in the top 10 cm of soil" based on bare-soil lysimeter tests, and noted that the addition of a vegetative layer would allow further uptake of pollutants. However it is clearly important to consider the risks of pollution to groundwater on a site-specific basis in light of the wider water management and activities occurring within the drainage area of the measure. In order to avoid contributing to pollution, it is important that all components of the permeable paving, such as the underlay and sub-base, must be composed of inert materials.
Soil Conservation	Reduce erosion and/or sediment delivery	None	
	Improve soils	None	
Creating Habitat	Create aquatic habitat	None	
	Create riparian habitat	None	
	Create terrestrial habitat	None	

Climate Alteration	Enhance precipitation	None	
	Reduce peak temperature	None	
	Absorb and/or retain CO2	None	

VI. Ecosystem Services Benefits

Ecosystem Services		Rating	Evidence
Provisioning	Water Storage	Low to medium	Permeable paving provides some storage and slowing of runoff from small drainage areas and in some cases route this, via infiltration, to soil and groundwater storage. Through this impact, they enhance the potential of the landscape to store water during floods and, through preventing rapid runoff, make this water available for other purposes (e.g. recharge to groundwater, offering soil moisture to support terrestrial ecology).
	Fish stocks and recruiting	None	
	Natural biomass production	None	
Regulatory and Matinenance	Biodiversity preservation	None	
	Climate change adaptation and mitigation	Low	By helping to limit urban runoff and flooding, permeable paving provides a contribution to adaptation to the higher intensity storm events expected due to climate change.
	Groundwater / aquifer recharge	None-Medium	Permeable paving can be designed to allow infiltration to underlying soils/groundwater, thereby providing a contribution to enhanced recharge.
	Flood risk reduction	Medium	Permeable paving contributes to reducing the rate of surface runoff, particularly from artificial surfaces (urban areas). Used in conjunction with other SuDS features, it can reduce the risk of surface runoff flooding and contribute to the reduction in peak river flows in small catchments.
	Erosion / sediment control	Low	By limiting runoff from impermeable surfaces, permeable paving thus reduces downstream overland and stream flow and hence can contribute to reducing soil and sediment erosion.
	Filtration of pollutants	Low	Permeable paving can capture sediment and reduce concentrations of associated pollutants in runoff. Where

			infiltration is allowed, there is some risk of the introduction of pollutants to groundwater, but in general, CIRIA (2009) concludes that this risk is low.
Cultural	Recreational opportunities	None	
	Aesthetic / cultural value	None	
Abiotic	Navigation	None	
	Geological resources	None	
	Energy production	None	

VII. Policy Objectives

Policy Objective		Rating	Evidence
Water Framework Directive			
Achieve Good Surface Water Status	Improving status of biology quality elements	None	
	Improving status of physico-chemical quality elements	Low	Through contributing to reduction in diffuse pollution through interception of surface runoff and capture/filtration of pollutants, permeable paving can make a small contribution to improving water quality in receiving waters.
	Improving status of hydromorphology quality elements	None	
	Improving chemical status and priority substances	Low	Through contributing to reduction in diffuse pollution through interception of surface runoff and capture/filtration of pollutants, permeable paving can make a small contribution to improving water quality in receiving waters.
Achieve Good GW	Improved quantitative status	None-Low	Permeable paving can be designed to allow infiltration. As such, it can provide a minor contribution to enhancing recharge to groundwater.

	Improved chemical status	None	
Prevent Deterioration	Prevent surface water status deterioration	Low	By intercepting a potential diffuse pollution vector from the contributing catchment, permeable paving can help to protect the receiving water body from deterioration as a result of new diffuse pollution sources.
	Prevent groundwater status deterioration	None	Although permeable paving can be designed to allow infiltration, the spatial extent will be limited and the potential to influence groundwater status is likely to be negligible.
Floods Directive			
Take adequate and co-ordinated measures to reduce flood risks		High	Permeable paving can be an effective source control component of a SuDS 'train', thereby contributing significantly to sustainable runoff management, particularly in urban areas.
Habitats and Birds Directives			
Protection of Important Habitats		None	
2020 Biodiversity Strategy			
Better protection for ecosystems and more use of Green Infrastructure		Low	As an effective component in sustainable urban water management, permeable paving provides a contribution towards improved green infrastructure and protection of ecosystems. However in isolation the contribution is limited, particularly because the permeable paving itself does not contribute any new habitat.
More sustainable agriculture and forestry		None	
Better management of fish stocks		None	
Prevention of biodiversity loss		None	

VIII. Design Guidance

Design Parameters	Evidence
Dimensions	The drainage area of a pervious pavement is generally the area of the pavement itself, as it captures the rain which falls directly onto it. This can correspond to any size of, e.g., car park or road. Permeable paving can also be used to collect drainage from the surrounding area, but this should be limited by the maximum sub-base volume it can hold (CIRIA, 2007). CIRIA (2007) provides guidance on appropriately sizing permeable paving.
Space required	No additional space is required to implement a pervious pavement, as the structure is simply built as an alternative to an impermeable surface.
Location	Since urban development sites are predominantly hardstanding, there are ample locations where impermeable paving may be replaced by pervious paving. They are commonly used in car parks and relatively lightly trafficked roads (since fewer or no heavy vehicles pose lower clogging and structural risks), but have also been used in locations with heavy axle loads.
Site and slope stability	There are no specific constraints, being possible wherever a hardstanding surface would otherwise be used. They require only a small head difference from the runoff surface to their outflow and so can be employed on very flat terrain (CIRIA, 2007). Permeable paving may have a lined or unlined sub-base, depending on the suitability of the land it is constructed on. Where infiltration below the permeable paving could cause slope and foundation instability, a lined sub-base should be used to control drainage towards a suitable outflow from the pavement. The use of unlined permeable paving should only be used on embankments, cuttings and close to foundations if a geotechnical survey by a qualified engineering geologist has taken place. On steeper slopes, internal dams may also be used in the sub-base to control drainage flow and maximise the sub-base storage. However, to be very efficient, the slope should not exceed 2.5% (Technical sheet, Grand Lyon) or even 1% (Road Research Centre of Brussels, 2008) to avoid surface runoff.
Soils and groundwater	The main considerations are sub-surface permeability, groundwater level and contamination of soils or aquifers. Where the soil or geology has low permeability, groundwater levels are high (e.g. less than 1m below the ground surface), or underlying substrate is contaminated, infiltration is generally not recommended. The effects of water storage on the structural capacity of the underlying soils must also be assessed carefully and slopes and collection systems used to manage the risks associated with ponding water. Any permeable pavement will need to be able to capture the required design storm event and discharge it in a controlled manner to the sub-grade or drainage system, while providing sufficient structural resistance to withstand loadings imposed by vehicles above.
Pre-treatment requirements	Permeable paving generally provides the first stage of runoff management, capturing runoff directly from impermeable or low permeability areas. As such, no pre-treatment is required.

Maintenance requirements	Regular inspection and maintenance is important for the effective operation of permeable pavements. They should be inspected regularly, preferably during and after heavy rainfall to check effective operation and to identify any areas of ponding: • Monitoring of pavement for weed growth and sediment build up • Monitoring of pavement slabs and sub-base lining for damages • Cleaning of the system once a year to prevent clogging: brushing and vacuuming (particularly in autumn and during/after winter) or use of using pressurised water hoses. This maintenance is essential to preserve the porosity of the material. • Stabilising and mowing of adjacent areas • Clearing of silt build up in sub-layer to maintain infiltration capacity • Repairing of broken pavement slabs and sub-base lining When removing snow from porous surfaces, consideration should be given to use of appropriate salt to prevent downstream pollution.
Synergies with Other Measures	Permeable paving is most effective if applied at the start of a SuDS 'train', for example, feeding in to a detention or infiltration basin.

IX. Cost

Cost Category	Cost Range	Evidence
Land Acquisition		No additional land acquisition is required to implement this measure, as the pervious pavement simply replaces an impervious hardstanding area. There is no opportunity cost for not using that land for development, as it already would have been identified as an open area such as for road or parking.
Investigations & Studies	€0-€5k	Where infiltrating or partially-infiltrating permeable paving is used, geotechnical investigations should be undertaken to confirm underlying soil/geology conditions prior to construction. These may need to be intrusive and require analysis of land contamination to determine the suitability of infiltration techniques.
Capital Costs	€40-€90 / m^2 permeable paving area	There is considerable variation in the capital cost of permeable paving, reflecting the range of design approaches and construction materials available. The typical cost range is between €40 and €90 per square metre of permeable paving area, indicated by: • CIRIA (2007) - €40-€50 per m^2 • Atkins (2010) - €90 per m^2 • www.uksuds.org - €80 per m^2 • Environment Agency (2007) - €70 per m^2 Use of recycled materials may significantly reduce costs of permeable paving, as indicated by Environment Agency (2012)

		which provides a cost for plastic recycled paving grids of lee than €25 per m^2. When considering the capital costs of construction alone, permeable paving is generally 10-15% more expensive than standard paving. However, that does not take account of the rainwater management benefits, as described throughout this factsheet, that are provided by permeable paving.
Maintenance Costs	€1-€5 / m^2 per year	Environment Agency (2007) concluded that "permeable paving costs less on a lifecycle basis than traditional surfaces, with reduced maintenance costs outweighing increased capital costs. While extra excavations are required to lay permeable paving, replacing worn out paving blocks is less costly than the digging required to renew worn-out tarmac". As with capital costs, maintenance cost estimates vary widely. The typical cost range is between €1 and €5 per square metre of permeable paving, with CIRIA (2007) and Environment Agency (2007) indicating costs towards the lower end of this range and www.uksuds.org indicating maintenance costs between €3 and €5 per m^2.
Additional Costs		

X. Governance and Implementation

Requirement	Evidence
Stakeholder involvement	The effective planning, design, construction and operation of urban NWRM requires the involvement of a wide range of stakeholders. This may include local planning authorities, environmental regulators, sewerage undertakers, highways authorities, private landowners and land managers, and other bodies with responsibilities for drainage and water management (e.g. irrigation bodies, drainage boards, etc). Effective planning is essential to delivering urban NWRM, since they must be delivered within the constraints of the urban environment. This requires alignment between stakeholders from planning authorities through to developers and land owners. Although this may be a minor consideration for permeable paving at the individual property level, where applied at a larger scale and as an integral part of a SuDS scheme, stakeholder consultation will continue to be important.
Ensuring clear responsibility for maintenance	Ensuring clear responsibility for maintenance and restoration of the permeable paving following construction, (which could otherwise fall between highways authorities, developers and private landowners). The adoption of SuDS has historically been a major issue in ensuring their long-term effectiveness.

Ensuring that appropriate design standards and effective designs are implemented appropriately at each location	The preparation of planning guidance and/or SuDS guidance documents that set out planning and design criteria, as well as local technical information (e.g. on soil types and underlying geology) can assist in this.

XI. Incentives supporting the financing of the NWRM

Type	Evidence
National and local legislative and regulatory requirements	Some countries and territories encourage and/or require the use of Sustainable Drainage systems in new development. For example: - In England households are required to gain planning permission for impermeable surfaces in front gardens, whereas permeable paving can be installed without planning permission. - In Dresden, Germany, Prokop et al (2011) report that the use of permeable surfaces for new parking areas is compulsory National and local instruments are the most widely effective for SuDS due to their wide-scale application at the household or very local level. The possibility of local incentives should always be explored (since they cannot be covered here comprehensively).
National and local charging incentives	The uptake of SuDS may be achieved by tax or water charging incentives. For example, in England households can receive a reduction on their water bills if their surface water drainage does not discharge to the sewerage network, which may be achieved partly through use of permeable paving.

XII. References

Reference	Comments
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DTI (2006) Sustainable drainage systems: a mission to the USA.	

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Environment Agency (2012) Rural Sustainable Drainage Systems (RSuDS)	
Ilgen M, Harting K, Schmitt T.G. and Welker, A (2007). Runoff and infiltration characteristics of permeable pavements- Review of an intensive monitoring program. NOVATECH Conference 2007: Integrated approaches of urban planning, urban design and stormwater management. Lyon, France, Jun 25-28, 2007.	
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Pratt, C, Wilson, S and Cooper, P (2001) Source control using constructed pervious surfaces- Hydraulic, structural and water quality performance issues. CIRIA C582.	
SNIFFER (2004) SUDS in Scotland- The Monitoring Programme of the Scottish Universities SUDS Monitoring Group. SR(02)51. Final Report.	
SNIFFER (2008) Source Control of Pollution in Sustainable Drainage (UEUW01)	
www.uksuds.org – SuDS Construction and Maintenance Costs Calculator	This site has been developed by HR Wallingford to provide tools for site drainage design and evaluation, aimed at developers and SuDS Approval Bodies in the UK and Ireland. The site is updated with current thinking on SuDS and the requirements of UK and Ireland SuDS standards. The site includes a cost calculator to provide indicative costs of SuDS scheme components for construction and maintenance – the generic unit cost factors have been used when this website is referenced.
Woods-Ballard, B, Kellagher, R, Martin, P, Jefferies, C, Bray, R and Shaffer, P (CIRIA) (2007) The SuDS Manual, CIRIA C697.	
Communauté Urbaine du Grand Lyon (2008), Revêtements de surface poreux	Grand Lyon Urban Community (2008) Information sheet on porous pavement surfaces
Centre de recherches routières de Bruxelles (2008) Revêtements drainants en pavés de béton	Road Research Centre of Brussels (2008) Technical information sheet on pervious pavement