European Commission

Natural Water Retention Measures

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Service contract n°07.0330/2013/659147/SER/ENV.C1

Individual NWRM

Green roofs

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This report was prepared by the NWRM project, led by Office International de l'Eau (OIEau), in consortium with Actéon Environment (France), AMEC Foster Wheeler (United Kingdom), BEF (Baltic States), ENVECO (Sweden), IACO (Cyprus/Greece), IMDEA Water (Spain), REC (Hungary/Central & Eastern Europe), REKK inc. (Hungary), SLU (Sweden) and SRUC (UK) under contract 07.0330/2013/659147/SER/ENV.C1 for the Directorate-General for Environment of the European Commission. The information and views set out in this report represent NWRM project's views on the subject matter and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this report. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein.

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I. NWRM Description

Green roofs are multi-layered systems that cover the roof of a building with vegetation and/or green landscaping over a drainage layer. There are two types of green roof:

- **Extensive green roofs** cover the entire roof area with lightweight, low growing, self-sustaining, low maintenance planting. They are only accessed for maintenance. Vegetation normally consists of hardy, drought tolerant, succulents, herbs or grasses. Extensive green roofs are often known as sedum roofs, eco-roofs or living roofs.
- **Intensive green roofs** are landscaped environments with high amenity benefits including accessible planters or trees and water features. These impose a greater load on the roof structure and require significant ongoing maintenance including irrigation, feeding and cutting. Intensive roofs are also termed roof gardens.

A typical structure for a green roof includes a surface vegetation layer underlain by a substrate (growth medium), geotextile filter layer, and an aggregate or geo-composite drainage layer. The green roof materials are underlain by a waterproof membrane, with an additional layer of insulation between that and the roof itself.

Green roofs are designed to intercept rainfall, which is slowed as it flows through the vegetation and a drainage layer, mimicking the predevelopment state of the building footprint. Some of the rainwater is stored in the drainage layer and taken up by the vegetation, with the remainder discharged from the roof in the normal way (via gutters and downpipes). Flow rates from the green roof are reduced and attenuated compared to a normal roof, and the total volumes discharged from the roof are also reduced. Green roofs therefore intercept rainfall at source and provide the first component of a SuDS management train.

II. Illustration

Example of extensive green roof in Augustenborg, Malmo, Sweden (photo courtesy of susdrain.org)

III. Geographic Applicability

Land Use	Applicability	Evidence
Artificial Surfaces	Yes	Green Roofs are applicable to all types of buildings, subject to the design and function requirements of the

		roof. Green roofs can be grown on any pitch of roof, including vertical walls, although roofs with a pitch greater than 1 in 3 may require additional support and may have other specific design requirements. With respect to CORINE Level 2 land uses, green roofs are applicable to: • Urban Fabric • Industrial/Commercial/Transport Units
Agricultural Areas	No	(although applicable to buildings in agricultural areas)
Forests and Semi-Natural Areas	No	
Wetlands	No	

Region	**Applicability**	**Evidence**
Western Europe	Yes	
Mediterranean	Yes	Potential restrictions relating to high temperatures and dry weather, which provides challenges for vegetation maintenance, although these can potentially be overcome through irrigation (preferably using water stored from runoff from the green roof) and careful choice of drought tolerant vegetation.
Baltic Sea	Yes	Potential restrictions relating to high snowfall, where the green roof will be covered by snow for a significant proportion of the year, which may limit the effectiveness of vegetation in spring and early summer. Effective for summer rainfall events, but limited effectiveness for spring snowmelt. In areas of significant snowfall, this requires specific consideration in design. Nevertheless green roofs are not uncommon in the Baltic Sea region and in fact Scandinavia has some of the earliest examples of the use of green roofs (Prokop et al, 2011). Research is ongoing in to their effectiveness in the region (see case study Finland_03, which involves a green roofs research project being carried out by the University of Helsinki).
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	Building roof area suitable for green roofs is highly unlikely to be greater than 0.1 km²					

V. Biophysical Impacts

Biophysical Impacts		Rating	Evidence
Slowing & Storing Runoff	Store Runoff	Medium	Green roofs are most effective for frequent, less extreme rainfall events, and a good design would typically capture all rainfall from a two year event, without overflow from the roof. For larger rainfall events with a return period greater than two years, there will be some overflow, although the green roof will provide some benefit. A higher volume of rainwater can be stored if a layer of porous material is included. For intense, in extreme rainfall events (e.g. the 100 year event) the hydraulic performance of the roof is likely to be similar to a normal roof (CIRIA, 2007). Quantification of the effectiveness of green roofs at attenuation and peak flow reduction has shown widely varying values, with a literature review by Blanc et al (2012) finding values varying from 5% up to 95% reduction in runoff compared to a hard roof surface. Oberndorfer et al (2007) found a similarly wide range in their literature review, from 25-100% rainfall retention. Overall it is generally accepted that green roofs are effective, particularly for smaller events, but the wide range of reported effectiveness is a result of variables including substrate type and depth, antecedent conditions, season, and rainfall intensity and volume. For example: - Multiple studies have shown the reducing effectiveness with increasing rainfall and wetter antecedent conditions. For example, Stovin et al (2012) found overall 50% cumulative annual rainfall retention, but reducing to 29% for a 2 year event and 15% for a 16 year event; - A range of studies have measured the influence of substrate depth and type. For example EA (2012) referred to Van Woert et al (2005), who monitored rainfall retention with differing roof material, and found that a vegetated roof
	Slow Runoff	Medium	

			performed more effectively than other media such as gravel, while FLL (2008) report higher retention with increasing substrate depth on a vegetated roof; - Czemiel and Berndtsson (2010) monitored seasonal variations, and found reductions of 70% in the warm season and 33% in the cold season. Seasonal differences relate to evapotranspiration rates and differing patterns of rainfall.
	Store River Water	None	-
	Slow River Water	None	-
Reducing Runoff	Increase Evapotranspiration	High	Increased evapotranspiration occurs as a result of introduction of vegetation to an otherwise hard surface. Evapotranspiration is likely to be more significant where the substrate is thicker.
	Increase Infiltration and/or groundwater recharge	None	-
	Increase soil water retention	None	-
Reducing Pollution	Reduce pollutant sources	Low	Green roofs can provide some water quality benefits, through filtration, adsorption, biodegradation and uptake by plants. However this is only effective in terms of improvements to the quality of the rainwater and atmospheric deposits, since green roofs intercept rain directly prior to runoff. They can also be designed to take runoff from adjacent (non-green roofs), which will increase the overall effectiveness at pollutant reduction. They are effective in removal of suspended solids, and fairly effective for heavy metals (CIRIA, 2007).
	Intercept pollution pathways	None to low	
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	Low	Green roofs have aesthetic and biodiversity benefits, through introducing vegetation to what would otherwise be a hard surface with no biodiversity interest. The level of biodiversity interest will depend on the size of the

			green roof, whether it is extensive or intensive, and on the type of vegetation.
Climate Alteration	Enhance precipitation	None	-
	Reduce peak temperature	Low-Medium	When widespread across an urban area, green roofs may contribute to improvements to air quality, lower air temperatures and higher humidity levels in urban areas, thus assisting with climate regulation. When only used on a small scale, a contribution towards these impacts will still be made, but will have only a low impact individually. Green roofs with deeper substrate are more effective. Lower level green roofs (i.e. not high-rise) are more likely to have a positive influence on the heat island effect. Oberndorfer et al (2007) discuss effects of green roofs on temperature, both to outside air temperatures in urban areas, as well as the insulating effect inside the building. They refer to Bass et al (2003), who modelled the influence of 50% green roof coverage in the city of Toronto, and found temperature reductions of up to 2 °C. Cooling effects in the building occur due to a combination of substrate thickness and evapotranspiration.
	Absorb and/or retain CO_2	Low	Oberndorfer et al (2007) state that "extensive green roofs, being low in biomass, have little potential to offset carbon emissions from cities…intensive roof gardens that support woody vegetation could make significant contributions as an urban carbon sink".

VI. Ecosystem Services Benefits

Ecosystem Services		Rating	Evidence
Provisioning	Water Storage	None	Although green roofs do provide attenuation (i.e. storage) of water, this is generally not with the end result of making water available for other uses (e.g. irrigation).
	Fish stocks and recruiting	None	
	Natural biomass production	Low	Green roofs introduce vegetation to areas of otherwise hardstanding. This may be more notable for intensive than extensive green roofs, but in either case provides only a minor contribution to biomass production.

Regulatory and Maintenance	Biodiversity preservation	Low	Green roofs introduce vegetation to areas of otherwise hardstanding. Although the diversity of the vegetation may be low (for extensive green roofs) or managed (for intensive green roofs) this nevertheless provides an improvement over a hard roof.
	Climate change adaptation and mitigation	Medium	Green roofs contribute to climate change adaptation and mitigation through: temperature regulation, potential carbon sequestration (in some circumstances) and management of urban flood risk. As discussed above, their effectiveness at providing these benefits depends on the design (particularly substrate thickness) and over what area they are implemented.
	Groundwater / aquifer recharge	None	
	Flood risk reduction	Medium	Green roofs store rainfall and help to reduce the total volume and the rate of runoff (more effectively so where the substrate is deeper), thereby contributing to flood risk management.
	Erosion / sediment control	None	
	Filtration of pollutants	Low	Green roofs can make a contribution to improved water quality in relation to atmospheric deposition becoming entrained in runoff (including, where incorporated in to design, pollution in runoff from upstream roofs).
Cultural	Recreational opportunities	Low	Intensive green roofs are designed for small-scale domestic/amenity/recreational use, although extensive roofs are unlikely to be used in this way and hence will not provide this benefit.
	Aesthetic / cultural value	Medium	The introduction of green spaces to urban areas, particularly for intensive green roofs which are more likely to be accessible, and/or lower green roofs visible from higher buildings, and/or when implemented in combination with green walls, contributes to aesthetic benefits.
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	Whilst green roofs contribute to sustainable water management, they are highly unlikely on their own to cause significant enough changes to influence biology quality elements.
	Improving status of physico-chemical quality elements	Low	As green roofs can make some localised contributions to water quality of rainfall runoff, they have some potential to contribute towards improved physico-chemical quality elements as a source-control component in an effective sustainable drainage system.
	Improving status of hydromorphology quality elements	None	
	Improving chemical status and priority substances	Low	As green roofs can make some localised contributions to water quality of rainfall runoff, they have some potential to contribute towards improved chemical status as a source-control component in an effective sustainable drainage system.
Achieve Good GW	Improved quantitative status	None	
	Improved chemical status	None	
Prevent Deterioration	Prevent surface water status deterioration	Low	As green roofs can make some localised contributions to water quality of rainfall runoff, and as a component in an effective sustainable drainage system, they can contribute to sustainable water management in a catchment and hence help to prevent surface water status deterioration.
	Prevent groundwater status deterioration	None	
Floods Directive			
Take adequate and co-ordinated measures to reduce flood risks		Medium	Green roofs store rainfall and help to reduce the total volume and the rate of runoff, thereby contributing to flood risk management.
Habitats and Birds Directives			
Protection of Important Habitats		None	
2020 Biodiversity Strategy			

Better protection for ecosystems and more use of Green Infrastructure	Medium	Green roofs are an example of green infrastructure, introducing biodiversity and green spaces to urban areas, with the potential to assist with ecological habitat connectivity.
More sustainable agriculture and forestry	None	
Better management of fish stocks	None	
Prevention of biodiversity loss	Low	Green roofs allow biodiversity and green space to be retained in areas that would otherwise be entirely hard surface and represent a loss of biodiversity from the natural land cover.

VIII. Design Guidance

Design Parameters	Evidence
Dimensions	Can be applied to any size roof, as long as the structure is able to support it. There should be multiple outlets from the green roof, to reduce the risks from blockages. The structural roof strength must provide for the full additional load of saturated green roof elements. It is important to use a waterproof membrane with good root penetration resistance (CIRIA, 2007).
Space required	No land space requirements, since located on roof tops.
Location	Located on roof tops. Appropriate for all kinds of sites and development types.
Site and slope stability	No land slope restrictions, but roof slope is an important consideration. The roof pitch should generally be between and 1 in 3 (CIRIA, 2007).Very flat roofs may be susceptible to ponding, although some drainage solutions can be provided. Steep roofs may have increased risk of soil slippage and erosion, unless additional support can be provided or a raised grid structure is used.
Soils and groundwater	No restrictions regarding site soil or groundwater. The soil type to be used in green roof construction is an important consideration and must be a light weight soil. The thickness of the substrate can have a significant influence on retention. CIRIA (2007) suggests typical substrate thicknesses between 100-250 mm, which corresponds to FLL (2008) who found increasing retention up to 250 mm, but then little change with further increases in thickness. Thicker substrate is likely to be able to support more biological diversity.
Pre-treatment requirements	None: directly intercepts rainfall.

Maintenance requirements	Maintenance requirements are important to ensure continued effectiveness. Vegetation will need to be maintained, and any damage to waterproof membrane may be more critical since water is encouraged to remain on the roof (CIRIA, 2007). Maintenance requirements differ between intensive and extensive green roofs. Intensive green roofs require regular maintenance, such as mowing lawns and weeding, whereas extensive green roofs should require only annual or bi-annual visits. Regular maintenance requirements include irrigation during establishment of vegetation; inspection for bare patches and replacement of plants; litter removal. Regardless of the nature of substrate or vegetation, maintenance is more important the first year (watering, weeding, etc.) Note: maintenance should not be done during the bird nesting period.
Synergies with Other Measures	Most effective if applied at the start of a SuDS 'train' – for example, the roof drainage from green roofs could feed into rain gardens and downspout outlets.

IX. Cost

Cost Category	Cost Range	Evidence
Land Acquisition	n/a	There are no land requirements for green roofs.
Investigations & Studies	n/a	Site investigations are not necessary, but green roof needs to be considered as an integral part of building design, to ensure loading is taken account of, the roof slope is appropriate, and the overall design will be effective in storing rainfall. Structural engineers should always be consulted when considering retrofitting of green roofs.
Capital Costs	€25-€130 per m^2 extensive green roof area €130-€300 per m^2 area for intensive green roofs	Capital costs are likely to differ depending on whether green roofs are being incorporated in a new building, or retrofitting. Costs are likely to be higher for retrofitting. Capital cost range estimates vary in the literature, although consensus indicates ranges of €90-€130 per square metre green roof for extensive design and €130-€180 per square metre for intensive design. Ranges identified in the literature: • €25-€90 /m^2 for extensive (Atkins, 2010) • €90-€130 /m^2 for extensive (www.uksuds.org) • €80-€130 /m^2 for extensive and €130-€180 /m^2 for intensive (www.thegreenroofcentre.co.uk) • €25 to €100 for extensive and €100 to €300 for intensive (Mairie de Paris, 2014) • €80 to €300 for extensive and intensive (www.toiture-vegetalisee.architecteo.com/)

		Costs are likely to be higher where the substrate is thicker, due to structural requirements. Large areas of roof are generally more cost-effective (CIRIA, 2007).
Maintenance Costs	Up to €55 per m^2 area of green roof for each maintenance event	Extensive green roofs: general maintenance every 6-12 months. The SuDS construction and maintenance costs calculator (www.uksuds.org) indicates a maintenance cost of up to €55 per square metre of green roof area for each maintenance event, although this will vary depending on the type of roof. Economies of scale may be gained for larger roofs. Intensive green roofs: regular maintenance, which is likely to be considered as a landscape maintenance cost since these areas are used for amenity uses.
Additional Costs	n/a	n/a

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.
Ensuring clear responsibility for maintenance	The adoption of SuDS has historically been a major issue in ensuring their long-term effectiveness, although there may be less uncertainty for green roofs in comparison to other types of SuDS.
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 can assist in this.

Ensuring that building design is appropriate to accommodate a green roof	Whether for a new building or retrofitting, it is important to consider the additional loading that a green roof places on the building structure.

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 (with some specific to green roofs). For example, Copenhagen requires green roofs for all new buildings with a roof slope of less than 30°. 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, including green roofs, 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 green roofs may provide some contribution to achieving).
Municipal subsidy schemes	Some cities provide financial incentives to encourage the implementation of green roofs, for example Vienna (see case study Austria_03), where financial subsidies of 8-25 € per m^2 are available. Prokop et al (2011) identified other European cities with subsidies for green roofs including Linz, Austria and Groningen, Rotterdam, Amsterdam and The Hague, the Netherlands.

XII. References

Reference	Comments
Atkins (2010) Bath and North East Somerset Flood Risk Management Strategy Report (www.bathnes.gov.uk)	
Bass, Krayenhoff, Martilli, Stull and Auld (2003). The impact of green roofs on Toronto's urban heat island. P292-304 in Proceedings of the First North American Green Roof Conference: Greening Rooftops for Sustainable Communities.	

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.	A literature review of hydrological effectiveness of SuDS, focussed on Scotland but drawing on literature from elsewhere.
Czemiel and Berndtsson, J., Green roof performance towards management of runoff water quantity and quality: A review, Ecological Engineering, 36:351–360.	
Environment Agency (2012) Rural Sustainable Drainage Systems (RSuDS)	Guidance document by the Environment Agency of England, with information on measures relevant for rural (agricultural) sustainable drainage.
FLL (Forschungsgesellschaft Landschaftsentwicklung und Landschaftbau e.V) (2008) Richtlinie für die Planung, Ausführung und Pflege von Dachbegrünungen–Dachbegrünungsrichtlinie.	German guidelines for the planning, execution and upkeep of green roof sites.
Oberndorfer, Lundholm, Bass, Coffman, Doshi, Dunnett, Gaffin, Köhler, Liu and Rowe (2007). Green roofs as urban ecosystems: ecological structures, functions and services. BioScience, 57(10): 823-833.	
Prokop, G., Jobstmann, H. and Schonbauer, A (2011) Overview of best practices for limiting soil sealing or mitigating its effects in EU-27.	
Stovin, V, Vesuviano, G and Kasmin, H (2011) The hydrological performance of a green roof test bed under UK climatic conditions, Journal of Hydrology, 414-415, pp 148-161.	
Van Woert, Bradley-Rowe, Andresen, Rugh, Fernandez and Xiao (2005) Green Roof Stormwater Retention: Effects of Roof Surface, Slope and Media Depth. Journal of Environmental Quality 34, 1036-1044.	
www.thegreenroofcentre.co.uk – website of The Green Roof Centre	The Green Roof Centre is the UK's national centre of excellence for green roofs, based at the Department of Landscape, University of Sheffield. It includes design information for green roofs and information on green roof research.

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.	A comprehensive manual for SuDS design and wider information. Draws on the knowledge developed through many preceding CIRIA studies.
www.toiture-vegetalisee.architecteo.com/ - website belonging to the Architecteo network dedicated to the environmentaly friendly home	The Architecteo network has been developed to provide advice wooden houses, modular construction, eco-construction etc.
Mairie de Paris (2014), Végétalisation des murs et des toits, Habiter durable, Edition 1	Study on the Parisian approach to regulation and different types of green roofs
Mairie de Paris (2012), Toitures végétalisées, Cahier Technique, 15 fiches pratiques	15 technical sheets about green roofs, suitable plants, maintenance, building structure, etc.
APUR (2013), Etude sur le potentiel de végétalisation des toitures terrasses à Paris	Study on the potential of green roofs in Paris