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Natural Water Retention Measures

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Individual NWRM

Swales

Environment

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I. NWRM Description

Swales are broad, shallow, linear vegetated channels which can store or convey surface water (reducing runoff rates and volumes) and remove pollutants. They can be used as conveyance features to pass the runoff to the next stage of the SuDS treatment train and can be designed to promote infiltration where soil and groundwater conditions allow. Three kinds of swale give different surface water management capabilities:

- Standard conveyance swale – Generally used to convey runoff from the drainage catchment to another stage of a SuDS train. They may be lined or un-lined, depending on the suitability for infiltration.
- Enhanced dry swale – Includes an underdrain filter bed of soil beneath the vegetated conveyance channel to accommodate extra treatment and conveyance capacity above that of the standard swale. The underdrain leaves the main channel dry except for larger runoff events, and will prevent channels becoming waterlogged where the swale is situated on gentler slopes. A lining can also be incorporated into the underdrain if infiltration to underlying ground is not appropriate.
- Wet swale - Where prolonged treatment processes are required for the storm runoff, the swale's conveyance channel can be encouraged to maintain marshy conditions by using liners to control infiltration, or by siting in an area with high water table.

The promotion of settling is enhanced by the use of dense vegetation, usually grass, which promotes low flow velocities to trap particulate pollutants. In addition, check dams or berms can be installed across the swale channel to promote settling and infiltration. As a result, swales are effective in improving water quality of runoff, by removing sediment and particulate pollutants. In wet swales, the effectiveness is further enhanced by providing permanent wetland conditions on the base of the swale.

Swales are applicable to a wide range of situations. They are typically located next to roads, where they replace conventional gullies and drainage pipe systems, but examples can also be seen of swales being located in landscaped areas, adjacent to car parks, alongside fields, and in other open spaces. They are ideal for use as drainage systems on industrial sites because any pollution that occurs is visible and can be dealt with before it causes damage to the receiving watercourse.

The introduction of vegetation to what would otherwise generally be a hard surface such as a drain provides a biodiversity and amenity benefit. The vegetation that can be incorporated into swales is relatively diverse depending on the design. However, vegetation should be tolerant of pollution and changes in moisture level, and provide a dense sward to trap sediments. Native vegetation should be used, and wild grasses and flowers can be added to improve site aesthetics and amenity value.

II. Illustration

Swale (courtesy of Andras Kis)

III. Geographic Applicability

Land Use	Applicability	Evidence
Artificial Surfaces	Yes	Swales are potentially applicable to all artificial surfaces, particularly since the swale type can be adapted to be suitable to the local conditions (e.g. water table depth and suitability for infiltration).
Agricultural Areas	Possible	Swales are most effective when receiving runoff from impermeable or low permeability surfaces, which is most effective in the context of artificial surfaces (including artificial surfaces in agricultural, forest and semi-natural areas), but can also be appropriate where there is runoff from low-permeability surfaces in other areas (e.g. compacted soils, farm tracks, etc), and can be used to manage runoff from fields (Environment Agency, 2012).
Forests and Semi-Natural Areas	Possible	
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	Swales should generally be used as the first stage of a SuDS 'train', accepting diffuse runoff from adjacent impermeable/ low permeability areas. They are more effective when accepting runoff in this way rather than a point inflow. As a result, the contributing catchment area tends to be relatively small, for example a car park, road surface or small field.					

V. Biophysical Impacts

Biophysical Impacts		Rating	Evidence
Slowing & Storing Runoff	Store Runoff	Medium	Swales are intended to slow and store runoff (Certu, 2008). CIRIA (2007) states that the capacity of a swale should be designed to attenuate and treat a rain event with a 10 – 30 year return period, although there is potential for runoff rate control up to a 1 in 100 year event (Blanc et al, 2012). Blanc et al (2012) carried out a literature review of the hydrological effectiveness of swales. They found that while the literature almost invariably reports some level of effectiveness, the efficiency of swales is highly dependent on good design and catchment/local landscaping characteristics. The literature they reviewed showed significant variations in the runoff reduction achieved from swales, but in general more than 50% reduction in mean runoff. In terms of reduction in peak runoff rates, SNIFFER (2004) found reductions of peak flow of 52% and 65% in two swales in Scotland.
	Slow Runoff	High	
	Store River Water	None	
	Slow River Water	None	
Reducing Runoff	Increase Evapotranspiration	Low to medium	The rate of evapotranspiration will depend on the swale dimensions, residence time and type of vegetation (being higher with dense vegetation and relatively low velocities). Evapotranspiration in swales is more efficient than predicted by agricultural engineering. Hess (2014) carried out experiments that showed vegetation can

			evapotranspire more than needed if there is an excess of water, by up to 30mm per day.
	Increase Infiltration and/or groundwater recharge	Medium	Swales are often 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). Infiltration potential is likely to be enhanced for 'dry swales' compared to other types of swale, due to the increased permeability of the sub-surface medium, and increased retention time compared to a standard conveyance swale. Infiltration increases where the residence time is higher, soil permeability is high and the infiltration surface is large. However where water quality or ground conditions mean that infiltration is not suitable, the base can be lined. Le Coustumer (2008) found that soil permeability is likely to be halved by clogging over a period of two years (depending on maximum water levels and the quantity of sediment). This can be allowed for in design. Some plants may reduce clogging (Le Coustumer, 2008; Citeau, 2006)
	Increase soil water retention	None to low	Introduction of vegetation may over time increase the organic matter content and associated ability of the soil to retain water.
Reducing Pollution	Reduce pollutant sources	None to low	Where infiltration 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, activities occurring within the drainage area of the measure and groundwater sensitivity (depth, soil permeability). Creating green areas reduces hard surfaces and leads to reduced surface leaching of pollutant sources.
	Intercept pollution pathways	Medium	Swales are designed with vegetation. The denser the vegetation, the more it will retain sediment and particulate pollutants. Check dams may further assist with sediment retention. Literature reviews of the effectiveness of swales at pollutant removal have been carried out by Environment

<table>
<tr><td></td><td></td><td></td><td>Agency (2012- UK based) and DTI (2006- US based). Wide ranges of effectiveness were found:
- Suspended solids reduction: EA (2012) 31-81%; DTI (2006) average 38%
- Total phosphorus reduction: EA (2012) 7-100%; DTI average 14%
- Total nitrogen reduction: EA(2012) 25-90%; DTI average 14%
- Metals: DTI (2006) reported a range of 9-62%. However effectiveness may be very variable, and either positive or negative. For example, SNIFFER (2004), on an individual swale in Scotland, reported mean reduction of Ni of 50%, but increases in Cu (85% and Zn (14%) compared to runoff directly from the adjacent road.
It is likely that achieving high effectiveness at pollutant removal will be improved by good design, adequate maintenance and limited fertiliser use. This is particularly evident from the occasional negative values reported in the literature, suggesting that a reduction in water quality could potentially occur over time due to a lack of maintenance and build-up of sediments, or by application of fertiliser. However CIRIA (2009) concluded that “there is no indication of a drop in operational performance as long as standard maintenance is carried out”.</td></tr>
<tr><td rowspan="2">Soil Conservation</td><td>Reduce erosion and/or sediment delivery</td><td>Medium</td><td>Sediment deposition is one of the primary aims of swales, and is achieved through slowing runoff and the roughness of the vegetation. The total loading of suspended sediments is reduced from a swale as a result of reduction in total runoff volume, along with reduced concentrations of suspended solids (as discussed above) in the remaining runoff.</td></tr>
<tr><td>Improve soils</td><td>None</td><td></td></tr>
<tr><td rowspan="3">Creating Habitat</td><td>Create aquatic habitat</td><td>None</td><td></td></tr>
<tr><td>Create riparian habitat</td><td>None to Low</td><td>Wet swales maintain wet or marshy conditions, and hence provide some aquatic or wetland/riparian habitat.</td></tr>
<tr><td>Create terrestrial habitat</td><td>Medium</td><td>Swales provide a ‘green’ alternative to conventional drains. They should be planted with native vegetation to be most effective in enhancing biodiversity. They can be incorporated as an element in a network of green areas, thereby creating green corridors, which are important for the provision of terrestrial habitat.</td></tr>
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Climate Alteration	Enhance precipitation	None	
	Reduce peak temperature	Low	Swales provide green areas. Depending on vegetation density and how widespread they are, they can contribute to creating cool islands in urban landscapes (as a result of evapotranspiration, water supply, shading).
	Absorb and/or retain CO_2	Low	If a swale is added where no vegetation would otherwise be present, this will result in a localised increase in uptake of CO_2, particularly if woody vegetation is included.

VI. Ecosystem Services Benefits

Ecosystem Services		Rating	Evidence
Provisioning	Water Storage	Low	Swales provide localised storage and can be an important source control component of a SuDS 'train'. They contribute to making water available for other uses (e.g. recharge to groundwater, offering soil moisture to support terrestrial ecology).
	Fish stocks and recruiting	None	
	Natural biomass production	Low	By creating green areas, swales may contribute to natural biomass production, particularly if the vegetation is dense.
Regulatory and Matinenance	Biodiversity preservation	Low to medium	By creating green areas within the urban landscape where there would otherwise be hard surfaces, swales provide a contribution to biodiversity preservation. The extent to which this benefit is provided depends on the soil moisture and choice of vegetation. Even when their individual contributions are minor, their potential for contributing to networks of vegetated areas and green corridors can make them an important element in biodiversity preservation in urban landscapes.
	Climate change adaptation and mitigation	Low to medium	Swales can contribute to climate change adaptation. Predominantly this is by improving adaptation to the more intense rainfall events that are expected as a result of climate change. In addition, if new vegetation is introduced, particularly woody vegetation, they may also make a contribution to increasing carbon sequestration and helping to regulate urban temperatures.
	Groundwater / aquifer recharge	Low to medium	Swales can be designed to allow infiltration to underlying soils/groundwater. Although the surface area is limited, this provides a contribution to enhanced recharge.
	Flood risk reduction	Medium	Swales contribute to reducing the rate of surface runoff, particularly from artificial surfaces (urban areas). Used in conjunction with other SuDS features, they can reduce

			the risk of surface runoff flooding and contribute to the reduction in peak river flows in small catchments.
	Erosion / sediment control	Low	COWI (2014) identify urban runoff as being a relatively minor consideration for erosion and sediment control at the catchment scale. Nevertheless, sediment deposition as a result of reduced runoff rates is one of the key functions of swales, and so does provide some contribution to this benefit.
	Filtration of pollutants	Medium	Swales are effective in capturing sediments and reducing concentrations of associated pollutants. 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	While it is possible that in some situations dry swales may end up being used for recreation (most likely as children's play areas), they would only be used for such a purpose incidentally and would not be deliberately designed to provide such a benefit.
	Aesthetic / cultural value	Low to medium	Creation of green areas contributes to improving urban landscapes. Using swales is a communication tool for promoting sustainable water management. Keeping water on show (rather than hiding it in traditional drainage systems) helps to raise people's awareness and knowledge. This is particularly the case where the detail and value of SuDS is communicated to the public, for example by installing information panels.
Abiotic	Navigation	None	
	Geological resources	None	
	Energy production	None	

VII. Policy Objectives

Policy Objective		Rating	Evidence
Water Framework Directive			
Achieve Good Surface Water	Improving status of biology quality elements	None	
	Improving status of physico-	Low	Through contributing to reduction in diffuse pollution through filtration of pollutants and interception of surface

	chemical quality elements		runoff, swales 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 filtration of pollutants and interception of surface runoff, swales can make a contribution to improving water quality in receiving waters.
Achieve Good GW Status	Improved quantitative status	None-Low	Swales can be designed to allow infiltration. As such, they can enhance recharge to groundwater, although since the surface area is small this is a relatively minor contribution.
	Improved chemical status	None	
Prevent Deterioration	Prevent surface water status deterioration	Low/ Medium	By intercepting a potential diffuse pollution vector from the contributing catchment, swales can help to protect the receiving water body from deterioration as a result of new diffuse pollution sources.
	Prevent groundwater status deterioration	None to low	Although swales can be designed to allow infiltration, the spatial extent will be limited and the potential to influence groundwater status is likely to be negligible. If swales are part of a SuDS 'train' that allows infiltration, they can make some contribution to preventing groundwater status deterioration.
Floods Directive			
Take adequate and co-ordinated measures to reduce flood risks		High	Swales 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		Medium	As a green infrastructure component, increased application of swales will contribute to meeting the objectives of the 2020 Biodiversity Strategy, particularly in urban areas. The extent of contribution will be more or less effective depending on the type of vegetation used and how widespread they are.

More sustainable agriculture and forestry	Low	Where used to intercept and infiltrate runoff from low permeability surfaces in agricultural areas (i.e. as rural SuDS components) swales can contribute to more sustainable agricultural practices.
Better management of fish stocks	None	
Prevention of biodiversity loss	Low to Medium	By providing green space in urban areas, swales can make a contribution to the prevention of biodiversity loss. The extent of contribution will be more or less effective depending on the type of vegetation used and how widespread they are.

VIII. Design Guidance

Design Parameters	Evidence
Dimensions	Generally, swales are most efficient, and easier to construct and maintain, if the channel is trapezoidal or parabolic in shape, with shallow sides (between 1 in 3 and 1 in 4), shallow depths (no greater than 600mm) and a shallow gradient (between 1 in 100 and 1 in 300). This promotes lower velocities and increases the wetted perimeter, which in turn minimises erosion, promotes filtration and enhances safety. The base of a swale should be flat and 0.5-2m wide. (CIRIA, 2007) If the natural longitudinal slope is more than 2 in 100, it is possible to use check dams in order to divide the swale into several segments, to reduce velocities and optimise storage volumes. A minimum length of 30m is recommended by CIRIA (2007) to maximise water quality benefits, although it is recognised that this may be constrained by the site (i.e. a site length of less than 30m should not necessarily preclude the use of swales).
Space required	As swales are wide, shallow channels, they do often involve a significant increase in land uptake compared to conventional drainage. They must be incorporated into landscaping and public open spaces, or on private property adjacent to roads. They can therefore be difficult to incorporate into densely developed urban spaces for retro-fitting, but have been effectively incorporated in to many new developments with good landscaping. However, as swales may be used in many different ways (aesthetic value, recreational opportunities) the space requirements should not be considered to be purely dedicated to water management.
Location	Swales should be located over an area where they can maintain a shallow gradient over their entire length, and where runoff from impermeable catchments is able to flow into them. Swales should also be located in sun lit areas to allow for vegetation growth within them – a key requirement for their effective functionality. Easy access to the swales would also aid regular maintenance of the vegetation. Therefore swales are likely to be most effective if incorporated in to a site's development plans.

Site and slope stability	As noted in the 'dimensions' section, the longitudinal gradient of a swale should be shallow, although not flat. There should be sufficient slope to prevent ponding, but shallow enough to ensure effectiveness at sediment deposition and attenuation of peak flows. If ground is naturally steep (greater than 2 in 100) it is possible to use check dams to increase storage capacity and reduce velocities. However in the case of particularly steep longitudinal gradients, infiltration is unlikely to be possible. Swales should not be used on cuttings or embankments where slopes may become unstable.
Soils and groundwater	Swales allowing infiltration should not be used on brownfield sites or other areas where there is a risk of leaching contaminants into underlying groundwater. They should also not be used to treat runoff from pollution hotspots, again to avoid pollution risk to underlying groundwater. To ensure that infiltration potential is maintained, the seasonally high groundwater table should be more than 1m below the base of the swale. However, where these conditions are not met, swales can still be used but the base should be lined to prevent infiltration. In the case of wet swales, a shallow water table is desired to maintain permanently wet conditions on the base of the swale.
Pre-treatment requirements	Swales generally provide 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 essential to ensure functionality of the swale is preserved. Maintenance should include: • Litter and debris removal • Grass cutting to maintain within specified design range • Manage vegetation and weeds • Check for poor vegetation growth – alter/reseed plant types and remove sunlight blockages • Repair erosion and reinstate design levels • Break up or remove build-up of sediments in swale channel • Inspect inlet / outlet for blockages (CIRIA, 2007). Over time, swales allowing infiltration may need the infiltration surface to be rehabilitated and clogging sediment removed, although literature reviews have found little evidence of significant deterioration over time (e.g. Blanc et al, 2012).
Synergies with Other Measures	Swales are 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		Swales are typically relatively low land-take measures and can often be incorporated within the masterplan for new developments without significant opportunity costs for land use.
Investigations & Studies	€0.5k-€2k	Where infiltration is intended, geotechnical investigations may be required to confirm the suitability of underlying soils and groundwater 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	€15-€ 80 / m^2 swale area	Costs can be variable depending on the design (type of vegetation; dimensions; connections to upstream and downstream drainage). Cost ranges generally fall within €15 to € 80 per square metre of swale area constructed, with the highest costs being attributable to ‘enhanced’ swales with an underdrain filter bed. Ranges identified in the literature: CIRIA (2007) - €15-€20 per m^2 swale area Atkins (2010) - €20-€30 per m^2 swale area UK SuDS Cost Calculator (www.uksuds.org) - €20-€45 per m^2 swale area Environment Agency (2007) - €15 per m^2 swale area Environment Agency (2012) - €15-€20 per m^2 swale area ADOPTA (2006): €20-€80 /m^2 swale area depending on whether an underdrain filter bed is included.
Maintenance Costs	€0.50-€4.00 / m^2 swale area	Ongoing maintenance is required to maintain the functionality of the swale. Costs will vary depending on swale design (accessibility and type of vegetation). Cost ranges for annual maintenance in the literature: CIRIA (2007) - €0.50 per m^2 swale area Wilson et al (2009) - €1.50-€2.50 per m^2 swale area Environment Agency (2007) - €0.5 per m^2 swale area UK SuDS Cost Calculator (www.uksuds.org) - €3-€4 per m^2 swale area
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 and operators.
Ensuring clear responsibility for maintenance	The adoption of SuDS has historically been a major issue in ensuring their long-term effectiveness. This is important for linear features such as swales, which may cross different land ownerships and will reduce in effectiveness if only partially maintained.
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 the use of SuDS is required through planning policy for new developments over a certain size. 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).
CAP funding for rural SuDS	Where applied in agricultural areas, swales may constitute (all or part of) an ecological focus area, as defined under CAP Pillar I, or may be eligible for the European Agricultural Fund for Rural Development (EAFRD) in relation to improving water management and preventing soil erosion.
LIFE+	In some cases integrated SuDS schemes (i.e. which may include swales along with other measures) may be eligible for LIFE+ funding.

XII. References

Reference	Comments
ADOPTA (2006) Fiche technique “Noues et fossés”	Adopta is a French independent association promoting sustainable water management. This is a technical document about designing swales.
Atkins (2010) Bath and North East Somerset Flood Risk Management Strategy Report (www.bathnes.gov.uk)	
Blanc, J, Arthur, S and Wright, G (2012) Natural flood management (NFM) knowledge system: Part 1- Sustainable urban drainage systems (SUDS) and flood management in urban areas.	
CERTU (Ministère de l’Ecologie, du développement et de l’aménagement durables) (2008), L’assainissement pluvial intégré dans l’aménagement	Guidance document by a department of the French Environment Ministry
Citeau (2006), Transfert eaux-sols-plantes de micropolluants : état des connaissances et application aux eaux de ruissellement urbaines, INRA Unité des Science du sol, AESN	Study about the reduction in diffuse pollution through filtration of pollutants and the role played by vegetation
CIRIA (2009) Overview of SuDS performance: Information provided to Defra and the EA.	
COWI (2014) Support Policy Development for Integration of Ecosystem Service Assessment into WFD and FD Implementation – Resource Document, January 2014. Draft report.	
DTI (2006) Sustainable drainage systems: a mission to the USA.	
Environment Agency (2007) Cost benefit of SUDS retrofit in urban areas.	
Environment Agency (2012) Rural Sustainable Drainage Systems (RSuDS)	
Hess (2014), Monitoring of evapotranspiration and infiltration in rain gardens designs, Vilanova University	
Le Coustumer (2008), Colmatage et rétention des éléments traces métalliques dans les systèmes d’infiltration des eaux pluviales, Institut National des Sciences Appliquées de Lyon	Study about the pollutant removal capabilities of infiltration basins, and their potential for clogging

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.
Wilson, S, Bray, B, Neesam, S, Bunn, S and Flanagan, E (2009) Sustainable Drainge: Cambridge Design and Adoption Guide	
Woods-Ballard, B, Kellagher, R, Martin, P, Jefferies, C, Bray, R and Shaffer, P (CIRIA) (2007) The SuDS Manual, CIRIA C697.	