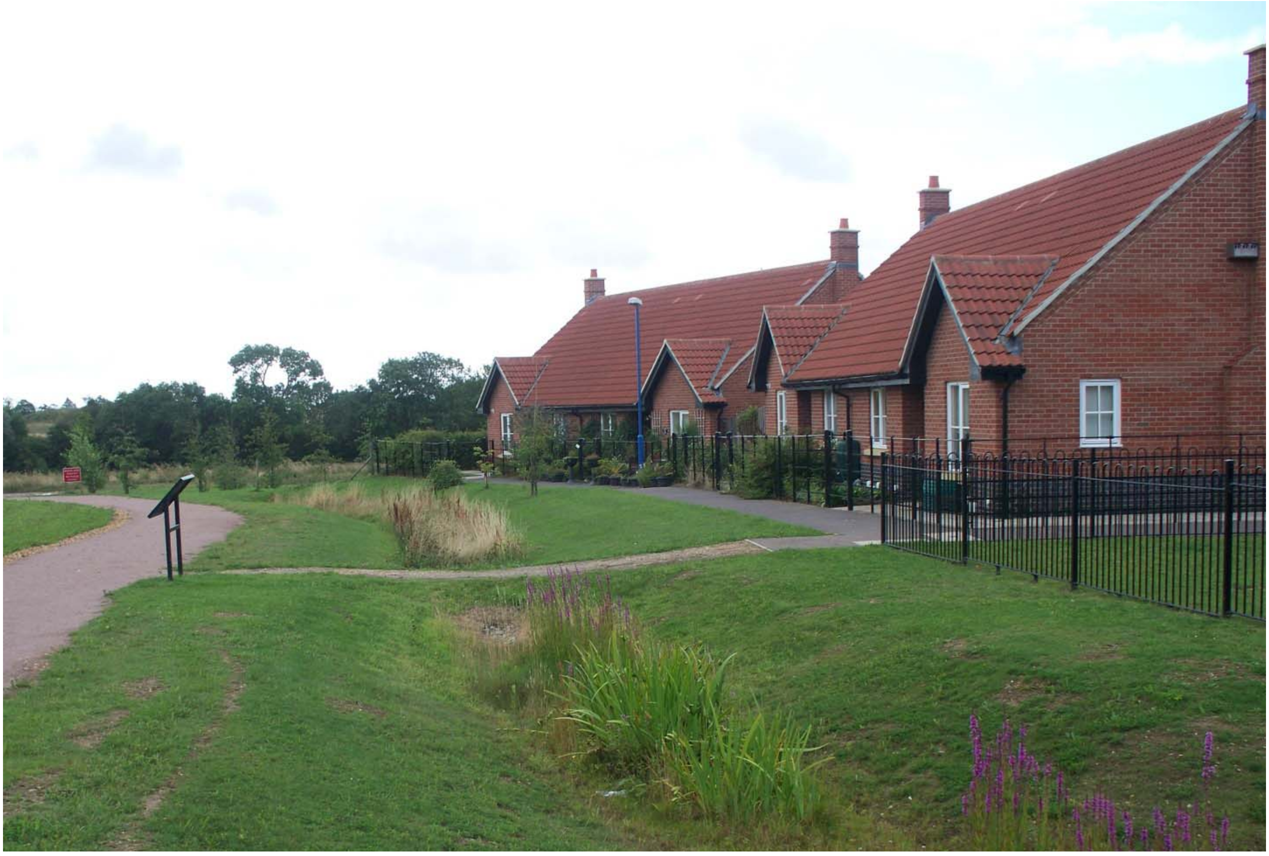

Costs and Benefits of Sustainable Drainage Systems

Committee on Climate Change

July 2012

Final Report

9X1055

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CONTENTS

1 INTRODUCTION

The Committee for Climate Change Adaptation Sub-Committee appointed Royal HaskoningDHV to undertake "research to identify the type and level of adaptation action that could cost-effectively manage current and future flood risk in England".

The aims of the study set out in the project brief were:

1. To estimate the scale of property-level action that would be cost-effective for society to take in England today given current conditions; and when accounting for future climate uncertainty, future flood defence investment scenarios and future development.

2. To estimate the type and scale of SuDS that would be cost-effective for society to take in England today for new and existing developments, when accounting for future climate uncertainty.

This report sets out the methodology and results of the investigation into potential for Sustainable Drainage Systems (SuDS) to enable adaptation to flood risk at present and into the future, addressing the second aim of the study. The first aim of the study to consider property level measures is dealt with in a separate report (Royal Haskoning, 2012).

Peer review of the report has been undertaken by Professor Edmund Penning-Rowsell (Flood Hazard Research Centre) and Professor Gary Pender (Herriot Watt University). Their comments and the responses to these comments are documented in Appendix A.

1.1 Background

The Adaptation Sub-Committee (ASC) of the Committee on Climate Change was established under the 2008 Climate Change Act. The role of the ASC is to provide independent advice on adaptation and preparedness of the UK to climate change.

In England over 2.4 million properties are at risk of flooding from rivers or the sea, of which nearly half a million are at significant risk. One million of these are also at risk from surface water flooding with a further 2.8 million properties vulnerable to surface water flooding alone (Environment Agency, 2009).

In 2011 the ASC commissioned Davis Langdon (AECOM) to identify low-regret adaptation options to protect existing and new homes from flood risk in the Aire Catchment in Yorkshire and Humber. In addition to the measures identified in this report, SuDS were identified as an alternative approach for enabling adaptation to climate change. This study outlines the current evidence base for the cost-effectiveness of SuDS and how these measures may form part of the suite of measures available to manage flood risk.

1.2 Report Structure

The remainder of the report is divided into 6 sections; Section 2 summarises a review of the current literature for the costs and benefits of SuDS in the UK. Section 3 outlines the development of a unit-cost database for SuDS measures based upon the available literature. Section 4 provides a discussion of the cost-effectiveness of SuDS based on available case study evidence. Section 5 discusses the potential for the national assessment of the costs and benefits of SuDS based upon the available evidence. Section 6 summarises the key findings of the study and gives recommendations for future work that could improve the understanding of the costs and benefits of SuDS, and how these could be assessed at the national scale.

2 LITERATURE REVIEW

The literature review into the costs and benefits of SuDS techniques has considered a range of information sources. The review has primarily been limited to studies that considered the United Kingdom. However for the benefits of SuDS it has been extended to international literature due to the lack of studies undertaken in the UK. The unit capital and maintenance costs of individual measures have been considered in detail, usually reported per unit area of the measure being used or unit volume of water stored. In addition the potential for land take costs have been investigated. Information regarding the benefits of SuDS has been found to be far less detailed and at present contains significant uncertainties.

2.1 Costs of SuDS

The cost of SuDS can be considered as two components, the capital expenditure to build the measures including potential land take costs and the on-going operational costs to maintain them to ensure continued performance.

The existing literature provides sporadic information on these costs at differing levels of detail. These include generalised costs at the level of individual SuDS measures and the total costs of case study SuDS Schemes. The cost of land take that occurs with certain types of SuDS has also been investigated.

The following sections outline the existing information on the costs of SuDS and the potential for this information to be used in the development of a benefit-cost model.

2.1.1 Factors Affecting Costs

The actual costs of SuDS measures and therefore SuDS schemes are dependent upon a large number of factors. Many of these factors are site specific and therefore generalisation about costs can be problematic and includes high levels of uncertainty.

A summary of the factors that affect the costs of SuDS solutions are listed below:

- Soil type; excavation costs are higher on rocky soils and the opportunity to implement infiltration solutions varies;
- Groundwater vulnerability; in vulnerable areas some SuDS measures will need impermeable geomembrane liners to prevent infiltration which will increase costs;
- Design criteria; more stringent requirements for run-off control will lead to larger and more SuDS measures in the system;
- Design features; extensive planting is more expensive than SuDS measures that are allowed to colonise naturally;
- Access issues and space requirements, some measures take up land that would otherwise be used for development;
- Location; regional variations in labour and material costs, topography, soil conditions including permeability and local rainfall characteristics will affect design criteria;
- System Size; larger schemes offer the opportunity for economies of scale to be realised; and
- New build or Retrofit; the cost of installing a SuDS solution into an existing development involves very different costs to one designed as part of a new development.

2.1.2 Capital Costs

High level assessments of the costs of SuDS have been undertaken by Defra for their impact assessments which support the sustainable drainage elements of the Flood and Water Management Act 2010 (Defra, 2011) (Defra, 2009). The two relevant impact assessments made the general assumption that the capital costs for SuDS are generally similar to traditional drainage systems and therefore these were excluded from the assessments. It was recognised that this is a conservative assumption as the cost of SuDS to provide the same performance criteria as traditional drainage are much lower. However conventional drainage systems are not designed to the same requirements as SuDS (Defra, 2009). Defra (2011) noted from case study examples that overall evidence suggests SuDS may be up to 30% cheaper to construct, however for challenging sites can be 5% more expensive to construct than traditional drainage.

As the assessment of the costs of SuDS measures require detailed construction estimates taking into account the exact design, UKWIR (2005) developed detailed spread sheet based tools for the assessment of costs. The SuDS measures considered were detention basins, filter drains, permeable pavements, retention ponds and swales. The report recognises that the cost of a SuDS feature can only be reliably determined based on an engineering estimate for a particular site. Therefore it does not make generalisations about the costs of the construction and maintenance of SuDS measures. Therefore this information does not lend itself easily to broad scale assessments of the capital costs of SuDS measures.

The most appropriate source of capital costs for SuDS measures in new developments the literature review undertaken by CIRIA as part of Collating the Urban Drainage Evidence Base (CIRIA, 2008) and Stovin and Swan (2007). Both give unit capital costs for different SuDS measures. The capital costs of retrofit SuDS are given by the Environment Agency's assessment of the costs and benefits of SuDS retrofit (Environment Agency, 2007).

CIRIA (2007) undertook a comprehensive review of the existing information regarding the costs of SuDS. The main source for capital costs of SuDS was avaliable from HR Wallingford's 2004 work for the DTI on Whole Life Costing for SuDS (HR Wallingford, 2004), these are given in Table 2.1.

Table 2.1: Capital costs of SuDS components (HR Wallingford, 2004)

SuDS Measure	Capital Expenditure (2002)	
	Cost (£)	Unit
Filter drain	100 - 140	/ m^3 stored volume
Infiltration trench	55 -£65	/ m^3 stored volume
Soakaway	> 100	/ m^3 stored volume
Permeable pavement	200 - 250	/ m^3 stored volume (assuming depth 0.3m, void ratio: 0.3)
Infiltration basin	10 - 15	/ m^3 detention volume
Detention basin	15 - 20	/ m^3 detention volume
Wetland	25 - 30	/ m^3 treatment volume
Retention pond	15 - 25	/ m^3 treatment volume
Swale	10 - 15	/ m^2 swale area
Filter strip	2 - 4	/ m^2 filter strip area

CIRIA (2007) identified that the work for Interpave in 2006 (Interpave, 2006) gave capital costs for permeable pavements of £15 - £30/m^2, which suggests that the costs from HR Wallingford were high. Green roof costs were considered in the Solution Organisation's report for Sarnafil (The Solution Organisation, 2005), this gave the following estimates of capital costs per unit area:

Table 2.2: Capital costs of green roofs (The Solution Organisation, 2005)

Type of Green Roof	Capital Expenditure	
	Cost (£)	Unit
Exposed roof	47	/m^2
Covered roof with sedum mat	93	/m^2
Biodiverse covered roof	97	/m^2

Another assessment of the unit costs of SuDS was made by Stovin and Swan (2007) for retrofit SuDS. The costs were developed for appropriate design dimensions for urban situations. Upper and lower costs were developed for SuDS measures where site specific factors such as soil type or use of alternative materials led to differences in cost. The unit capital costs for the selected SuDS measures were obtained from the Civil Engineering and Highways Works Price Book (Spon, 2001) and the Landscape and external Works Price Book (Spon, 2001). The cost presented below do not include for design and supervision of works.

Table 2.3: Capital costs of SuDS components (Stovin & Swan, 2007)

SuDS Measure	Capital Expenditure (2002)		
	Upper Cost (£)	Lower Cost (£)	Unit
Water butt (0.3m^3)	243	100	/property
Infiltration trench	99	74	/m
Swale	20	18	/m
Soakaway	552	454	/soakaway
Porous car park (grasscrete)	63	63	/m^2
Pond / basin	55	35	/m^3
Storage tank (concrete)	518	449	/m^3

The capital costs of retrofit SuDS from Environment Agency (2007) are given for rainwater harvesting, water butts, permeable paving and swales (Table 2.4). More extensive measures such as basins, ponds and wetlands are not usually retrofitted to existing developments due to space constraints and therefore were not considered by this study.

Table 2.4: Unit costs for Retrofit SuDS Measures (Environment Agency, 2007)

SuDS Measure	Capital Expenditure	
	Cost (£)	Unit
Rainwater Harvesting	45 (Detached/semi-detached houses) 45 (Terraced Houses) 9 (Schools) 3 (Leisure centres) 9 (Other non-domestic buildings)	/m^2
Water Butts	0.75 (Terraced Houses) 0.50 (Detached/semi-detached houses)	/m^2
Permeable Pavement	54	/m^2
Swales	12.50 (Rural and urban roads)	/m^2

2.1.3 Maintenance Costs

The high level impact assessments for the Flood and Water Management Act 2010 (Defra, 2011) (Defra, 2009) determined that the cost of maintenance of a traditional pipe system was on average £40 per property. SuDS schemes were assessed to be £6/per property more expensive than a traditional system. This was based on the mid-point of the data available from CIRIA (2008). However this is acknowledged to be conservative and in many cases SuDS can be cheaper to maintain depending upon the size and nature of the scheme.

Several studies give unit costs for maintenance of different SuDS measures and the frequency with which these activities should be carried out; these are the whole life cost study for UKWIR (2005), Environment Agency (2007) and CIRIA (2008).

The whole life cost study for UKWIR (2005) does give unit costs of the elements of maintenance cost for the measures considered. For permeable paving, detention basins, swales and retention ponds this is supplied per unit area or volume and therefore can be applied to the general assessment. The maintenance costs for permeable pavements are outlined in Table 2.5.

Table 2.5: Maintenance unit costs for permeable paving (UKWIR, 2005)

Activity	Cost (2005)		Frequency of Maintenance Activity			
	(£)	Unit	Low	Medium	High	Unit
Inspection, reporting and information management	39.58	None	1	0.5	0.1	Years
Litter and minor debris removal	0.024	m^2	5	1	0.1	Years
Permeable pavement sweeping	0.038	m^2	1	0.5	0.3	Years
Remove block paves and stockpile to be washed with membrane in a containment area. Remove and dispose 5mm single aggregate.	17.54	m^2	45	35	25	Years
Install replacement geotextile, install new 5mm single aggregate bedding layer and reinstate block.	12.13	m^2	45	35	25	Years

The routine maintenance costs for detention basins are outlined in Table 2.6 and infrequent maintenance costs are outlined in Table 2.7.

Table 2.6: Regular Maintenance unit costs for detention basins (UKWIR, 2005)

Activity	Cost (2005)		Frequency of Maintenance Activity			
	(£)	Unit	Low	Medium	High	Unit
Inspection, reporting and information management	48.00	nr	3	0.5	0.1	years
Litter and minor debris removal	0.024	m^2	1	0.5	0.1	years
Grass cutting	0.026	m^2	3	0.3	0.1	years
Barrier vegetation pruning	0.12	m^2	3	3	3	years
Shrub area weeding	12.13	m^2	0	1	1	years

Table 2.7: Infrequent maintenance unit costs for detention basins (UKWIR, 2005)

Activity	Cost (2005)		Frequency of Maintenance Activity			
	(£)	Unit	Low	Medium	High	Unit
De-silting detention basin	6.89	m^3	50	25	10	years
Mobilisation for sediment removal from detention basin	4675.50	nr	50	25	10	years
Disposal of the sediment from the detention basin on-site	2.19	m^3	50	25	10	years
Disposal of the sediment from the detention basin off-site	35.00	m^3	50	25	10	years
Replace geotextile (25 % of area)	3.31	m^2	50	25	10	years
Vegetation replacement (25% of area)	13.45	m^2	50	25	10	years

The routine maintenance costs for detention basins are outlined in Table 2.8 and the infrequent maintenance costs are outlined in Table 2.9

Table 2.8: Regular Maintenance unit costs for swales (UKWIR, 2005)

Activity	Cost (2005)		Frequency of Maintenance Activity			
	(£)	Unit	Low	Medium	High	Unit
Inspection, reporting and information management	48.00	nr	3	0.5	0.1	years
Litter and minor debris removal	0.024	m^2	1	0.5	0.1	years
Grass cutting	0.04	m^2	3	0.25	0.1	years

Table 2.9: Infrequent maintenance unit costs for swales (UKWIR, 2005)

Activity	Cost (2005)		Frequency of Maintenance Activity			
	(£)	Unit	Low	Medium	High	Unit
De-silting swale	0.2	m^2	50	25	10	years
Deposition of sediment from the swale on -site	2.19	m^3	50	25	10	years
Deposition of sediment from the swale off-site (e.g. landfill)	35.00	m^3	50	25	10	years
Reapply top soil (250 mm thick)	1.38	m^2	50	25	10	years
Vegetation replacement	0.51	m^2	50	25	10	years

The routine maintenance costs for retention ponds are outlined in Table 2.8 and the infrequent maintenance costs are outlined in Table 2.9

Table 2.10: Regular Maintenance unit costs for retention ponds (UKWIR, 2005)

Activity	Cost (2005)		Frequency of Maintenance Activity			
	(£)	Unit	Low	Medium	High	Unit
Inspection, reporting and information management	300.00	nr	3	0.5	0.1	years
Litter and minor debris removal	0.038	m^2	1	0.5	0.1	years
Grass cutting	0.074	m^2	3	1	0.3	years
Barrier vegetation pruning	0.33	m^2	0	3	3	years
Barrier vegetation weeding	0.24	m^2	3	1	1	years
Aquatic vegetation management	0.34	m^2	10	4	1	years

Table 2.11: Infrequent maintenance unit costs for retention ponds (UKWIR, 2005)

Activity	Cost (2005)		Frequency of Maintenance Activity			
	(£)	Unit	Low	Medium	High	Unit
De-silting pond	6.89	m^3	50	25	10	years
Mobilisation for sediment removal from pond	4676	nr	50	25	10	years
Disposal of the sediment from the pond on-site	2.19	m^3	50	25	10	years
Disposal of the sediment from the pond off-site (e.g. landfill)	35.00	m^3	50	25	10	years
Vegetation replacement	13.45	m^2	50	25	25	years

Unit costs for maintenance were also given by Environment Agency (2007) for the four types of retrofit SUDS that they considered (Table 2.12).

Table 2.12: Unit maintenance costs for SuDS Measures (Environment Agency, 2007)

SuDS Measure	Operational Expenditure Unit Cost (£)
Rainwater Harvesting	*Regular* £0.60/m^2 Detached, semi-detached and terraced houses £0.15/m^2 Other properties *Occasional* £0.40/m^2 Detached, semi-detached and terraced houses £0.10/m^2 Other properties
Water Butt	N/A
Permeable Pavement	*Regular* £0.40/m^2
Swale	*Regular* £0.10/m^2 *Occasional* £0.15/m^2

CIRIA (2008) also reviewed maintenance costs from several sources, maintenance costs of several types of SuDS were avaliable from HR Wallingford's 2004 work for the

DTI on Whole Life Costing for SuDS (HR Wallingford, 2004), these are given in Table 2.1.

Table 2.13: Capital and Maintenance costs of SuDS components (HR Wallingford, 2004)

SuDS Measure	Annual maintenance (2002)	
	Cost (£)	Unit
Filter drain	0.2 - 1	/ m^3 stored volume
Infiltration trench	0.2 - 1	/ m^3 stored volume
Soakaway	0.1	/ m^2 treated area
Permeable pavement	0.5 - 1	/ m^3 stored volume
Infiltration basin	0.1 - 0.3	/ m^2 infiltration basin area

In addition maintenance costs for green roofs were obtained from Solution Organisation (2005) and are outlined in Table 2.14.

Table 2.14: Maintenance costs of green roofs (The Solution Organisation, 2005)

Type of Green Roof	Annual Maintenance Cost (2005) (£)	Repairs (years 1 and 2 only) (2005) (£)	Unit
Exposed roof:	0.15	0	/ m^2 surface area
Covered roof with sedum mat	0.60	2.50	/ m^2 surface area
Biodiverse covered roof	0.15	1.25	/ m^2 surface area

2.1.4 Land Costs

CIRIA (2007) found that take land costs are likely to be the most significant factor in influencing capital costs of SuDS schemes. Parts of a scheme can have no land costs if the feature has dual use and is required within a development. Such instances include; car parks with permeable paving, swales and basins within the required allocation of public open space or green roofs. However conversely in high density developments land take costs can be very high and certain types of SuDS that require more space can be unacceptable to developers.

The following types of SuDS are always installed in locations which have another use and therefore land take is not an issue:

- Permeable surfaces such as concrete block permeable paving
- Green Roofs
- Rainwater Harvesting
- Water Butts

SuDS measures that may have land cost implications if they do not form part of the open space requirements for a site are:

- Swales
- Detention and infiltration basins
- Ponds
- Wetlands

The amount of land take that will lead to additional cost in a development is therefore highly dependent upon the measures used and the amount of open space that is provided irrespective of the SuDS system.

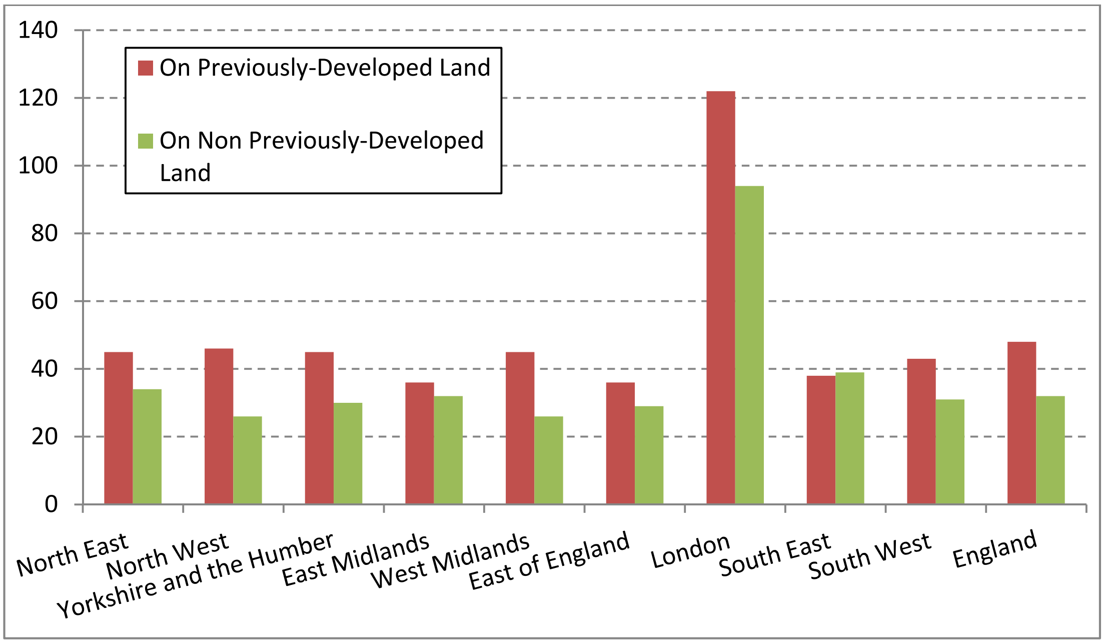
When retrofitting SuDS land take can become more of an issue as existing developments will tend to have utilised all existing space. Therefore if large land take costs are to be avoided SuDS that have small footprints or can be incorporated into the existing open space are required. These include retrofitted permeable surfaces for car parking, roads and pedestrian walkways, or measures incorporated into existing green space such as swales or basins.

Local planning authorities are required to develop housing density policies that define the amount of open space that is required. National standards were not developed as local circumstances are thought to require different approaches to the provision of open space (DCLG, 2002). As the requirements vary between the planning authorities there are no standard values and the approach varies greatly. Some local authorities apply the National Playing Field Association standard of 2.4ha per 1000 people, while it can vary between 1.6ha and 2.8ha (Scottish Executive Social Research, 2005).

Housing densities for new build are typically being set at about 30 houses per hectare (e.g. South West) to 40 houses per hectare (e.g. Ashford), though these may change with the change in policy on minimum housing density targets (Defra, 2011). Analysis of case study sites for new development SuDS schemes shows that housing densities typically range from 25 to 35 properties per hectare.

The Land Use Change Statistics in England: 2010 (Communities and Local Government , 2011) estimated that new dwellings were built at an average density of 43 per hectare. These statistics also noted a significant difference between development on previously developed land and those that are not. Development on non-previously developed land was built at an average of 32 per hectare, while development on previously developed land was built at an average of 48 per hectare. These averages are generally reflected across the country except for London where densities are far higher; 120 dwellings per hectare on average (Figure 2:1). The proportion of developments on previously developed land was 76% (Communities and Local Government , 2011).

Figure 2:1: Density of new development in 2010 (Communities and Local Government , 2011)



Bastien *et al.* (2010) analysed the land take of a variety of SuDS solutions for a case study site in Scotland. The site comprised 1500 houses over an area of 20 hectares; this gives a density of 75 properties per hectare which is above the current averages for England. The land take of the SuDS solutions varied between 2.5% and 8.5% of the total development area.

Further analysis of importance of land take costs and its impact on the cost-effectiveness of SuDS is discussed in Section 4.3.

2.1.5 Design Costs

The design costs of SuDS schemes have been found to be <5% of the total costs (Defra, 2011), however this varies depending upon how early SuDS are considered in the design process. Additional costs are incurred where SuDS are considered late and designs need to be revised to accommodate them. In addition on larger sites economies of scale may reduce the percentage of the costs that are required for design.

2.1.6 Case Study Costs

A review of the available case study information on the costs of SuDS schemes has been undertaken to assess typical total costs of schemes for different development densities and sizes.

The available capital cost data is limited however it does give some indication of costs for typical new residential development (Table 2.15). There is also some information on the cost of schemes installed in schools; the two schemes cost £61,400 and £93,000.

Table 2.15: Case study evidence of capital costs of new residential development SuDS schemes

Scheme Name	Site Size		Property Density (Per Hectare)	Capital Cost (£)		
	Area (ha)	Properties		Total	Per Property	Per Hectare
Lamb Drove, Cambridgeshire	1	35	35	197,600	5,646	197,600
Elvetham Heath, Hampshire	62	1868	30	2,140,000	1,146	34,516
Caledonia Road, Islington	0.3	150	500	47,500	317	158,333
Daniel's Cross, Newport	7	171	24	780,800	4,566	111,543
Ramshill	Unknown	287	Unknown	350,000	1,220	Unknown
Marlborough Road, Newport	11	387	35	966,100	2,496	87,827

Information regarding the maintenance cost for SUDS is also limited; The Lamb Drove Scheme currently costs £1,340 per year to maintain (Royal Haskoning, 2012) which equates to £38 per property. This is slightly less than the cost of traditional drainage suggested by the impacts assessments for SuDS (Defra, 2011) (Defra, 2009).

The cost of maintaining the SuDS scheme at Matchborough First School was reported to be marginal as landscaping activities are already undertaken for the school grounds (Defra, 2011).

Further analysis of these case study costs and comparison to the costs of equivalent traditional drainage solutions are outlined in Section 4.1.

2.2 Benefits of SuDS

The consideration of the direct benefits of SuDS for an economic analysis is challenging and currently has been undertaken in the UK with broad and general assumptions. The benefits that could be considered by the benefit–cost assessment are outlined below:

1. Reduction in surface water run-off from new and existing developments. This will lead to reduced risk of pluvial flooding events, and reduced run-off loading on surface water sewer systems. The required capacity in the surface water sewer system will be reduced leading to savings in expenditure to increase capacity and energy costs through reduced pumping requirements.
2. Reduction in diffuse pollution in surface water bodies such as rivers and lakes.
3. Provision of an alternative source of non-potable water for domestic and commercial uses, improving water efficiency and reducing water bills.
4. Recharge of groundwater aquifers where appropriate through infiltration measures.
5. Enhancement of biodiversity through habitat provision in SuDS measures such as swales, basins, ponds and wetlands
6. Reduction in energy consumption, particularly through installation of green roofs.
7. Enhanced amenity and quality of life for residents of developments incorporating SuDS, particularly through measures that incorporate water in the landscape or provide recreational space when dry.

The impact assessment for the Flood and Water Management Bill (Defra, 2009) made assumptions regarding the level of surface water flood risk and the value of the damages avoided by SuDS. The damage per property due to surface water flooding was taken to be between £23,290 and £29,430, 2% of homes were estimated to be at risk of flooding from surface water, and the number of homes susceptible to flooding was taken to be between 2.8 million and 3.8 million. Using these assumptions the impact assessment concluded that the net benefit of SuDS to new developments over a 50 year period would be between £56 million and £5,608 million.

The impact assessment for the national SuDS standards (Defra, 2011) also assessed the benefits of SuDS with regard to reduced flood damages and sewerage costs. This included developers saving £600 per property from not connecting to a sewer through the use of SuDS. Water and sewage companies (WaSC) will also benefit from the reduction in the need for future investment and reduced operation and maintenance costs. This assessment has assumed that WaSCs will save £60 per year for each development unit built with SuDS. This figure relates to savings in operation and maintenance, and excludes savings to the wider network which may be significant. General assumptions regarding reduced surface water flood risk leading to avoidance of damages to property were also incorporated in this assessment.

The Environment Agency's assessment of SuDS retrofit (Environment Agency, 2007) monetised the benefits of reduced water bills, indirect capital and operational savings by deferring expenditure on the existing drainage system and reductions in the costs due to surface water flooding. The cost-benefit model developed by this study made broad assumptions about the benefits that the different SuDS measures provide (Table 2.16).

Table 2.16: Benefits of SuDS Measures (Environment Agency, 2007)

SuDS Measure	Estimated Benefits
Rainwater Harvesting	*Water use savings per m^2 of impermeable building area* 66m^3 Detached/semi-detached houses 66m^3 Terraced houses 0.5m^3 Schools 0.5m^3 Leisure centres 0.5m^3 Other non-domestic buildings *Run-off reduction per m^2 of impermeable building area* 0.65m^3 for all retrofit areas
Water Butts	*Water use savings per m^2 of impermeable building area* 6m^3 Detached, semi-detached and terraced houses *Run-off reduction per m^2 of impermeable building area* 0.25m^3 Detached, semi-detached and terraced houses
Permeable Pavement	*Run-off reduction per m^2 of impermeable area* 0.8m^3 Car parking/hard-standing surfaces
Swales	*Run-off reduction per m^2 of impermeable area* 0.8m^3 All retrofit areas

The monetary values of these benefits were also calculated using broad assumptions. The monetary benefits of the reduction in run-off through the use of all four measures were calculated by making assumptions as to the reduction in the number of flooding incidents due to hydraulic overload of the sewer system. A saving of £39,000 per incident was used, however the approach to relate this to the reduction in runoff presented in Table 2.16 is not clear. The water bill savings were estimated to be £2.01/m^3 based on the amount of mains water saved for water saved through the use of rainwater harvesting and water butts.

The Solution Organisation estimated that electricity savings form green roofs could be £5.20 / m^2 / year (The Solution Organisation, 2005).

In the United States the Centre for Neighbourhood Technology has developed a national tool that assesses the cost and benefits of SuDS measures (http://greenvalues.cnt.org/). This gives the monetary value of twenty different benefits of SuDS; these include flood risk reduction, pollutant removal, environmental and amenity benefits. For flood protection the calculator values the benefit at $1,000 per acre-foot (1,230m^3) of reduced flow from a site during the 100 year storm. This equates to $0.81 / m^3 and is based upon flood damage data from case studies in the United States.

2.3 Summary

The current evidence provides varying degrees of information regarding the costs and benefits of SuDS measures and schemes. The unit capital and operational cost of individual SuDS measures is available from several sources and can be used to develop outline estimates of specific schemes. In addition there is sporadic case study evidence for the overall costs of a small number of SuDS schemes. The assessment of benefits is less well developed with very little information on their monetary value. Significant further work is required to enable consistent calculation of the benefits of SuDS.

3 DEVELOPING UNIT COSTS

This study has developed a unit cost database from a synthesis of the available data, which can be used as the basis for generalised costing of SuDS solutions for new developments.

3.1 Unit Costs

To develop the unit costs for installing the different SuDS measures the data obtained from the literature review and presented in Section 2.1 were reviewed to develop a representative unit cost database. The costs have been updated to 2011 prices using the consumer price index.

The capital costs are presented in Table 3.1 and the annual maintenance costs in Table 3.2.

Table 3.1: Capital Unit Cost Database for SuDS

SuDS Feature	2011 Unit Cost (£)			Unit	Data Source
	Low	Medium	High		
Filter drain	125	150	175	/ m^3 stored volume	HR Wallingford (2004)
Infiltration trench	70	75	80	/ m^3 stored volume	HR Wallingford (2004)
Soakaway	125	125	125	/ m^3 stored volume	HR Wallingford (2004)
Permeable pavement	275	337.5	400	/ m^3 stored volume	Average of HR Wallingford (2004), Interpave (2006), Environment Agency (2007) and Lamb Drove Scheme (Royal Haskoning)
Infiltration basin	15	18	20	/ m^3 storage volume	HR Wallingford (2004)
Detention basin	20	23	25	/ m^3 storage volume	HR Wallingford (2004)
Wetland	30	35	40	/ m^3 treatment volume	HR Wallingford (2004)
Retention pond	30	40	50	/ m^3 treatment volume	Average of HR Wallingford (2004) and Stovin and Swan (2007)
Swale	15	15	15	/ m^2 swale area	Average of CIRIA (2007), Environment Agency (2007) and Stovin and Swan (2007)
Filter strip	5	5	5	/ m^2 filter strip area	HR Wallingford (2004)
Exposed green roof	55	55	55	/ m^2 surface area	Solution Organisation (2005)
Green roof covered with sedum mat	110	110	110	/m^2 surface area	Solution Organisation (2005)
Biodiverse green roof	115	115	115	/m^2 surface area	Solution Organisation (2005)
WaterbButt	380	652.5	925	/ m^3 stored volume	Stovin and Swan (2007)
Rainwater harvesting	1140	1140	1140	/property	Roebuck (2008)
Storage tanks	515	553	590	/ m^3 stored volume	Stovin and Swan (2007)

Table 3.2: Annual Maintenance Unit Cost Database for SuDS

SuDS Feature	2011 Unit Cost (£)			Unit	Data Source
	Low	Medium	High		
Filter drain	0.3	0.8	1.3	/ m3 stored volume	HR Wallingford (2004)
Infiltration trench	0.3	0.8	1.3	/ m3 stored volume	HR Wallingford (2004)
Soakaway	0.1	0.1	0.1	/ m2 treated area	HR Wallingford (2004)
Permeable pavement	0.6	1.0	1.3	/ m3 stored volume	HR Wallingford (2004)
Infiltration basin	0.1	0.3	0.4	/ m2 infiltration basin area	HR Wallingford (2004)
Detention basin	0.1	0.3	0.4	/ m2 detention basin area	HR Wallingford (2004)
Wetland	0.1	0.1	0.1	/ m2 wetland surface area	HR Wallingford (2004)
Retention pond	0.6	1.3	1.9	/ m2 pond surface area	HR Wallingford (2004)
Swale	0.1	0.1	0.1	/ m2 swale area	Average of CIRIA (2007), Environment Agency (2007) and Stovin and Swan (2007)
Filter strip	0.1	0.1	0.1	/ m2 filter strip area	HR Wallingford (2004)
Exposed green roof	0.2	0.2	0.2	/m2 surface area	Solution Organisation (2005)
Green roof covered with sedum mat	0.7	0.7	0.7	/m2 surface area	Solution Organisation (2005)
Biodiverse green roof	0.2	0.2	0.2	/m2 surface area	Solution Organisation (2005)
Water butt	N/A	N/A	N/A	N/A	N/A
Rainwater harvesting	120	120	120	/property	Roebuck (2008)
Storage tanks	Unknown	Unknown	Unknown	Unknown	Unknown

3.2 SuDS Scheme Costs

The next step in assessing the overall cost of SuDS schemes would be to assess the whole life cost of packages of measures for typical developments. This would include all capital and operational costs required to ensure performance is maintained over the life of the measures, design costs and any land take costs.

The SuDS Manual (CIRIA, 2007) does not give definitive guidance for the period over which the costs of SuDS should be assessed; however it does state that all significant future maintenance activities are accounted for (CIRIA, 2007). As SuDS are generally related to property development, it is appropriate that a SuDS scheme that deals with runoff from that development is assessed over the development's design life. A typical design life for a residential development is around 100 years, while non-residential developments are usually shorter and 50 years may be more appropriate.

However the development of packages of SUDS is very problematic due to the site specific nature of SUDS solutions as described in Section 2.1.1. Therefore this has not been undertaken by this project, although assessment of SuDS packages would be a useful exercise in the future.

4 COST EFFECTIVENESS OF SUDS

As the benefits of SuDS are challenging to monetise, the cost effectiveness of SuDS measures has been assessed through cost information from case study sites. This has been compared to typical costs for traditional drainage solutions and has included assessment of the relative importance of land take costs.

4.1 Capital Cost Comparison (New Development)

The capital costs obtained from case study examples of new development are presented below for a range of development size and density combinations Table 4.1. This illustrates that the unit costs of SuDS decreases with development size as economies of scale are realised while costs reduce for higher density developments. Several of the case studies considered also developed theoretical costs for an equivalent traditional piped drainage system. These indicate that SuDS systems are cheaper to install than the equivalent traditional drainage solution.

Table 4.1: Capital Cost of SuDS and Traditional Drainage Systems per property

Development Density	Capital Cost per Property (£)					
	Small (<100 properties)		Medium (100-500 properties)		Large (> 500 properties)	
	SuDS	Traddiitional	SuDS	Traddiitional	SuDS	Traddiitional
Dense (urban) (100 properties/ha)	No data	No data	500	1000	No data	No data
Moderate density (40 properties /ha)	5,500	6,000	1,000 – 4,500	3,000 – 5,000	1,000	No data

4.2 Maintenance Costs Comparison

The limited evidence from case studies suggests that SuDS are cheaper to maintain for many new developments. In some circumstances SuDS may be more expensive due to site specific reasons and stringent performance criteria. However where SuDS are predominantly green landscaped SuDS measures such as swales and basins much of the maintenance forms part of the site landscaping and is at little or no extra cost.

4.3 Land take Costs

As discussed in Section 2.1.4 land take can affect the cost of SuDS solutions that implement certain measures. Bastien *et al.* (2010) found for a large site with a density of 75 properties per hectare land take comprised 2.5 – 8% of the total area depending upon the types of SuDS used. For sites of different size and density this is likely to change; for denser sites SuDS measures with lower land take are likely to be used as space is limited. While with more extensive sparser sites the available area for SuDS will be greater and land take is unlikely to be that much of an issue.

The latest data on the price of residential building land in England with outline planning permission is for 2010 (DCLG, 2012). The average price for England is £2,371,549 per hectare; this varies between a maximum of £6,457,285 in London and 1,067,924 in the East Midlands. Using these prices land take costs have been estimated (Table 4.2) assuming the findings of Bastien *et al.* (2010) and based upon the property density of the case study development (75 properties/hectare). At the upper end of this estimate this forms significant proportion of the total costs of SuDS and in some cases present a barrier to implementation. However this is based on evidence from one site alone and therefore the relevance is limited.

Table 4.2: Estimated Land Take Costs

	Land Price (DCLG, 2012)	**Land Take Costs**	
	(£/ha)	**(£/ha)**	**(£/property)**
Upper Estimate	6,457,285	190,000	2,500
Lower Estimate	1,067,924	60,000	800

The typical area of open space required by planning policy is between 16 and 28m^2 per person (Scottish Executive Social Research, 2005) and the average number of people per household is 2.4 (Office for National Statistics, 2012). Based on this assumption the open space requirements for a typical new residential development with a housing density of 40 properties are outlined in Table 4.3. This equates to between 15% and 27% of the total open site area and therefore in this case if the SuDS can be accommodated within the open space it would not require additional land take.

Table 4.3: Open Space Requirements

	Open Space Required	
	(m^2/household)	**(m^2/ha)**
Upper Estimate	38.4	1,540
Lower Estimate	67.2	2,690

Although this indicates that SuDS will be most cost-effective where densities are higher and there is more space for SuDS, the greatest benefit of SuDS can be achieved in areas where housing density is high as there is the greatest potential for flood damage.

Overall the evidence indicates that in certain situations land take may become an issue if extensive SuDS are required to meet the design criteria. However intelligent SuDS design and use of certain types of SuDS measures where space is limited can reduce the impact of land take upon cost of a SuDS scheme. Therefore the cost of land take for a SuDS scheme can be seen to be very site specific. In some cases the available open space or type of SuDS used will allow SuDS to be installed with no land take. However in high density sites or where design requirements are more stringent this cost could become significant.

4.4 Retrofit SuDS

In addition to incorporating SuDS in new development there is potential for certain types of measures to be retrofitted into existing developments. While SuDS in new properties will prevent increases in flood risk from surface water, retrofit SuDS can reduce the existing risk. New build properties only represent a very small proportion of the total housing stock and therefore retrofitting SuDS has an important role to play in controlling surface water.

There is limited evidence for the costs of retrofit SuDS and as with new developments there are numerous site specific factors that lead to significant variation. Therefore further quantitative analysis of this type of SuDS has not been progressed significantly.

Compared to new build, retrofit SuDS are more likely to be taken up where there is an existing sewer capacity or surface water flooding issue, or where SuDS have been identified by a strategic study (Surface Water Management Plan or modelling studies) as a possible solution to these issues. Where this is not the case it will require clear financial or other benefits to the funders for retrofit SuDS to be successfully implemented.

In terms of flood risk reduction a significant opportunity is available through retrofitting of permeable surfaces to existing impermeable surfaces such as car parks and pedestrian areas. These do not require any additional land as there is no change in use, so land take costs are not an issue. Rainwater harvesting systems also have potential however their impact upon flood risk is less than permeable surfaces.

Retrofitting SuDS into existing developments has the potential to provide significant impacts upon surface water flood risk. However where they would be of the greatest use will be in high density locations where it is most challenging to install the measures and the costs will be higher.

4.5 Summary

In most situations SuDS have been shown to be less expensive to install and maintain than a traditional drainage system. There are exceptions and land take could potentially lead to significant increases in the costs of SuDS. However in many cases SuDS can be incorporated into the open space requirements or be designed so that it is a multifunctional use of space such as a permeable parking area.

The exact conditions that affect the switching point between SuDS being more cost beneficial are varied and the associated factors outlined in Section 2.1.1 illustrate this. The costs and benefits of SuDS are very site specific, and further generalisations cannot currently be justified without further research.

Therefore all new development where site specific constraints do not lead to excessive cost implications should find it cost beneficial to install a SuDS system in preference to a traditional drainage system. The larger and less dense the development the more likely it is that this will be the case.

5 SUITABILITY OF SUDS AT THE NATIONAL SCALE

5.1 Introduction

The potential for the assessment of the suitability of SUDS at the national scale has been made. A comprehensive assessment is not possible at present due to the available data on flood risk from surface water and limited knowledge on the monetary benefits of SuDS. Therefore an estimate has been derived using the available information.

5.2 National Estimate

As discussed in Section 2 there are numerous reasons why SuDS may be challenging or unsuitable. However it is technically feasible to install SuDS in all areas apart from those of very high surface water flood risk. In areas of high surface water flood risk SUDS are not effective as the ground is likely to be saturated when required and the SuDS measures will be inundated. Only measures that are located off the ground such as green roofs and elevated rainwater harvesting systems would be effective. However the attenuation of flows from such elevated measures within a typical SuDS scheme is only a small proportion.

The current national data for surface water flood risk gives the areas at risk from a 0.5% (1:200 year) and 3.33% (1:30 year) chance of occurring in any one year event. Therefore to give an indicative estimate of the number of new developments that should be installing SuDS it has been assumed that development outside the 3.33% chance of occurring in any one year event flood risk area will install SuDS measures. The exact level at which SuDS are not suitable due to high levels of flood risk is highly uncertain, however at present using this approach gives the best estimate available at present. Future development in the understanding of surface water flood risk at the national scale will enable this estimate to be improved.

The annual rate of development between 2001 and 2011 in areas outside the 3.33% chance of occurring in any one year event flood risk area has been calculated to be 164,100 by HR Wallingford for their *Spatial analysis of indicators that describe how England's vulnerability to flood risk is changing*. Therefore this represents an indicative estimate of the number of properties that should install SuDS each year. However it is unlikely that this level of uptake will occur due to site specific constraints and there is a large amount of uncertainty with this estimate.

6 CONCLUSIONS AND RECCOMENDATIONS

6.1 Conclusions

The current evidence base for SuDS limits the potential for the assessment of their costs and benefits.

The costs of individual SuDS measures are fairly well understood, as their use increases, the confidence in these unit costs will improve. Developing the costs for typical SuDS schemes for typical developments is challenging and would require significant effort which is outside the scope of this project. Further work to develop typical packages of SuDS would enable assessment of the cost effectiveness of these measures in comparison with traditional drainage.

The current case study evidence illustrates that SuDS can be significantly cheaper to install than traditional drainage. There are certain conditions that will increase the cost of SuDS however the wide range of potential measures that can be applied can often overcome these issues. The maintenance costs for SuDS are also lower than traditional drainage for many schemes. Therefore the whole life costs for SuDS are likely to be less than equivalent traditional drainage systems in the majority of cases.

Land take costs can be significant if certain SuDS measures are used, however the types of SuDS which require greater area are only likely to be installed where there is sufficient space. Therefore land take costs are only expected to be an issue where design requirements lead to the need for significant capacity that cannot be accommodated on the site. Space constraints due to the nature of the site may also lead to land take increasing the cost of the SuDS system. However open space requirements for new development can often accommodate the required SuDS measures which provide both recreational space and a drainage function.

The benefits of SuDS are understood and generally accepted from a conceptual stand point but the actual monetary value of these benefits is hard to determine. The benefits of SuDS for reducing flood risk require a whole system approach and hydraulic modelling to determine the impact they have on surface water flood risk downstream of their location. This is also site specific and generalisations would lead to significant over simplification. SuDS schemes also provide additional benefits beyond drainage and management of flood risk; this includes water quality improvement, amenity, environmental enhancement and biodiversity.

Retrofitting SuDS into existing developments has the potential to provide significant reduction in surface water flood risk. Certain types of SuDS which do not take up significant space and are multifunctional have high potential. However where SuDS would be of the greatest use in high density locations, it is likely that they will be technically challenging to install and the costs will be higher.

Assessment of the cost and benefits at a national scale is limited by the available data on surface water flood risk as well as the limitations in the evidence on costs and benefits alone. An indicative estimate suggests that around 160,000 new properties would be suitable for SuDS each year.

This study shows that SuDS have the potential to contribute to the reduction or prevention of surface water flood risk in a variety of situations, and in many cases will be cost-effective. However site specific constraints will prevent the use of some SuDS measures in some locations due to technical and/or economic factors. SuDS are not appropriate for dealing with other sources of flood risk such as tidal or fluvial flooding from a main river.

6.2 Recommendations

The current state of evidence for SuDS has limitations and there is significant potential for improvements as this evidence base grows.

The cost of SuDS on an individual measure basis has strong grounding, but the cost of a typical scheme or per unit area has proven hard to determine. A comprehensive collation of the costs of SuDS schemes in England would provide valuable information on what the real costs of installing SuDS measures are. This could also incorporate a survey of whether land take issues are being experienced.

An alternative approach could be to undertake a detailed costing exercise for theoretical SuDS packages for typical types of developments. This would build upon the detailed unit cost information that is available and enable general conclusions regarding typical costs of SuDS to be determined using a bottom up approach.

The benefits of SuDS are inherently hard to quantify, however effort is required to develop broad estimates such that the real value of these measures can be understood and realised. This will require improvements in the data at a national level for surface water flood risk. A probabilistic assessment similar to the Environment Agency's National Flood Risk Assessment which considers fluvial and tidal flooding is required.

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Appendix A
Peer Review Comments

Reference	Comment	RH Response
Edmund Penning-Rowsell 1	The ‘sting in the tail’ of this report is contained on the penultimate page where it is said that "it is technically feasible to install SUDS in all areas apart from those of high surface flood risk. In areas of high surface water flood risk SUDS are no (sic) effective as the ground is saturated and the SUDS measures will be inundated". This has always been my interpretation of the problem with these measures; they are only effective for small floods and while these small floods may contribute substantially to annual average damage values, it is the major floods (I would think?) that will be of most significant concern to those seeking adaptation to climate change.	Points noted, the limitations of SuDS have been discussed further in the conclusions section.
Edmund Penning-Rowsell 2	There are obviously a no-regret solution, but almost impossible to retro-fit, and expensive where land is scarce or expensive (which is where you want them because here flood damage potential will be greatest). It is not particularly helpful to be told that SUDS will be cost-effective where housing densities are low and land is cheap, because this is not where the greatest problems of flood risk with climate change can be anticipated to occur: SUDS are most useful where you least need them, and vice versa. Oh dear!	Recognise the point that where retrofitting SuDS will be of most use is in high density locations where it will be technically difficult and more costly to install the measures. This has been added to the discussion of retrofit SuDS and the conclusions.
Edmund Penning-Rowsell 3	The report is perhaps most useful in indicating that is no "silver bullet" here, which many of the more extreme advocates of SUDS pretend is the case.	Agree, text added to discussion to make the point that SuDS are not appropriate everywhere. As with other measures to reduce flood risk they are part of a range of measures.
Edmund Penning-Rowsell 4	It also needs to be noted that SUDS will be completely inappropriate for coastal flooding, and much main river fluvial flooding. It will be important therefore not to exaggerate any effect that may be beneficial.	Text added to discussion to make this clear, part of making the limitations of SuDS clear.
Gary Pender 1	The report provides a comprehensive review of the data available to undertake the analysis and identifies gaps in data and knowledge necessary to answer either of the two questions set out in the brief. In this respect the conclusions are rather disappointing as I though as a minimum the authors could have been specific as to the analysis and data collection strategies that would enable the brief to be fully addressed in future.	Recommendations section enhanced to make clearer how this area of research should be progressed in the future.