CREW CENTRE OF EXPERTISE FOR WATERS

Increasing flood resilience: residential and community runoff retention solutions

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Glossary

Curtilage	The land immediately surrounding a building that belongs to the owner of the building for which they are responsible
Place Making	The people-centred approach to planning and design of public spaces
Regional Control	Regional SuDS are larger controls used as development size increases
Retrofit	Improvement work on an existing building
Site control	Site controls SuDS serve several properties
Source Control	Source control SuDS manage water at or near its source, so that it does not enter the drainage system or is delayed and attenuated before it enters the drainage system
SuDS	Sustainable drainage systems that manage surface water that take into account water quantity and quality (flooding and pollution) as well as biodiversity and amenity
Uplift value	Making allowances for climate change in flood risk assessment to help minimise vulnerability and provide resilience to flooding
Urban creep	The process of converting gardens and other vegetated areas, which help to soak up rain, into built-up (impermeable) surfaces

Executive Summary

Background

In recent years there has been an increased awareness and need to address surface water runoff in urban environments. This includes understanding where flood risk may arise, increase, or change in the future due to increased urban creep and the impacts of climate change on rainfall patterns. To support resilient surface water management in urban environments, the identification, efficacy, cost effectiveness and prioritisation of implementable flood risk management solutions is essential. This aligns with the Scottish Government's "*Water-resilient places – surface water management and blue-green infrastructure: policy framework*", as well as several elements of the National Planning Framework 4 (NPF4) and supports the development of the Flood Resilience Strategy for Scotland. This project can also support local authorities, as part of their climate adaptation duties, in assessing how urban creep and rainfall intensity changes, due to climate change, may impact the future water retention capacity of Scottish urban areas and consequently their ability to be flood resilient.

Research Aim

The project aim was to evaluate and compare the cost effectiveness and efficacy of residential and community property rainwater runoff retention solutions (source control) to increase flood resilience. Source control Sustainable Drainage Systems (SuDS) manage water at or near its source, in order to slow down or stop the water entering the drainage system. The project undertook a literature review, case study reviews and a cost benefit analysis exercise to consider the following key issues:

i. What are the multiple benefits of Source control SuDS and their suitability for different urban land types?

ii. What are the barriers to adopting these solutions at both residential and community property level?

iii. What are the opportunities and recommendations for overcoming these barriers?

The project also sough to develop a decision support infographic to incentivise and support opportunities for stakeholders to take actions at a household or community level.

Key Findings

i. The capacity, treatment performance and cost benefit of different rainwater runoff retention solutions and suitability for different urban land types.

Multiple benefits delivering cost effective solutions

- Well-designed in-curtilage source control Sustainable Drainage Systems (SuDS), both retrofit and in new developments, can deliver multiple benefits to households and communities. Successful implementation can lead to solutions where flood risk reduction benefits become a part of the wider placemaking agenda, a people-centred approach to planning and design of public spaces. For example, the biggest impact of implementing nature-based in-curtilage measures such as raingardens or SuDS trees in urban areas is in providing green spaces for residents and communities, particularly in areas where quality outdoor space is limited.
- Applying cost-benefit analysis tools supports designers to identify the benefit value of different SuDS approaches. Even with limited data the tool can provide an overview of what the main benefits will be, and what range of additional benefits are provided on top of flood risk reduction.
- In community-level projects, community engagement should begin with co-creation sessions at the design phase and continue during the development phase. Community-driven projects may open avenues that attract complimentary additional funding from other funding sources thus sharing the financial burden. (See Case Study 3.1).

Technical performance and land use

- Where space is limited, small footprint techniques can be used such as porous surfaces, underground attenuation and rain barrels. For single properties, the most suitable retrofit option for attenuation that is low in cost and easy to implement are rain barrels. Whilst rain barrels are simple to retrofit, routine maintenance to reduce the stored volume of rainwater will be required in winter months to ensure efficacy. Smart rain barrels provide automatic release of stored rainwater, but these are more expensive and more difficult to retrofit.

- Boxed, above-ground raingardens are also suitable where space is limited and provide treatment as well as attenuation. They can also provide amenity value for the resident through offering an additional area for planting. In-ground raingardens can provide more amenity benefit but also require more useable land and access for excavation.
- For new building development, amenity benefits from SuDS can add value to homes whilst also managing surface water flooding risks. By using proprietary SuDS systems, it is possible to achieve 1 in 200 year protection in-curtilage. In-curtilage solutions also provide the opportunity to decrease the size of downstream infrastructure (pipes, manholes and or SuDS) enabling the creation of additional space in new developments. (See Case Study 2.2).

ii. Impact of urban creep and the impact of changes in rainfall duration and intensity as a result of climate change.

Efficacy through the lens of climate change

- Increased rainfall intensity, duration and frequency are well-recognised implications of climate change. Studies have indicated that climate change will result in much more frequent and intense rainfall over Northern Europe. In a Scottish context, winters are projected to become wetter, both in terms of the total amount of rainfall and the number of wet days. This is likely to impact how drainage systems perform which highlights the crucial role of sustainable systems in flood management.
- Urbanisation and increased rainfall intensity will raise drainage flow volumes, which will cause more frequent and severe pluvial floods. More research on the specific impacts on sustainable drainage systems is required to fully understand the impact of increased rainfall intensity, duration, and frequency. Studies to date are very limited but indicate that routine maintenance will become more critical to ensure efficiency of performance.
- Studies on urban creep have demonstrated that areas with increased urban creep exhibit faster hydrological response times, whilst more frequent and intense rainfall is being driven by climate change. This combination presents an increased risk of flooding to urban environments that have high percentages of impermeable surfaces within catchments.
- Retrofit in-curtilage source control is an effective approach to reduce the impact of increased rainfall intensity, duration and urban creep on drainage systems. Managing water at source so that it does not enter, or is delayed and attenuated before it enters the drainage system, can mitigate the impact of climate change on existing drainage infrastructure. (See Case Study 1.1).
- In community projects, converting previously impermeable surfaces into permeable surfaces is also an effective approach to reducing the impact of urban creep and climate change. This allows rainwater to infiltrate into the ground as opposed to running off impermeable surfaces into piped infrastructure. (See Case Study 1.3).

iii. Barriers to adopting measures at both residential and community property level.

Barriers for adoption

Currently, the use of in-curtilage source control is low, and there remain barriers to wide-scale use. These barriers can be categorised as:

- Legislative – SuDS are required for new development, but source control is not mandatory. Most developments use only site and regional control where rainwater is directed away from properties and is managed centrally through solutions such as attenuation ponds.
- Regulatory – approval of SuDS design and regulation sits within planning policy and Scottish Water's technical standards, but these do not include in-curtilage source control. Ensuring ongoing compliance of in-curtilage source control would rest with Local Authority Building Control. Local authorities are reluctant to promote in-curtilage source control as the resident may not properly maintain the system, causing the solution to fail with the potential for localised flooding.
- Financial – the cost to design, implement and maintain in-curtilage source control for the resident. In Scotland where for the vast majority of households, the water supply is not metered and is based on Council Tax bands, there is no financial gain to the resident to be made from retrofitting source control techniques to attenuate and store rainwater for reuse.

- Social – awareness and acceptability of in-curtilage source control. Residents may not fully understand the environmental benefits of retrofitting source control. Cheaper attenuation devices such as standard rain barrels are typically plastic and may not be considered aesthetically desirable. If residents only have a small outdoor space, they may be reluctant to retrofit source control measures such as a rain garden when they do not fully understand the benefits.

Recommendations

The case studies demonstrated the importance of stakeholders including statutory authorities, local communities, and individual consumers in the successful implementation of SuDS. The document *Towards Scotland's first Flood Resilience Strategy* (Sniffer 2023) identified the key pillars of People, Place and Process to achieve a flood resilient Scotland. In the context of these pillars, and also reflected in the *Flood Resilience Strategy Consultation Document* (May 2024), there are further opportunities to take action to support the increased uptake of in-curtilage source control in Scotland:

People

- Engage with consumers as early as possible when statutory authorities are improving surface water management through retrofit techniques. This will provide opportunities for consumers to co-design and inform the decisions for source control measures ensuring that consumers' needs are met, and amenity benefit is maximised.
- Increase awareness around the impact of urban creep and how removing permeable surfaces from properties can have a significant impact on flood risk. Residents can be encouraged to do their bit to mitigate climate change impact by introducing source control techniques to compensate for the additional runoff associated with urban creep.
- Ensure efficacy of new-build and retrofit SuDS in the long-term, particularly in the face of climate change. Develop maintenance guidance documents for residents who choose to include in-curtilage source control on their property. This would encourage local authorities to promote in-curtilage source control since it will inform residents how to maintain SuDS.

Place

- Include source control at the design stage of projects, with additional focus on placemaking. This will help to produce sustainable, well-designed places and homes which meet people's needs to improve their overall quality of life.
- Develop collaboration amongst different stakeholders including statutory authorities, local communities, and individual consumers to enhance the co-benefits of source control. This is particularly important in community projects which create quality spaces in urban areas where green space is either limited in its amenity value or lacking in terms of footprint. Involving residents will ensure that the space is designed to be useable by the community. This can be achieved through consultation and engagement in design workshops, surveys and community engagement.

Process

- Coordinate approaches to identify and develop responses to surface water flooding among stakeholders including statutory authorities, local communities, and individual consumers. Mainstream the requirement for statutory authorities (i.e. local authorities and Scottish Water) to coordinate resources to manage and reduce flood risks. Successful partnerships include the Metropolitan Glasgow Strategic Drainage Partnership (MGSDP) and the Dundee Drainage Partnership. Case Studies 1.3 and 3.1 are examples of integrated flood management that reduces flood risk, but also creates amenity value for residents.
- Encourage the use of in-curtilage source control to decrease the size and cost of site control SuDS. In-curtilage source control can be encouraged through financial incentives, such as reducing the fixed water charge fee in council tax if source controls are implemented and maintained by the resident. Governments may also consider subsidising the cost of in-curtilage source control through grants, similar to household energy efficiency grants.

- Encourage legislative changes that require the use of in-curtilage source control for all new developments to ensure that all new properties have source control. This would create a level playing field amongst developers who would all have to include in-curtilage source control. This would overcome the financial barriers associated with unequally passing on the costs of source control to the consumer. Including source control also allows the opportunity to decrease the capacity of regional and site control techniques which can increase space for development.

Further recommendations related to research needs:

- There is a lack of research which investigates the behaviour of specific SuDS measures and how they will perform under different climate scenarios, i.e. more intense and frequent rainfall in winter months. This is particularly important in understanding maintenance requirements to ensure efficacy.
- More research on uplift values used by designers to account for the influence of urban creep and climate change. There has been limited research on uplift factors and if they are fit for purpose in the Scottish context.
- Improved availability of real cost data across the sector to enhance the cost benefit analysis process for In-curtilage source control. Uncertainty and lack of clarity relating to delivery and design costs is a key barrier to the implementation of SuDS with assumptions required when assessing benefit value of options at the early stages of projects.

1 Introduction

1.1 Background and scope

The Centre of Expertise for Waters (CREW) commissioned a capacity building project within CREW's Hydrological Extremes, Coasts and Risk Management theme, aligned to Scottish Government's Water-Resilient Places and National Planning Frameworks, which supports the development of the flood resilience strategy for Scotland. Urbanisation has been shown to increase flood risks due to the increase of impermeable surfaces as well as the urban heat island effect which results in more prolonged intense periods of rainfall (Yazdanfar *et al*., 2015). As a result, there has been an increased awareness and need to address the issue of surface water management in urban environments.

To mitigate flood risks and increase resilience to flooding events, it is crucial that efficient and cost-effective solutions are identified. The *Water-resilient places – surface water management and blue-green infrastructure: policy framework* (Scottish Government, 2021) tries to quantify and account for the wider benefits to health and wellbeing, as well as the benefits to flood risk reduction. *Towards Scotland's first Flood Resilience Strategy: Engaging with Stakeholders* (Sniffer, 2023) supports the development of the strategy to create flood resilient places. It sets out a vision where "land management and placemaking decisions at all scales reflect good practice for flood resilience, achieving multiple benefits and working with nature, with long-term thinking and putting people and nature first". Flood risk reduction and the promotion of more resilient, particularly water-resilient, urban spaces are two objectives that can be achieved through the implementation of sustainable drainage solutions (SuDS). Enabling these objectives requires that decision makers, including those involved in the planning system, to have the knowledge needed to create resilient places and how to effectively involve communities. Decision support systems are crucial tools for handling the complicated issues posed by urbanization, particularly when dealing with surface water management's intricacies and reducing the increasing danger of flooding that comes with urban expansion (Ferrans *et al*., 2022).

1.2 Project objectives

The aim of this project is to evaluate and compare the efficacy and cost-effectiveness of residential and community property rainwater runoff retention solutions (i.e., source control) to increase flood resilience. To support future planning and policy decisions, decision support infographics were developed for typical solutions both in residential and community spaces. In support of the overall aim of this project, the research team compiled a review of different rainwater runoff retention solutions, both residential and community property. The review considered the following:

i. The capacity, treatment performance and cost benefit of different rainwater runoff retention solutions and suitability for different urban land types.

ii. Impact of urban creep and the impact of changes in rainfall duration and intensity as a result of climate change.

iii. Barriers to adopting solutions at both residential and community property level, and opportunities to overcome them.

1.3 Outline of the report

The report structure follows a three-stage methodology adopted to fully address the project objectives in Section 1.2. Section 2 summarises the findings of the literature review of different rainwater runoff retention solutions, both for residential and community property. Section 3 provides an overview of a range of case studies providing examples of different in-curtilage source control techniques identified from the literature review. Section 4 presents the barriers to implementation of in-curtilage source control. Section 5 provides conclusions and high-level recommendations based on the literature review, and case studies. Appendix A presents the full literature review, Appendix B presents the full evaluation of the Case Studies, and Appendix C presents the decision support infographics.

2 Literature review

Sustainable Drainage Systems (SuDS) are drainage solutions for managing urban water runoff and are designed to try to maximise the potential opportunities and benefits that can be drawn from the management of surface water (Woods Ballard *et al.,* 2015). SuDS are designed to temporarily store water during rainfall events, reduce peak flows and surface water runoff, a process commonly referred to as ***slowing the flow***.

SuDS can take many forms both below and above ground and can include nature-based solutions such as vegetative strips, tree planting, as well as proprietary and manufactured products (Woods Ballard *et al.,* 2015). SuDS are designed in line with the ***four pillars*** concept (Woods Ballard *et al.,* 2015):

- **Water Quantity:** this controls the quantity of runoff to support the management of flood risk, and to maintain and protect the natural water cycle.
- **Water Quality:** this manages the quality of the runoff to prevent pollution.
- **Amenity:** this creates and sustains better places for people.
- **Biodiversity:** this creates and sustains better places for nature.

SuDS are used at differing geographical scales, commonly referred to as source control, site control and regional control. Source control SuDS manage water at or near its source, so that it does not enter the drainage system or is delayed and attenuated before it enters the drainage system (Woods Ballard *et al.,* 2015). Site controls may serve several properties, and regional SuDS are larger controls used as development size increases. The Flood Hub (2021) lists three different types of source control:

- **Infiltration:** this method involves the infiltration of the collected runoff into the subsoil. This water permeates through the subsoil to the water table.
- **Detention:** these methods involve permanently or temporarily storing surface water runoff in storage areas at the surface, i.e. ponds or basins.
- **Conveyance:** these methods involve the transfer of surface water runoff to a point of discharge. This can be achieved through either underground pipes or by vegetated channels on the surface.

Table 1, below, provides a description of all the SuDS techniques reviewed in this study and is based on descriptions provided in the CIRIA SuDS manual (Woods Ballard *et al.,* 2015).

Section 2.1 presents the conclusions from the literature review. The full literature review is available in Appendix A.

2.1 Literature review conclusions

This literature review investigated source control SuDS for residential and community property. It considered the future implications of climate change and urban creep, as well as reviewing policy and guidance, and how these systems are analysed in terms of costs and benefits.

Increases in rainfall intensity, duration and frequency are well-recognised implications of climate change. Studies have indicated that climate change will result in a large uplift and steepening of intensity-duration-frequency curves over Northern Europe which will result in much more frequent, intense rainfall. More intense and more frequent rainfall is likely to impact how drainage systems perform which highlights the crucial role of sustainable systems in flood management. The design of the drainage systems must account for the likely impacts of climate change and changes in impermeable area over the design life of the development. The hydraulic design for new development in Scotland must meet local authority guidelines (Dundee City Council, 2020) i.e.:

- The post development critical 1:30 year rainfall event (plus allowance for climate change and urban creep) is managed (attenuated) by the surface water drainage system, and
- The difference between the post development critical 1:30 year and 1:200 year rainfall event (plus allowances for climate change and urban creep) generated from the site is accommodated within the site and must not create or increase flood risk to properties and/or sensitive/critical infrastructure on and off the application site.

Source control forms part of the larger site design, but source control techniques are usually designed to manage, so far as possible, any discharge from the site for the majority of rainfall events of less than 5mm. The difference between the design and the 1:200-year return period is managed by the site control SuDS. Subsequently, since source controls (like all SuDS) are designed to temporarily store runoff and slow it down; more frequent, intense and longer rainfall events as a result of climate change will impact how source controls operate and the available storage. Table 2 provides a review of how changes in rainfall as a result of climate change can impact different SuDS techniques.

The Scottish Government's (2021) *Water-resilient places – surface water management and blue-green infrastructure: policy framework* sets out that Scotland "should take a placemaking approach to achieving blue-green cities and water resilience involving partners in the public and private sectors, the third sector, individuals and communities." The combined work of organisations responsible for surface water management provide a mechanism for policy formation, implementation and monitoring which has resulted in appropriate management of surface water runoff, flood protection, natural flood management and flood warning. An example of policy formation, implementation and monitoring is the requirement for soakaways to be located at least 5m from a building and from a boundary in order that an adjoining plot is not inhibited from its full development potential, as a method to prevent damage to stability of building, particularly foundations. National Planning Framework 4 (2023), the national spatial strategy for Scotland plays an important role in flood risk management. Planning authorities have the power when determining planning applications to require developers to implement specified SuDS design and maintenance schedules. Section 7 of the Sewerage (Scotland) Act (1968) has enabled agreement between Scottish Water and local authorities to share responsibility for a single combined surface water system, thus eliminating the need and over-design of a two-pipe surface water sewer system. This agreement also specifies the terms and conditions agreed between both parties for the provision, management and future maintenance of the system. The key benefit of this process is bringing the responsibility of SuDS within regulatory bodies and defining the ongoing operation and maintenance obligations.

Table 1. SuDS techniques.

SuDS Technique	Description (based on Woods Ballard *et al.*, 2015)
Green roofs	Green roofs are areas of living vegetation installed on the roofs of buildings and other structures. Green roofs can be categorised as either extensive or intensive roofs which have shallower and deeper substrates, respectively. Extensive roofs have a lower maintenance and involve simple planting. Intensive roofs can support a wider variety of planting and will therefore have more maintenance requirements.
Raingardens	Raingardens are a type of bioretention system. In-ground raingardens are shallow landscaped depressions that use engineered soils, filter and drainage layers to provide water retention and treatment. Boxed raingardens are raised above ground level in a boxed structure that perform a similar function where space is limited.
Permeable surfaces	Permeable surfaces are typically pavements that can carry pedestrian and/or vehicular traffic that allow rainwater to infiltrate through the surface into the underlying structural layers. Porous pavements allow for infiltration across their entire surface, whilst permeable pavements allow water to infiltrate through the void spaces between impermeable blocks.
Rainwater harvesting	Rainwater harvesting is the collection of rainwater runoff for reuse. Runoff can be collected from roofs and other impermeable surfaces, be stored, and reused as required. These can be complex, below ground systems, or relatively simple above ground systems like rain barrels. Rain barrels are the most straightforward and common technique of rainwater harvesting.
Soakaways	Soakaways are excavations filled with a void-forming material that allows for the temporary storage of water before it soaks into the ground. Some soakaways use granular material as the permeable medium, but many now use geocellular units. Soakaways are typically fitted with inspection chambers for maintenance purposes.
Swales	Swales are shallow, flat bottomed, vegetated open channels designed to convey and often attenuate surface water runoff. Generally, these are used for roads, paths and car park drainage.
Trenches	Infiltration and filter trenches. Infiltration trenches are similar to soakaways but are linear structures. They are typically shallower than soakaways and can include a perforated pipe, but this is not always required. Filter trenches are used where infiltration is not possible or desirable, providing attenuation and conveyance, similar to swales.
SuDS trees	SuDS trees generally refer to trees planted within a SuDS infiltration component such as a bioretention system or planted within a planter structure which has been designed to collect and attenuate runoff by providing additional storage within the planter structure.
Proprietary SuDS	Proprietary SuDS are manufactured products. These are typically (but not always) below ground structures designed for a specific purpose such as stormwater management return period or specific pollutant removal.

Use of in-curtilage source controls is low within Scotland and the rest of the UK, and there are a number of challenges to wide scale use. From a volumetric perspective, where site control SuDS will be vested within Scottish Water, in-curtilage source controls are not included within the hydraulic design for the site as their future operation cannot be safeguarded. This is contradictory to design principles where attenuation volume is managed throughout the management train at source, site, and regional levels. The limited use of source control within Scotland is driven by the concern that source controls may not be maintained or subsequently removed (e.g., removal of porous surfaces or downpipe disconnection devices in raingardens and water barrels). Responsibility for in-curtilage source control remains with the owner of the property, and regulation of in-curtilage construction and ongoing standards is the responsibility of the local authority. Regulation of individual property level source controls would be extremely challenging based solely on the number of properties, not to mention the variety, types and detailing of source control used.

Table 2. Qualitative analysis of the likely impacts of climate change.

SuDS techniques	Impact of increased rainfall intensity, duration and frequency
Green roofs	Research conducted by Hamouz *et al.,* (2020) using field trials of green roofs under different rainfall intensity, frequency, and durations using an artificial rainfall simulator. This research found that the performance of the green roof is heavily dependent on initial water content, and that the performance was also worse when the shape of the hyetograph shows a peak towards the end of the storm. Although the performance was more sensitive to the initial water content compared to the shape of the hyetograph. Later peaks in the hyetograph influencing performance can also be linked to increases in water content given the green roof is likely to be saturated before the peak occurs. This research shows that runoff is likely to increase with more intense rainfall events, and with rainfall events that occur more frequently as the water content is more likely to remain above optimum levels. The same study also showed that including a clay layer to increase water holding capacity improves performance overall.
Raingardens	The performance of raingardens is linked to how much storage capacity is available within the raingarden, and the permeability of the surrounding soil in the case of in-ground raingardens. With increased intensity, duration, and frequency rainfall events, it is likely that raingardens will become more saturated between rainfall events, lowering storage capacity to attenuate any subsequent rainfall events. With raingardens surrounded by lower permeability soils, infiltration rates will be low. This means that increased intensity, duration, and frequency events will cause raingardens to reach capacity quicker as inflow will be at a much faster rate than the infiltration rate of the raingarden into the surrounding soil. Increased rainfall events may also cause the water table of the soil to rise over time, meaning capacity of the raingarden is reduced.
Permeable surfaces	Given that permeable surfaces require regular routine maintenance to ensure efficacy, it is likely that maintenance would be required more frequently since more frequent rainfall will result in clogging of the pore spaces that allow infiltration through the surface. Depending on the permeable paving design, increased rainfall intensity, duration, and frequency may also cause capacity issues. If the pavement is designed to infiltrate into the surrounding soil, then inflow in the substructure through the paving surface is likely to be faster than the infiltration into the surrounding soil causing capacity issues. The same issues may occur where there is a structure for attenuation where an outfall is connected to the local drainage network. If intense rainfall followed a period of dry weather, there is likely to be blockages in the pore spaces because of the 'first flush' (Mangani *et al.,* 2005) effect where the settled debris on the surface is washed into the drainage system quickly after the beginning of the rainfall event.
Permeable surfaces **Rainwater harvesting**	Rainwater harvesting relies on having sufficient storage capacity for when rainfall events occur. With increased rainfall intensity, duration, and frequency, it is likely that water will be stored faster than it is being reused for other purposes, particularly in winter months when there is reduced water requirements (watering gardens, washing cars etc. which is normally where most water is reused) which can result in the capacity of the rainwater harvesting system being reached more frequently. More maintenance to ensure water levels remain below capacity may be required. Water levels can be lowered through releasing some of the stored water. Some systems have automatic drawdown systems that will automatically release some of the stored water at a certain capacity. These systems will be more climate resilient, but may still become overwhelmed with increased rainfall intensity, duration, and frequency. Rainwater harvesting techniques, such as rain barrels, may also provide water storage during periods of drought, which is also a well accepted consequence of climate-change.

Table 2. Qualitative analysis of the likely impacts of climate change.	
SuDS techniques	**Impact of increased rainfall intensity, duration and frequency**
Soakaways	Soakaways are a type of infiltration drainage system that relies on infiltration into the surrounding soil. Like other infiltration methods, with higher intensity, duration, and frequency rainfall events, there is a possibility that the soakaway capacity would be breached more frequently as the inflow from storm water during rainfall events will be faster than outflow through infiltration. Soakaways will typically have a filter layer that is used to provide some treatment. With more frequent and intense rainfall, it is likely that more maintenance will be required to ensure the filter layers do not become blocked which will reduce efficacy. It is also likely, that like other systems that provide attenuation, capacity will be reduced as the storage system may still be saturated from previous storms which reduces the overall efficacy of the soakaway.
Swales	The primary purpose of swales is to provide some attenuation, but mostly to convey stormwater from one location to another. The capacity of the swale will be designed based on the chosen storm return period. With increased rainfall intensity, duration, and frequency, there is a possibility that the swale capacities will be breached more frequently and cause flooding around swales. Longer duration storms can also generate flooding as more intense rainfall over a longer period of time may cause swale capacities to be breached.
Trenches	Trenches are very similar to soakaways in their function. Like other infiltration methods, with higher intensity, duration, and frequency rainfall events, there is a possibility that the soakaway capacity would be breached more frequently as the inflow from storm water during rainfall events will be faster than outflow through infiltration. If the trench has a filter layer, then there is a possibility that the filter layer will require more frequent maintenance to prevent blockages. It is also likely, that like other systems that provide attenuation, capacity will be reduced as the storage system may still be saturated from previous storms which reduces the overall efficacy of the trench.
SuDS trees	The impact of higher intensity, duration, and frequency will depend on the design of the SuDS tree system. Some SuDS trees are designed with infiltration systems of granular material within the root zone, and other with geocellular structures although the basic function to infiltrate into the surrounding soil remains the same. Therefore, with higher intensity, duration, and frequency storms there is a likelihood that there may be capacity issues as with other systems relying on infiltration of attenuated storm water. Some research has shown that evapotranspiration increases with temperature (Swelam et al., 2010), meaning that a warmer climate could result in greater rates of evapotranspiration from the tree which could mitigate some of these issues. However, it is unlikely that this would be significant enough to entirely mitigate capacity issues. It has also been demonstrated that higher humidity can also reduce rates of evapotranspiration.
Proprietary SuDS	Because proprietary SuDS are so variable in design and purpose, it is difficult to attribute any potential climate change related issues with their efficacy. However, given these are designed to specific storm return periods, it is likely that larger storm return periods (i.e. lower probability events) will become more frequent, meaning that these systems may become overwhelmed and cause localised flooding more frequently with increased rainfall intensity, duration, and frequency.

The main benefits of SuDS identified through the review in addition to water management are improved health, amenity and aesthetic value, and biodiversity. Benefits can be subdivided into the benefits accrued by the property owner and the benefits accrued by the wider community. Addressing flood risk is often the initial primary driver for action, however successful implementation of SuDS can lead to solutions where the flood risk reduction element becomes part of a range of wider benefits.

Table 3 below provides a summary taken from the literature review of the relative capital costs, maintenance costs, and the relative suitability for retrofit as well as the range of multiple benefits each solution will bring to the consumer.

Table 3. Summary of surface water management techniques compiled from literature review.									
SuDS technique	Challenges to retrofit	Relative capital costs	Relative maintenance costs	Water quality	Water quantity	Amenity	Biodiversity	Cooling effect	Air quality
	1 (low) to 5 (high)			**x** means benefit relevant to SuDS technique					
Green roofs	4	4	2	x	x	x	x	x	x
Raingardens – boxed	2	2	2	x	x	x	x		x
Raingardens – in-ground	3	3	2	x	x	x	x		x
Permeable surfaces – pavement	3	3	3	x	x				
Permeable surfaces – other (gravel, woodchip etc.)	3	3	2	x	x				
Rainwater harvesting – standard rain barrel	1	1	1		x				
Rainwater harvesting – smart rain barrel	3	3	2		x				
Soakaways	4	4	3	x	x				
Swales	4	2	2	x	x				
Trenches	3	2	3	x	x				
SuDS Trees	4	4	3	x	x	x	x	x	x
Attenuation pond	5	5	4	x	x	x	x		x

A qualitative summary of relative suitability for retrofit, cost, as well as the range of multiple benefits is provided for each solution below:

- **Green roofs:** Green roofs provide a wide variety of benefits and are well researched as a surface water management solution. The range of benefits include thermal benefits (heating and cooling benefits), air quality benefits, biodiversity benefits and overall amenity benefit. Green roofs, however, are relatively expensive compared to other surface water management solutions in terms of capital cost. Maintenance costs are relatively minor although this depends on the type of green roof installed. The bigger barrier in terms of implementing green roofs as a retrofit solution are the potential structural alterations that could be required. Many houses will not have the required roof structure to withstand the additional increases in load that comes with a green roof, so structural alterations to strengthen the roof may be required. This would require a survey from a suitably qualified structural engineer, as well as building warrant drawings prepared by an architect and engineer. This makes the implementation of a green roof as a retrofit potentially even more expensive in terms of capital costs.
- **Raingardens:** Raingardens in this context can either be in-ground raingardens or boxed raingardens. In-ground raingardens will require more work to retrofit compared to boxed raingardens. Both will provide amenity benefit, enhance biodiversity, and provide benefits in terms of air quality. Choosing either boxed or in-ground will depend on a few factors. Firstly, in-ground raingardens are only suitable where the water table (i.e. the distance to the top of the water level below ground level) is not shallow (close to the surface). If the water table is close to the surface, in-ground raingardens will have a permanent water level which will limit the capacity in terms of how much can be stored, reducing overall efficacy. In-ground raingardens will also require more capital cost as excavation and replacement of the soils in the garden of the homeowner is required. Boxed raingardens are much easier to install and are ideally suited where space is restricted. Previous projects, such as the 10,000 raingardens project in Melbourne, have demonstrated that raingardens can be easily built and installed by homeowners with sufficient instruction.

- **Permeable surfaces:** Permeable surfaces (pavement and other surface types) are most likely to include permeable paving for a driveway, although permeable surfaces may also include areas of hardstanding other than a driveway inside the property boundary. Permeable paving provides treatment, but no other amenity benefits that are associated with nature-based solutions. Permeable driveways are useful for source control of pollutants, since the majority of surface water pollutants from within the property boundary are associated with the runoff from areas with vehicles.
- **Rainwater harvesting:** Rainwater harvesting is any technique that captures and stores rainwater but provides no treatment. Typically, this is most likely to be a rain barrel where the downpipe from the roof drainage is disconnected from the sewer and instead connected to the rain barrel. However, some underground solutions can also be used. Rain barrels are a relatively cheap option for harvesting rainwater because they can be purchased off the shelf and installed relatively easily. Standard rain barrels are the cheapest option, but there may be issues with capacity in winter months if the system cannot automatically regulate the water level in the barrel. With more rain in these winter months, the system needs to be drained regularly to ensure there is sufficient capacity to store water in rainfall events. Some rain barrels will have a drawdown system to automatically release water when it reaches a certain capacity, and more expensive 'smart' rain barrels can use weather forecast data to drain water in advance of a rainfall event. These are much more expensive than standard rain barrels, and in the case of a smart rain barrel, will also need electricity supply.
- **Soakaways:** Soakaways are a below ground engineered infiltration system. They provide treatment and storage capacity but provide no amenity benefit. Capital costs are relatively high, and they are generally not considered as an option for retrofit.
- **Swales:** Swales are generally not used at house level (but may be suitable for community buildings) and are primarily used to convey surface water from one location to another location. Swales offer limited amenity benefit. Small swales may be an option at property level to convey water from a disconnected downpipe to an in-ground raingarden system.
- **Trenches:** infiltration and filter trenches are shallow excavations filled with stone that create temporary subsurface storage of stormwater runoff. Ideally suited to receive runoff from lateral inflow from an impermeable surface, such as a driveway. Can be retrofitted within the property boundary. Capital costs are lower than an engineered soakaway system. Regular maintenance to prevent clogging of the upper layers is required to ensure efficacy.
- **SuDS Trees:** SuDS trees are engineered tree systems that combine tree planting with other SuDS components like engineered soil mixes or geocellular systems. SuDS trees are a specific type of surface water management and is not simply planting regular trees which is why these systems are generally very expensive for single properties. Such systems are normally used at development level or within community settings to enhance biodiversity, air quality, provide carbon sequestration benefits, and amenity value.
- **Proprietary SuDS:** Proprietary SuDS are off-the-shelf solutions that are manufactured for source control surface water management. These can also provide treatment but are generally for quantity control of surface water. Capital costs, maintenance costs, and challenges with retrofit will vary depending on the type of solution used.

The case studies in Section 3 support the literature review findings to further explore sustainable drainage techniques and their performance, scalability, and applicability for retrofit.

3 Case Studies

The full analysis of the case studies is available in Appendix B of this report. This section provides an overview of how the case studies are structured and presents some key findings of the case studies.

The case studies investigate the suitability of different in-curtilage source control techniques in the context of urban land type, climate change and urban creep. They explore issues around approval and regulation, design, detailing and survivability, public acceptance of different techniques and benefits to end users. Each case study sets out the driver, how it was funded, partners and stakeholders, a description of the case study location, site description and source control techniques. The case studies also provide a technical review of the performance of the systems, design, sequencing and survivability issues and potential issues with maintenance.

An evaluation of benefits and costs in reducing the incidence of flood and wider benefits to the community is also undertaken within the case studies. The purpose is to establish a clear structure of benefits vs costs based on the availability of data in each case study using the CIRIA B£ST tool. For each study, the B£ST tool was used to provide a summary of the benefit value of each of the surface water management techniques implemented, including quantified values for the additional benefits these techniques bring as well as reduction of flood risk. The final part of each case study collates the opportunities and challenges of source control techniques, homeowner options for retrofit, opportunity for new builds to implement a suite of options, role of the developer, role of consumer, partnership working, community engagement and stewardship. Table 4 summarises the four case study theme groupings.

3.1 Case study structure

3.1.1 Introduction

The introduction includes setting the scene for the development of the case study in question. This section includes the drivers for implementation of the surface water management techniques and if these drivers were primarily driven as a method of flood reduction or others social drivers, how the project was funded and also lists the key stakeholders and partners involved in the project and some images.

3.1.2 Case study location

In this section maps are provided to show the location of the case study. It also includes a site description, i.e. is the location within an urban setting, is it open to the public, is it for public use or is it homeowner use only.

3.1.3 Technical review

This section reviews the technical aspects of the design of the system, including sequencing and survivability, issues and potential issues with maintenance, and an assessment of the potential impacts of climate change based on an assessment of the literature and the qualitative assessment of each SuDS technique presented in Table 2.

3.1.4 Evaluations of benefits and costs

The benefits and the benefit value have been analysed using the B£ST tool developed by CIRIA. In each case study, a coarse assessment has been undertaken which is a simplified assessment of what benefits exist with different surface water management solutions, and an estimate of these

Table 4. Case study groupings.

1	Residential Source Control - Retrofit in-curtilage	Illustrative case studies showing homeowner options for retrofit, comparative costs, footprint, quality and quantity impact and challenges of implementation. Drivers for homeowners implementing retrofit source control.
2	Residential Source Control – New-build in-curtilage	Case study showing opportunity for new build to implement a suite of options, role of the developer, role of consumer in attenuation, potential for development of standard details for developers.
3	Community Level Source Control – Partnership delivery of source control	Case study illustrating partnership working, how retrofit interventions were enabled, funded, and maintained, and the multiple benefits for different groups.
4	Community Level Source Control – Community engagement and stewardship	Case study illustrating the role of community in maintaining SuDS, their involvement at stages in design, community engagement and stewardship.

values. The assessment is more accurate with more complete data, but even with limited data the tool can provide an overview of what the main benefits will be and what range of additional benefits are provided on top of flood risk reduction.

The Coarse Assessment uses 6 questions to generate data for amenity value and for flood risk. These questions are answered by the user of the tool and are relatively simple questions to answer meaning there is no real need to have an in-depth understanding of the surface water management systems utilised, which enhances the useability of the tool. The significance of these values is then modified using further screening questions, which again, are answered by the user. These modifications to the significance are through rating the criteria as, not significant at all (represented by two negative signs) to very significant (represented by two positive signs). Neutral is also an option. Where some benefits don't exist, the user can choose not to evaluate these as part of the Coarse Assessment.

The B£ST tool uses standard values to determine the benefit value of each of the assessment criteria, and where applicable, provides a lower, central, and upper estimate. For flood risk reduction, these values are all the same values. In these assessments, none of the standard values have been changed. The monetary values assigned are the result of an extensive literature review undertaken by the research team developing the tool, and the values come from a range of sources which includes governmental bodies such as the Department for Environment, Food & Rural Affairs (DEFRA), and research literature. The CIRIA RP1074: Making B£ST Better report provides a full list of evidence considered, including the number of evidence sources reviewed, the qualitative evidence, quantitative evidence and monetary values for each of the benefit categories in the tool (CIRIA, 2018). In the most recent B£ST tool, some of the monetary values have been updated to account for inflation.

There were some challenges in obtaining actual costs for each of the case studies presented, given that these costs may be considered as commercially sensitive. Where actual costs have been provided by the stakeholders involved in each of the case studies, these costs have been used to provide a benefit-cost ratio. The actual costs provided does not include a breakdown of individual costs for each surface water management solution but does include the cost for all of the drainage work including construction costs. Where costs are not publicly available or have not been provided by stakeholders involved in the project, costs have been estimated by the research team using a database of SuDS costs that has been developed by researchers at Abertay University on a range of research and consultancy projects, such as the development of a surface water management plan for Glasgow City Council. This database was last updated in 2016, a yearly inflation of 3.5% has been added to bring these estimated costs into line with what costs might be in 2024 based on the values from 2016. It should be noted that these costs are indicative costs only. In each study, a benefit-cost ratio is shown which is based on the indicative costs of the surface water management measures against the indicative benefits provided by the B£ST tool.

3.1.5 Lessons learnt

This section presents the opportunities and challenges of source control techniques based on the techniques used in each case study. This section evaluates how the stakeholders worked together to achieve the implementation of the surface water management techniques adopted, and also reviews some of the technical challenges faced during the project and makes recommendations as to how to ensure efficacy of each of the techniques employed. This section highlights the successes and identifies key lessons that can be taken and implemented in other projects to ensure success.

3.2 Case studies overview

The case studies were chosen to show the range of in-curtilage source control options and their suitability to different types of property, as well as wider benefits to relevant parties.

Case Study 1 focuses on the retrofit of in-curtilage source control techniques, and techniques that can be incorporated at both property and community level. Retrofit source control can help to reduce the rate and volume of runoff entering sewers, this is particularly beneficial where there are capacity issues leading to local flooding from the sewer network. Some source control techniques enable rainwater re-use at plot level (e.g. for washing cars, watering plants) however for the vast majority of households in Scotland, the water supply is not metered, and consequently there is little financial incentive to install source control for water reuse.

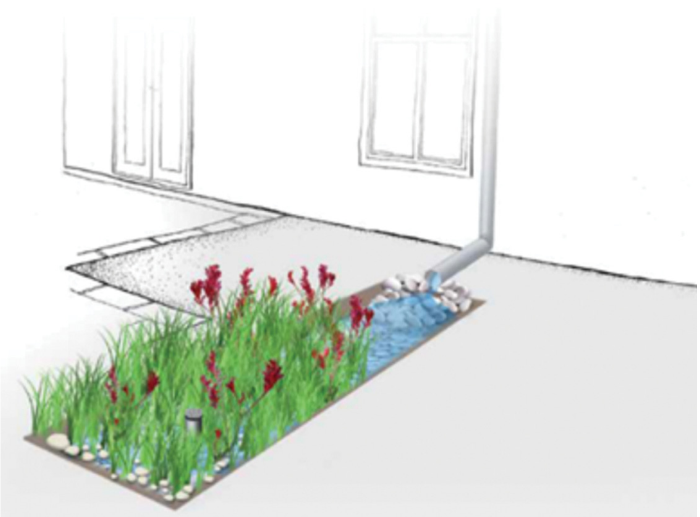
Case Study 2 focuses on new-build properties. The drivers for implementing in-curtilage source control for new build developments are focused on the opportunity to manage runoff at different stages of the management train, specifically managing the 1:200-year return period rainfall event at property level. Doing so will reduce the size of the site control and may allow additional house plots to be built.

Case Studies 3 and 4 are examples of projects with multiple stakeholders. In these cases, the projects are led, or heavily influenced by community groups and community engagement. The primary purpose of these case studies is not necessarily the benefits of reduced flood risk. In Case Study 3 the primary purpose is providing some amenity for the local residents whilst also reducing flood risk. The primary driver for Case Study 4 was reducing traffic congestion and encouraging the use of sustainable transport. These case studies are examples of projects that include collaboration between stakeholders for the benefit of the community.

The key lessons learned from the case studies are summarised in Table 5 and the full case studies can be found in Appendix B.

Table 5. Case studies overview

1. Residential Source Control: Retrofit In-curtilage	Key Lessons Learnt
1.1 – De-paving and Attenuation, Southwell Road, London  Image source: susdrain 2024, courtesy of Lambeth Council *et al*.	• De-paving of hardstanding is particularly beneficial in high density areas where there is little space to retrofit. • Social benefits to residents and other users of the space are the main additional benefits. • Creation of useable space for allotments, which is of high value in dense urban areas, and an attractive space for social interaction. • Ground investigation is necessary for infiltration techniques, particularly near building foundations. • If full infiltration is not permitted by the ground conditions, then it may be necessary to line the system to effectively create a tank below existing ground level. This will require more material and additional cost.
1.2 – Smart Rain Barrel Retrofit  Image source: SDS water	• Rain barrels are small footprint options and can be easily retrofitted. • Standard rain barrels must be used regularly or partially drained (manually or by installing a weep hole) to ensure adequate volume to store future rainfall events. • Smart rain barrels can overcome capacity issues by using weather forecast data to drain the barrel in advance of the storm.

Case Studies	
1. Residential Source Control: Retrofit In-curtilage	**Key Lessons Learnt**
1.3 – Downpipe Disconnection  Image source: Abertay University	• Engagement with the local community from the design stage has helped to drive community ownership as evidenced by the community using and caring for this space. • Consultations included a public open day, hand-delivered consultation, door-knocking of local residences and businesses, and an online survey. • High specification and visually interesting design have been used to create an inviting space and encourage public use. This has included high specification benches with rippled seats, and paving design mirroring the artistic brickwork of the adjacent tenement building.
1.4 – 10,000 Raingardens, Melbourne, Australia  Image source: Melbourne Water	• The focus was placed on promoting the benefit of raingardens as self-watering vegetable gardens to encourage uptake by the city residents. • Media promotion and local events were used to raise awareness of the project, driving a sense of 'doing-our-bit' to help neighbours, the community, and the city as a whole. • Factsheets were made freely available on how to design and build different types of raingardens. • An aide memoire to calculate the size of raingarden required based on roof area was a very useful tool, allowing homeowners to confidently design their system. • The use of a website showing progress towards the 10,000 raingardens kept the project in the public eye.

Case Studies	
2. Residential Source Control: Design and Build by Developer In-Curtilage	**Key Lessons Learnt**
2.1 – In-curtilage Attenuation, Holytown, Motherwell  Image source: James Travers	• In-ground and boxed raingardens are well suited for residential properties. The boxed raingarden was located close to kitchen door to encourage the growth of herbs for cooking. • Tolerance of wet and dry conditions must be considered for raingardens. • Underground attenuation offered an unobtrusive means to attenuate runoff and discharge at a controlled rate into the surface water sewer. • Use of standard rain barrel offers limited benefit, particularly in winter season when it is likely to be full and offer little to no attenuation. Fitting barrels with a slow drain down could improve their use at relatively low cost.
2.2 – New-build Residential In-curtilage SuDS, Dunbar  Image source: Civic Engineers	• The 1:200-year rainfall event can be managed within the property curtilage and can downsize the site control SuDS. • Permeable paving on the driveway can be incorporated without sacrificing useable space for drainage. • Porous paving manages the pollution risk from cars at source.

<table>
<tr><th colspan="2">Case Studies</th></tr>
<tr><th>3. Community Level Source Control: Partnership Delivery of Source Control</th><th>Key Lessons Learnt</th></tr>
<tr><td>

3.1 – Douglas Community Park Retrofit, Dundee

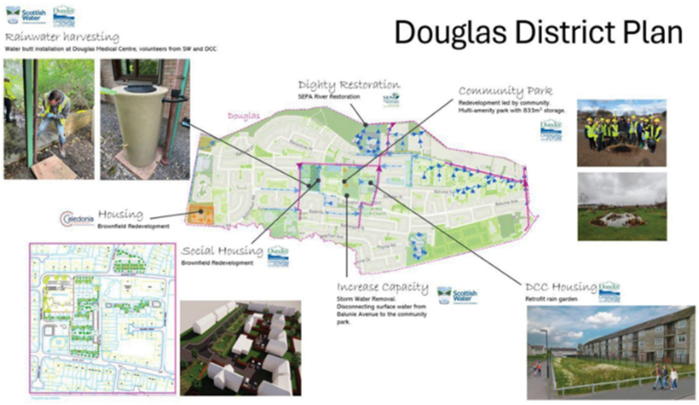


Image source: Scottish Water

</td><td>

- Illustrates the benefits of partnership working amongst stakeholders to fund, design, and implement retrofit SuDS as part of a multiple benefits project.
- In addition to removing rainwater from combined sewers, this case study demonstrates how redevelopment of open spaces can achieve placemaking objectives.
- Close partnership working between stakeholders (local authority and Scottish Water) has enabled successful delivery. The project was driven by the community, with community involvement at an early-stage key in delivering the project.
- Some details of the initial drainage design did not work as intended. Localised ponding on the west side led to installation of dropped kerbs to encourage more flow into the park.

</td></tr>
<tr><th>4. Community Level Source Control: Community Engagement and Stewardship</th><th>Key Lessons Learnt</th></tr>
<tr><td>

4.1 – Coppermill Community Raingardens

Image source: Tom Fewins

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- Community engagement from an early stage is highly beneficial. Understanding of what raingardens are and how they function was an initial barrier. This was overcome by working with the community during open days and consultations.
- Raingardens can result in loss of parking spaces, which requires engagement with the community in the early stages to help broaden the knowledge of the benefits of sustainable transport and active travel.
- Community engagement to help understand maintenance requirements has developed knowledge and a sense of ownership.
- Raingarden ownership has tended to reside within a small group within the community. This could be improved by appointing a local authority coordinator as someone who will have sufficient time and resource to work with the community.

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4 In-Curtilage Source Control Use: Barriers and Opportunities

In Scotland, the use of in-curtilage source control is low, and the barriers can be categorised as legislative, regulatory, financial and social. These are discussed for retrofit and new developments in the following sections.

4.1 Barriers to Retrofit In-Curtilage Source Control

Challenges to the uptake of retrofit in-curtilage source control within Scotland include:

- Regulation of in-curtilage source control, once built, is the responsibility of Building Control within the Local Authority. Regulation (i.e. inspection) of the ongoing operation of source control is not feasible, therefore it is not possible to take the role of source control in flood risk reduction into account, because of the difficulties of knowing if the owner is going to maintain them.
- Cost to purchase and install the source control device.
- Water is not metered in Scotland, for the vast majority of households, and there is no financial incentive to reuse water and reduce supplied potable water. The only current financial incentive would be where total infiltration of runoff from the property curtilage is infiltrated into the ground and the property disconnected from the surface water sewer.
- Consumer awareness of the environmental benefits of using in-curtilage source control. Consumers may not be aware or fully understand the environmental benefits of retrofitting source control techniques. These include reuse of rainwater and reduction in use of treated potable water and reducing the impact of urban creep.
- Aesthetics of devices and willingness to accept these in the garden on the property. Cheaper attenuation devices e.g. barrels and boxes are normally moulded plastic and may not be regarded as suitable for some homeowners. More aesthetically desirable options, for example wooden cask barrels, will have a higher unit cost.
- Limited space to implement retrofit options where there are high density properties or risk of vandalism. In this case, then, retrofit options may not suitable.
- Ease of installation of source control devices. Whilst off-the-shelf solutions like rain barrels and boxed planters are relatively easy to install, other techniques may require additional skills, resources, or requirements, for example excavation.

4.2 Opportunities to Increase use of Retrofit In-Curtilage Source Control

Opportunities to increase uptake of retrofit in-curtilage source control include:

- Changing legislation and building standards to reduce the impact of urban creep by making in-curtilage SuDS mandatory for extensions to buildings. This would include guidance for suitable techniques, methods to determine required sizing, and post installation operation and maintenance.
- Use of smart technology to receive rainfall predictions and ensure attenuation devices have appropriate storage.
- Increasing awareness of environmental benefits of in-curtilage source control, including the role of minimising the impact of climate change.
- Promoting the use of rain barrels as a cheap alternative to fitting an outside tap, reusing water for washing cars and the garden. Offering free, or subsidised, devices would also incentivise uptake.
- Source controls can be used to enhance biodiversity and social benefit. The use of green techniques e.g. raingardens can be designed to complement the house and garden design.

4.3 Barriers to New-Build In-Curtilage Source Control

Challenges to the uptake of new-build in-curtilage source control within Scotland include:

- In Scotland, SuDS are required for all new developments, but there is no legal requirement to use source control. Historically, this has resulted in most developments managing runoff with site controls, or site and regional controls for larger developments. Within *Sewers for Scotland (4th ed.)* there is a process for design variation, however, this not frequently pursued as it increases the design and approval time, and the variation is not guaranteed to be approved. Techniques (i.e. site control) that can be designed and approved quickly are often seen as desirable.

- Regulation of in-curtilage construction is the responsibility of Building Control within the Local Authority. Regulation of in-curtilage SuDS, post-construction, to ensure their operation is not feasible as this would mean the inspection of every house plot in Scotland. To ensure ongoing compliance with the Building Standards, in-curtilage source control would need to be designed so that if it is not maintained it causes nuisance to the homeowner, but not risk their property or others. It should not affect the foundations of the building or allow runoff to flow onto the road.
- A developer using in-curtilage source control will increase the unit cost per house, and this would likely be passed on to the purchaser placing the developer's product at a higher unit price than competitors.

4.4 Opportunities to deliver New-Build In-Curtilage Source Control

Opportunities to increase uptake of new-build in-curtilage source control include:

- Introduction of legislation requiring use of in-curtilage source control for all new development. Whilst this may increase unit costs of houses it would level the playing field where all housebuilders within Scotland would need to use in-curtilage source control.
- Legislation would need to be supported by technical standards for approved in-curtilage source control techniques, i.e. type, specification and sizing. The most likely type of control that could be easily designed and approved during the planning process would be proprietary attenuation systems, with treatment delivered by the site control. However, there should be a requirement for attenuation and treatment of the runoff from driveways. In this case, permeable pavement could be made mandatory for driveways to achieve treatment and attenuation of a 1:200-year return period event.
- Guidance for non-standard development would also need to be provided within the building regulations including managing runoff for properties that do not have front garden, such as blocks of flats. New-build in-curtilage source control would need to be compliant with standards to connect to the surface water sewer and to satisfy the requirements of the local authority.
- The in-curtilage source control technique would need to be designed so that if it failed it would cause localised nuisance (ponding) at the property and not runoff to the road or inundate the property foundations. Exceedance of design would need to be designed for, as it is currently with most developments using the road and kerbs to channel exceedance flow from the property. An approved disconnection point would need to be located at the property boundary.
- Approved in-curtilage source control techniques would need to be simple, accessible and easy to maintain by the homeowner, for example, removing debris to prevent blockages.
- New-build source controls could be designed to be non-visible, for example, by using porous paving on the driveway to attenuate runoff. This may be advantageous as there is no loss of usable space within the plot. There is also the opportunity to use source controls to enhance biodiversity and social benefit with the use of green techniques e.g. raingardens designed to complement the house and garden design.

5 Conclusions and Recommendations

This review of different rainwater runoff retention solutions for residential and community property considered: different rainwater runoff retention solutions and suitability for different urban land types; the impact of urban creep and the impact of changes in rainfall duration and intensity as a result of climate change; and the barriers to adopting solution measures at both residential and community property level. The conclusions and recommendations are drawn from the literature review, case studies of different in-curtilage source control techniques and review of barriers to implementation.

The report also presented a summary of available sustainable drainage techniques and their performance, scalability, relative capital costs, maintenance costs, and applicability for retrofit based on an assessment of the available literature.

The Scottish Government (2021) *Water-resilient places – surface water management and blue-green infrastructure: policy framework* recognises the range of multiple benefits from SuDS implementation. The main benefits of SuDS in addition to water management identified by the review are improved health, amenity and aesthetic value. Understanding and articulating the benefits of implementing SuDS could lead to stakeholders implementing some of these solutions for the multiple benefits rather than only for flooding.

Studies have indicated that climate change will result in more frequent and intense rainfall over Northern Europe. In a Scottish context, winters are projected to become wetter, both in terms of the total amount of rainfall and the number of wet days. More intense and more frequent rainfall is likely to impact how drainage systems perform in terms of attenuation capacity, which highlights the crucial role of sustainable systems in flood management. SuDS solutions may need to have an increased footprint to manage the increase in rainwater as a result of climate change.

Urbanisation and increased rainfall intensity will raise drainage flow volumes, which will cause more frequent and severe pluvial floods. Studies on urban creep have demonstrated that areas with increased urban creep exhibit faster hydrological response times, whilst more frequent and intense rainfall is being driven by climate change. This combination presents an increased risk of flooding to urban environments that have high percentages of impermeable surfaces within catchments.

Retrofit in-curtilage source control is an effective approach to reduce the impact of increased rainfall intensity, duration and urban creep on drainage systems. Managing water at source so that it does not enter or is delayed and attenuated before it enters the drainage system can mitigate the impact of climate change on existing drainage infrastructure.

Case Studies

The case studies explored examples of residential and community retrofit. It was concluded that for single properties, the most common retrofit option for attenuation that is low in cost and easy to implement were rain barrels. Whilst rain barrels are simple solutions that are easy to retrofit, routine maintenance to reduce the stored volume of rainwater will be required in winter months to ensure efficacy. Smart rain barrels provide automatic release of stored rainwater, but these are more expensive and more difficult to retrofit.

Boxed, above-ground raingardens also provide treatment as well as attenuation. The Melbourne Water project demonstrated that with adequate guidance it is much easier for homeowners to design and build their own rain gardens.

In new builds, it is possible to create amenity value which may add value to homes whilst managing surface water flooding risks. In new-builds, including source control techniques within the property boundary can create additional space which would normally be reserved for end-of-pipe sustainable drainage solutions. Using proprietary systems, it is possible to attenuate the 1: 200-year return period rainfall event in-curtilage.

In larger community-level projects, early community engagement is key. Community engagement should begin in the development and design phases. Community driven projects that include high amenity value may open avenues to attract additional funding from other sources, which reduces the financial burden on local authorities and other stakeholders involved in surface water management.

Community engagement should also include opportunities to provide education around sustainable drainage solutions and the wider benefits that are achieved through implementing such solutions. Projects that are driven by providing amenity for the local communities can also have significant benefits for flood risk reduction. Encouraging the local community to become involved in the design and maintenance of these sustainable drainage systems such as raingardens can enhance a sense of ownership amongst the community, meaning the solutions are more likely to be well maintained.

The B£ST tool has been used to generate Coarse Assessments of the benefit value of each case study. The assessment is more accurate with better data, but even with limited data the tool can provide an overview of what the main benefits will be, and what range of additional benefits are provided on top of flood risk reduction. The Coarse Assessment uses 6 questions to generate data for amenity value. The significance of how these values are weighted in the calculations is then modified using further screening questions. Where some benefits don't exist, the user can choose not to evaluate these as part of the Coarse Assessment.

Environmental drivers may incentivise homeowners to install source controls that will enable water reuse. However, there is a cost to implement the source control, for example, purchasing a barrel, diverter and time to install. Plastic barrels may not be seen as visually inviting, and use of wooden cask barrels may be more desirable, but they are likely to be more expensive and have a shorter operational life. A greener and visually more engaging option is to disconnect downpipes to direct them to raised, or in-ground, raingardens. These offer a growing medium to grow a range of different plants to promote pollination, colour and texture. In-ground raingardens require additional space and are restricted to areas where the soil porosity is suitable, or an overflow can be connected to existing infrastructure. There can be social concerns over the use of in-ground raingardens as they create temporary ponding which may not be desirable where there are young children.

Reuse of rainwater will reduce the volume of potable water used at property level for activities such as car washing and watering gardens. In Scotland, the vast majority of households pay unmetered charges based on the Council Tax banding of the property. Currently there is no subsidy or financial benefit for water reuse. Metering is more prevalent in other regions of the UK but there is a lot of variation regionally. Where there is metering implementation of source control may be a financial driver, with payback dependent upon the extent of water saving and the cost to implement.

Barriers to implementation

Barriers to implementation can be categorised as:

- **Legislative** – SuDS are required for new development, but source control is not mandatory. Most developments use only site and regional control where rainwater is directed away from properties and is managed centrally through solutions such as attenuation ponds.
- **Regulatory** – approval of SuDS design and regulation sits within planning policy and Scottish Water's technical standards, but these do not include in-curtilage source control. Ensuring ongoing compliance of in-curtilage source control would rest with Local Authority Building Control. Local authorities are reluctant to promote in-curtilage source control as the resident may not properly maintain the system, causing the solution to fail with the potential for localised flooding.
- **Financial** – the cost to design, implement and maintain in-curtilage source control for the resident. In Scotland where for the vast majority of households, the water supply is not metered and is based on Council Tax bands, there is no financial gain to be made from retrofitting source control techniques to attenuate and store rainwater for reuse.
- **Social** – awareness and acceptability of in-curtilage source control. Residents may not fully understand the environmental benefits of retrofitting source control. Cheaper attenuation devices such as standard rain barrels are typically plastic and may not be considered aesthetically desirable. If residents only have a small outdoor space, they may be reluctant to retrofit source control measures such as a rain garden which requires use of that space when they do not fully understand the benefits.

Recommendations to support the increased uptake of in-curtilage source control

The case studies demonstrated the importance of stakeholders including statutory authorities, local communities, and individual consumers in the successful implementation of SuDS. The document *Towards Scotland's first Flood Resilience Strategy* (Sniffer 2023) identified the key pillars of People, Place and Process to achieve a flood resilient Scotland. In the context of these pillars, and also reflected in the *Flood Resilience Strategy Consultation Document* (May 2024), there are further opportunities to take action to support the increased uptake of in-curtilage source control in Scotland:

People

- Engage with consumers as early as possible when statutory authorities are improving surface water management through retrofit techniques. This will provide opportunities for consumers to co-design and inform the decisions for source control measures ensuring that consumers' needs are met, and amenity benefit is maximised.
- Increase awareness around the impact of urban creep and how removing permeable surfaces from properties can have a significant impact on flood risk. Residents can be encouraged to do their bit to mitigate climate change impact by introducing source control techniques to compensate for the additional runoff associated with urban creep.
- Ensure efficacy of new-build and retrofit SuDS in the long-term, particularly in the face of climate change. Develop maintenance guidance documents for residents who choose to include in-curtilage source control on their property. This would encourage local authorities to promote in-curtilage source control since it will inform residents how to maintain SuDS.

Place

- Include source control at the design stage of projects, with additional focus on placemaking. This will help to produce sustainable, well-designed places and homes which meet people's needs to improve their overall quality of life.
- Develop collaboration amongst different stakeholders including statutory authorities, local communities, and individual consumers to enhance the co-benefits of source control. This is particularly important in community projects which create quality spaces in urban areas where green space is either limited in its amenity value or lacking in terms of footprint. Involving residents will ensure that the space is designed to be useable by the community. This can be achieved through consultation and engagement in design workshops, surveys and community engagement.

Process

- Coordinate approaches to identify and develop responses to surface water flooding among stakeholders including statutory authorities, local communities, and individual consumers. Mainstream the requirement for statutory authorities (i.e. local authorities and Scottish Water) to coordinate resources to manage and reduce flood risks. Successful partnerships include the Metropolitan Glasgow Strategic Drainage Partnership (MGSDP) and the Dundee Drainage Partnership. Case Studies 1.3 and 3.1 are examples of integrated flood management that reduces flood risk, but also creates amenity value for residents.
- Encourage the use of in-curtilage source control to decrease the size and cost of site control SuDS. In-curtilage source control can be encouraged through financial incentives, such as reducing the fixed water charge fee in council tax if source controls are implemented and maintained by the resident. Governments may also consider subsidising the cost of in-curtilage source control through grants, similar to household energy efficiency grants.
- Encourage legislative changes that require the use of in-curtilage source control for all new developments to ensure that all new properties have source control. This would create a level playing field amongst developers who would all have to include in-curtilage source control. This would overcome the financial barriers associated with unequally passing on the costs of source control to the consumer. Including source control also allows the opportunity to decrease the capacity of regional and site control techniques which can increase space for development.

Further recommendations related to research needs:

- There is a lack of research which investigates the behaviour of specific SuDS measures and how they will perform under different climate scenarios, i.e. more intense and frequent rainfall in winter months. This is particularly important in understanding maintenance requirements to ensure efficacy.
- More research on uplift values used by designers to account for the influence of urban creep and climate change. There has been limited research on uplift factors and if they are fit for purpose in the Scottish context.
- Improved availability of real cost data across the sector to enhance the cost benefit analysis process for In-curtilage source control. Uncertainty and lack of clarity relating to delivery and design costs is a key barrier to the implementation of SuDS with assumptions required when assessing benefit value of options at the early stages of projects.

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Appendix A – Literature

Sustainable Drainage Systems (SuDS) are a (predominantly) nature-based approach to managing urban water runoff and are designed to try to maximise the potential opportunities and benefits that can be drawn from the management of surface water (Woods Ballard *et al*., 2015). SuDS are designed to temporarily store water during rainfall events, reduce peak flows and surface water runoff, a process commonly referred to as slowing the flow.

SuDS can take many forms both below and above ground, can include nature-based solutions such as planting as well as proprietary and manufactured products (Woods Ballard *et al.,* 2015). SuDS are designed in line with the four pillars concept (Woods Ballard *et al.,* 2015):

- **Water Quantity**: this controls the quantity of runoff to support the management of flood risk, and to maintain and protect the natural water cycle.
- **Water Quality**: this manages the quality of the runoff to prevent pollution.
- **Amenity**: this creates and sustains better places for people.
- **Biodiversity**: this creates and sustains better places for nature.

SuDS are used at differing geographical scales, commonly referred to as source control, site control and regional control. Source control SuDS manage water at or near its source, so that it does not enter the drainage system or is delayed and attenuated before it enters the drainage system (Woods Ballard *et al*., 2015). Site controls and regional SuDS are larger controls used as development size increases. The Flood Hub (2021) lists three different types of source control:

- Infiltration: this method involves the infiltration of the collected runoff into the subsoil. This water permeates through the subsoil to the water table.
- Detention: these methods involve permanently or temporarily storing surface water runoff in storage areas at the surface, i.e. ponds or basins.
- Conveyance: these methods involve the transfer of surface water runoff to a point of discharge. This can be achieved through either underground pipes or by vegetated channels on the surface.

This literature review investigated source control SuDS for residential and community property. It considered the future implications of climate change and urban creep, as well as reviewing policy and guidance, and how these systems are analysed in terms of costs and benefits.

1.1 SuDS Techniques suitable for in-curtilage source control for residential and community buildings

The SuDS Manual (Woods Ballard *et al*., 2015) provides a comprehensive list of SuDS categories. The techniques suitable for in-curtilage source control for residential and community buildings are shown in Table A1.1, including a brief description and summary of their benefits.

Table A1.1. Source control techniques for in-curtilage residential and community property (adapted from O'Brien 2009 and Woods Ballard 2015).

Technique	Water Quantity Benefit (1:30 Year)	Water Quality benefit
Green roofs	High	Varies
Raingardens	Med	Med
Permeable surfaces	High	High
Rainwater harvesting	Low	High
Soakaways	High	High
Swales	Med	High
Trenches	Low	High
SuDS Trees	Med	High
Proprietary SuDS	High	Low

Green Roofs

Green roofs are a method of source control and refer to a roof that is either completely or partially covered with vegetation and soil, planted over a waterproof membrane. They may also include additional layers such as root barriers, drainage, and irrigation systems. Container gardens where plants are kept and maintained in pots are not considered to be green roofs. Green roofs are typically classified as extensive or intensive depending on substrate depth and type of planting. Extensive green roofs have low depth substrates with basic planting, for example sedum. Intensive green roofs have deeper substate depth and can support a wider range of plant species (Woods Ballard *et al*., 2015). Retrofitting is possible, but this depends on the structural capacity of the existing roof. An assessment of the existing roof capacity by a qualified structural engineer would be required before consideration of retrofitting a green roof to a property, and additional structural capacity may be required given the additional loads on the structure. This could potentially significantly increase costs to the consumer as costs would include assessment by a suitably qualified structural engineer, architect's fees, planning permission and a building warrant for making structural alterations, and then the strengthening work. These costs are likely to make a positive outcome from a cost-benefit analysis unlikely. Green roofs costs will depend on the type of green roof used, as will maintenance requirements.

Table A1.2. Green Roof Benefits

Category	Benefits
Water Quantity	In summer months, green roofs can retain 70 – 80% of rainfall and between 25 – 40% in winter (NHBC, 2010 and Woods Ballard *et al.,* 2015). This delays peak flows and therefore can reduce the risk of flooding. A number of factors influence the retention capacity, including water holding capacity of the growth medium, thickness of the growth medium, types of vegetation used and roof slope geometry as well as the rainfall intensity (Vijayaraghavan, 2016). Research has shown that for a rainfall intensity of 0.4mm/min, a green roof with a slope of 2°, 8° and 14° can retain 62%, 43% and 39% of the stormwater respectively. This figure reduces slightly with a rainfall intensity of 0.8mm/min to 54%, 30% and 21%, respectively (Villarreal and Bengtsson, 2005).
Water Quality	Runoff from roofs is widely accepted as the least polluted of urban runoff, however it can still contain pollutants from atmospheric deposition and other sources (Woods Ballard *et al.,* 2015). Green roofs can improve water quality with their ability to absorb pollutants from rainwater (Shafique *et al.,* 2018). A study from Berndtsson (2010) showed that the percentage of heavy metals in green roof runoff was lower than in the rainwater. It has been suggested that the enhancement of water quality depends on a number of factors, including the type of green roof (extensive or intensive), plant type, drainage layers, age of green roof, type of substrate and rainfall intensity (Shafique *et al.,* 2018). Despite some research showing a net positive impact on water quality enhancement there is still some disagreement on the positive impact of green roofs on water quality. This is often in instances where fertilizer has been used to achieve optimal vegetation cover which can lead to higher nutrient concentrations in green roof runoff (Berndtsson, 2010).
Thermal benefits	Green roofs have been shown to reduce the variation of indoor temperatures and building energy requirements in both warm and cold climates (Jaffal *et al.,* 2012). A study conducted using measurements from a green roof installed on a five-storey commercial building in Singapore showed a saving of between 1-15% in annual energy consumption which can have significant impact in terms of cost savings. Green roofs are also useful in mitigating the Urban Hear Island (UHI) effect. Studies have suggested that large-scale application of green roofs can reduce ambient air temperatures by 0.3-3°C (Santamouris, 2014).
Air Pollution	Green roof systems have potential to reduce air pollution in urban environments. Yang *et al.,* (2008) quantified that a total of 1675kg of air pollutants was removed by 19.8ha of green roofs in one year. It has also been demonstrated that a green roof can lower CO2 concentrations locally by up to 2% (Li *et al.,* 2010).
Noise reduction	Whilst studies on the acoustic benefits of green roofs are limited, some studies have demonstrated that green roofs generally reduce noise pollution in urban environments from road, rail and air traffic (Van Renterghem *et al*., 2008, Yang *et al*., 2012).
Social and Economic Benefits	Cost benefit analysis of green roofs is challenging based on variability in the performance and benefits of green roofs depending on factors such as rainfall intensity (Shafique *et al.,* 2018). Given this variability, Bianchini and Hewage (2012) used a probabilistic approach to cost benefit analysis and concluded that green roofs with the correct design are generally economically feasible. In terms of other social and economic benefits, green roofs have been shown to increase property values (Liu *et al.,* 2005).

Rain gardens

Rain gardens are small scale techniques that use engineered soil and vegetation to slow discharge of runoff and provide treatment. Raingardens can be in-ground or raised "boxed" structures. Downpipes are often disconnected from sewers and redirected into rain gardens. and can be particularly useful where there is limited space (The Flood Hub, 2021). Rain gardens are a solution that is practical for both new-build properties and for retrofit given the flexibility of their construction, i.e. in-ground or raised boxed structures. The UK Rain Garden Guide (Bray *et al*., no date) provides a table of planting suggestions for rain gardens with information on the optimal sunlight for each plant type. Maintenance of rain gardens is typically limited to trimming of vegetation with occasional clearing of inlet pipes.

Table A1.3. Rain Garden Benefits

Category	Benefits
Water Quantity	Rain gardens can control peak flows during a rainfall event. Between 46-100% of peak flows can be reduced by rain gardens. This percentage is influenced by raingarden design, season, and intensity of the rainfall event (Sharma and Malaviya, 2021). The greater the depth of the rain garden, the greater the volume reduction in peak flows (Brown and Hunt, 2011).
Water Quality	Rain gardens are effective at removing sediments, heavy metals, nutrients and hydrocarbons from stormwater (Sharma and Malaviya, 2021). Stormwater can contain particulate matter, heavy metals, nutrients and other pollutants in both suspended and dissolved forms. When stormwater enters the rain garden, finer particles are trapped at the surface, whereas suspended solids will be captured deeper within the media. These trapped particulate pollutants are converted into harmless products through chemical processes and other plant mechanisms (Li and Davis, 2008). Phosphorus and nitrogen removal is also a benefit of stormwater management through rain gardens. As much as 70-85% phosphorus removal is possible for both higher and lower hydraulic conductivity soils (Sharma and Malaviya, 2021). Much of the retained phosphorus is then available for plant uptake. The primary mechanism involved in phosphate removal is through adsorption. Phosphorus removal can be impacted by warmer climates but can also be improved through careful selection of soil materials. Sandy soils with higher metal contents can increase phosphorus removal capacity (Hsieh *et al*., 2007). In terms of nitrogen removal, the nitrogen will undergo a microbial transformation (Sharma and Malaviya, 2021). This includes assimilation of dissolved nitrogen by biomass, mineralisation of organic nitrogen to ammonium, oxidisation of ammonium to nitrate, denitrification of nitrate to nitrous oxide, immobilisation of nitrogen into the plant and microbial biomass (Bolan *et al*., 2004). Ensuring optimal pH and organic matter content can increase nitrate removal. Sandy loam soils with pH of 6.4 and 0.6% organic matter can remove nitrate up to 80% from stormwater (Kim *et al*., 2003).
Other benefits	Bąk and Barjenbruch (2022) conducted a review of the literature on raingarden and identified a number of other benefits other than stormwater management and improvements in water quality. These included; benefits to the natural environment through providing additional habitat, social integration, improvements in health, economic benefits, reducing the urban heat island effect, improvements in air quality, aesthetic benefits and short lead-in time to construction because of ease of design and implementation.

Permeable surfaces

Permeable surfaces allow infiltration through gaps and voids between paviours (porous pavement) or through the surface itself (e.g. porous asphalt, or reinforced grass). Permeable surfaces can be applied to both front and back gardens in residential areas (The Flood Hub, 2021) or used in parking areas for larger areas (for example parking for community buildings). Regular maintenance is required to maintain the effectiveness of the permeable surfaces, for example road sweeping to ensure that clogging of the pore spaces does not occur (NHBC, 2010). Permeable paving can be an option for both new-build and for retrofit.

Table A1.4. Permeable Surface Benefits

Category	Benefits
Water Quantity	Permeable surfaces offer good levels of attenuation of runoff. The material and geometric design can have a significant influence on the efficiency of the permeable paving system and its ability to drain surface water. Leipard *et al*., (2015) developed a design methodology based on a study which investigated various geometries and rainfall events, this included varying slope, installation pattern and spacing between paving slabs. The study found an inverse relationship between infiltration rates vs inclination of the paving surface. This study also concluded that horizontal infiltration of stormwater inside the paving structure moves much slower compared to vertical infiltration. Bentarzi *et al*., (2013, 2016) investigated the influence of material properties on efficiency of permeable paving systems, with a specific focus on the inclusion of materials to enhance water treatment performance such as mixing organic matter with other materials. The results from this study indicated that, although the organic matter/aggregate mixture could improve treatment, it also reduced the permeability of the mixture resulting in reduced performance in terms of stormwater infiltration. Clogging of permeable paving systems is one of the major issues. Studies show significant reduction in the efficiency of permeable paving systems due to clogging (Kuruppu *et al.*, 2019). Kumar *et al*. (2016) investigated the infiltration performance of different permeable paving systems and found that all types of system had significantly reduced performance after 3 years of operation. Winston *et al*., (2016) tested several maintenance techniques to prevent reduction in infiltration performance, these include; manual removal of the upper 2cm of material, street sweeping, pressure washing, hand-held vacuum cleaning, milling of porous asphalt and a combination of vacuum cleaning and pressure washing.
Water Quality	Recent studies (Melbourne Water, 2017) have found that correctly designed and regularly maintained systems can retain 80% of sediments, 60% of phosphorus, 80% of nitrogen, 70% of heavy metals and 98% of oils and greases from stormwater runoff.
Other benefits	In a review of the environmental benefits of permeable paving surfaces, Xie *et al.,* (2019) noted that the other benefits of permeable paving include mitigation of the urban heat island effect, where permeable paving systems have been demonstrated to have a lower solar reflectance index which reduces ambient air temperatures compared to traditional concrete pavements. Another noted benefit was the reduction of traffic noise, where permeable paving systems demonstrated traffic noise levels between 96 and 98 dBA compared with traditional concrete pavements which range from 100 to 110 dBA of traffic noise. The review also demonstrated that permeable paving systems have increased skid resistance, compared with traditional concrete pavements.

Rainwater harvesting

Water storage methods can either be at surface level, or below the surface (The Flood Hub, 2021). Water can either be stored on the property for reuse, or released slowly back into the ground once the storm is over.

At property level, water barrels are the most common method of rainwater harvesting which providing a method of source control whilst also reducing water usage (The Flood Hub, 2021). Rainwater harvesting is one of the most straightforward methods of stormwater attenuation and can be implemented in new-builds as well as retrofit to existing properties. Rainwater harvesting provides no treatment but can be a cost-effective method of stormwater attenuation. Above ground systems are more suitable for retrofit. Rainwater harvesting using simple methods such as water barrels is among the cheapest solution in terms of capital costs but also low in terms of maintenance costs.

Table A1.5. Rainwater harvesting Benefits

Category	Benefits
Water Quantity	Rainwater harvesting systems are considered a low impact development practise. These practises involve decentralising water supply and implement the natural hydrological process (Stec and Zeleňáková, 2019). Rainwater harvesting systems can be used to reduce runoff and therefore reduce the risk of flooding, particularly in urban areas where there are more impermeable surfaces. Herrmann and Schmida (2000) analysed 11 storms in Germany between 1981 and 1990 and found that there were significant reductions in runoff in extreme events with return periods of less than 10 years. The study found that the volume reduction depended heavily on the level of rainwater already inside the harvesting system. The study also found that rainwater harvesting is much more efficient when used in buildings with many floors or in densely populated areas since the specific area of the roof per inhabitant is smaller and all the water captured during the rainfall event can be reused. In semi-arid climates, long-term studies that analysed the impact of rainwater harvesting systems on drainage have shown that runoff can be reduced by between 4.4% and 13.1% depending on the capacity of the rainwater harvesting system and the intensity of the rainfall event (Walsh *et al*., 2014).
Water Quality	The studies describing the benefits to water quality are limited, however, a review by de Sa Silva *et al*., (2022) highlighted that rainwater harvesting systems when combined with some treatment can reduce non-point pollution which is associated with runoff.
Social benefits	A review by de Sa Silva (2022) identified significant social benefits of using rainwater harvesting systems. This review shows that water savings can be significant. The review demonstrated that savings of up to 79% have been demonstrated in the research literature. The review also identified studies which have shown reductions in greenhouse gas emissions. These reductions are primarily driven by the reduced energy requirements. Studies have shown that savings of between 0.14 to 1.38 kg CO_2eq/m^3 are possible with using rainwater harvesting systems. Many of the social benefits are more applicable in either arid, or semi-arid climates, developing nations, and rural areas where water shortages are a more pressing issue. This is because the biggest social benefit is the benefit of saving water, and having the ability to supply water where water sources are scarce. In rural areas, rainwater harvesting systems can be useful as a means of irrigation of agricultural crops (Christian Amos *et al*., 2016). In terms of rainwater harvesting system implementation, the biggest barriers appear to be economic viability of such systems. Economic viability can be analysed using several metrics, such as the time it takes to achieve a return on investment, the rate of return, the net present value and the cost-benefit ratio (Christian Amos *et al*., 2016). In a study on the return period for a single family home, and buildings with multiple families, Domenech and Sauri (2011) found that return periods are between 33 and 43 years for a single family home and between 20 to 29 years for buildings with multiple families.

Soakaways

Soakaways are a type of infiltration system. Their use is restricted to locations where there is suitable ground porosity and where there is no risk of mobilising existing pollutants in the ground (e.g. brownfield site) or where groundwater is abstracted for potable use. Soakaways can be retrofitted in existing properties but are more commonly included as part of a new build property. Soakaways can be suited to single properties or community buildings depending on the land available. The larger the area drained, the larger the soakaway needs to be. These are sub-surface structures usually excavated and filled with aggregate providing a transient reservoir to allow the infiltration of surface water runoff into the ground (NHBC, 2010). Stormwater flows into the soakaway trench and infiltrates into the ground. For pre-treatment before reaching the soakaway, a filter strip, gully or sump pit can be used to remove excessive solids (NHBC, 2010). Soakaways can also provide considerable storage during heavy rainfall events. Soakaway maintenance requires regular removal of sediment from the surface to prevent clogging. Like all infiltration systems, replacement of the filter material might also be required in longer term maintenance (20 – 25 years).

Table A1.6. Soakaway Benefits

Category	Benefits
Water Quantity	One of the major benefits of soakaways compared to surface infiltration systems, is that soakaways are sub-surface and therefore require less available surface area for construction (Qin, 2020). This makes them a popular choice in urban areas where space for construction is a challenge. Soakaways have been shown to reduce local runoff and also attenuate peak flows as runoff is returned to the ground much more slowly (Qin, 2020). Soakaways can also be combined with pipe networks connected to traditional drainage systems to help flooding during extreme events beyond the design return period of the soakaway (Qin, 2020). Soakaways work by reducing peak and volume stormwater runoff, however, for significant reductions, large retention volumes are required (Locatelli *et al*., 2015). In order to improve performance, Locatelli *et al*., (2015) investigated the influence of a detention-retention system retrofitted to existing soakaways on the overall performance in terms of runoff retention. The study showed that annual stormwater runoff was reduced by between 68-87% and that flooding was prevented during a 10-year rainfall event. Allocating between 20-40% of soakaways to detention would significantly increase peak runoff retention. There are some limitations that need to be considered before using a soakaway system. Firstly, the permeability of the local soils needs to be considered. Local soils should be permeable enough to allow for timely draining of surface water from the soakaway (Qin, 2020). Another issue is the presence of shallow groundwater which may inhibit the effective draining of the soakaway (Roldin *et al*., 2013). In these cases, pipes can be placed near the top of the soakaway to drain excess surface water.
Water Quality	Soakaways should be used with pre-treatment (or a full stage of treatment) to extend the operational life and ensure groundwater is not polluted.

Swales

Swales are vegetated channels that are used to collect and convey water to reduce the risk of flooding. Swales provide temporary storage and allow for infiltration of stormwater (The Flood Hub, 2021). Swale design can vary dependent on requirements, they are referred to as conveyance, dry or wet swales (Woods Ballard *et al*., 2015). Conveyance swales are simple grassed channels used to convey runoff downstream. Dry swales have gravel layers below that can be designed for infiltration or attenuation. Wet swales have shallow volumes of permanent water and will store and convey water above ground (Woods Ballard *et al*., 2015, and The Flood Hub, 2021).

Swales are easy to retrofit and are easily maintained which makes them a popular solution for both retrofit and new-build properties. Swales are generally used at community level, i.e. for an entire development of properties as opposed to retrofit for single properties. Swales will perform better where there are no steep slopes (The Flood Hub, 2021), but can be used in steeper areas by stepping the base or use of check dams. Swales typically have depths of between 400 – 600mm and should be no wider than 0.5m, with a maximum longitudinal slope gradient of 6% to ensure maximum efficiency (Koiv-Vainik *et al*., 2022). Swale vegetation should be native plant species and maintained at a height of between 75 – 150mm to ensure treatment efficiency (Woods Ballard *et al*., 2015).

Table A1.7. Swale Benefits.

Category	Benefits
Water Quantity	The performance of a swale in terms of runoff reduction generally relates to the design and also the intensity of the rainfall event. In small events, swales will generally produce no runoff but in larger events swales act as a conveyance system that helps to delay runoff peaks. Studies have reported runoff volume reductions of between 23 – 48% (Koiv-Vainik *et al*., 2022). To obtain the greatest benefit from the use of swales in terms of volume of runoff in large precipitation events, swales are generally used in conjunction with grey infrastructure (Woznicki *et al*., 2018). The performance of swales in the literature shows significant variation in peak flow attenuation with studies reporting values between 19 – 85% (Koiv-Vainik *et al*., 2022). However, there does appear to be a variation in how swales perform seasonally with better performances in summer months compared with winter months. Zaqout and Andradottir (2021) reported average peal flow attenuation of 13% in winter months compared to 38% in summer months.
Water Quality	Because swales are often used with other sustainable drainage solutions, isolated studies showing the benefits to water quality are limited. However, there are studies where swales have been part of the overall sustainable drainage system alongside other techniques such as detention basins such as Stewart and Hytiris (2008) who reported results from a case study where the quality of the runoff from the drainage system was in line with the quality outlined in the water framework directive.
Other benefits	Studies focusing on other benefits, other than water quantity and quality enhancement through filtration, of swales is limited. Instead, studies tend to focus on the additional benefits of nature-based solutions in general. These include climate mitigation, enhancement of biodiversity and ecosystem conservation, providing amenity for local populations, improving quality of life through promotion of healthier lifestyles and improvements in mental health and also physical health through improvements in levels of air pollution, and mitigation of the urban heat island effect (Huang *et al*., 2020).

Trenches

Trenches are stone filled linear SuDS that can be used for all scale of development. Like porous surfaces, they can be designed for infiltration (infiltration trench), attenuation and conveyance (filter trench) or be leaky, i.e. partial infiltration. Trenches are more commonly used for developments as opposed to single properties. Trenches, like other infiltration systems, can be retrofitted but are more likely to be constructed alongside new builds.

Trenches include a top-slotted perforated pipe at either low level (filter trench) to convey runoff, or at a high level (infiltration trench) as an overflow (Woods Ballard *et al*., 2015).

Table A1.8. Trench Benefits

Category	Benefits
Water Quantity	Trenches provide good attenuation of runoff, the extent of which is governed by void ratio of the stone and the extent of throttling of forward flow (Woods Ballard *et al*., 2015).
Water Quality	Trenches can be prone to sedimentation (blocking) in the upper section (Pittner, 2009, Woods Ballard *et al*., 2015, and Mitchell, Oduymei & Akunna, 2019) and should be designed with pre-treatment, for example a filter strip, to extend the operational life. Where pre-treatment is not feasible (for example due to available space) then geotextiles can be used in the upper section of the trench to limit the extent of material to be removed during maintenance (Pittner, 2009).

SuDS Trees

SuDS trees are designed as attenuation devices that receive runoff from sheet or point (pipe) flow from paved areas, typically roads and footpaths. They manage runoff at source (by canopy interception and by water uptake, underground attenuation/infiltration. SuDS trees provide a wide range of additional benefits including placemaking, improved air quality, and reduction of urban heat island effects. Trees are typically used at community property level and are often found near car parking areas or roads. SuDS trees are not typically associated with single properties.

Table A1.9. SuDS Tree Benefits

Category	Benefits
Water Quantity	The volume of stormwater retention for tree systems is influenced by a number of factors, which includes the catchment size, rainfall intensity, capacity of the substrate, available storage and infiltration rate of the surrounding soil as well as the tree type and its evapotranspiration rate (Richter *et al*., 2024). Rates of water retention in the literature vary significantly, from as low as 5% for smaller systems, up to 24% for medium-sized systems. Higher retention rates have been reported (up to 83%) but these are typically for tree systems which include another type of water retention, i.e. in suspended paving systems (Richter *et al*., 2024). The use of trees in conjunction with other SuDS techniques also provides an additional benefit in that moisture is removed from the soil even in dry periods, which removes water from pore spaces and provides potential for additional storage during rainfall events (Berland *et al*., 2017). An additional benefit that tree pits provide in terms of reduction of runoff is canopy interception. Canopy interception is the sum of the water stored in tree canopies and evaporated from tree surfaces (Berland *et al*., 2017).
Water Quality	Trees offer pollutant removal primarily through the filter media in the same way other infiltration systems work, but can also provide some quality enhancement though canopy interception by reducing the volume of runoff and also reducing soil erosion (Berland *et al*., 2017). A study by Denman *et al*., (2016) studied four types of tree species in experimental rain gardens and found that trees grown in infrastructure installations also provided enhancements in water quality through reduced nutrient concentrations in water leaching from the systems.

Proprietary SuDS

Proprietary SuDS is a term used to describe manufactured off-the-shelf drainage systems. They typically function as volumetric solutions (attenuation) offering little treatment. There are a vast range of products available and can be above or below ground and of differing sizes. Proprietary SuDS can be used in conjunction with other SuDS techniques. These are systems that can easily be used for retrofitting, for example storage beneath a porous pavement. Above ground systems are much easier to retrofit than anything below ground.

Table A1.10. Proprietary SuDS Benefits	
Category	**Benefits**
Water Quantity	Proprietary SuDS offer high levels of attenuation, particularly in comparison with other in-ground systems (for example filter trenches). Historically, there were issues with structural integrity causing failure, however, guidance provided O'Brien *et al*. (2016) has addressed some of these concerns.
Water Quality	Proprietary SuDS offer very little treatment except settlement of solids (and associated pollutants) and entrapment of oils. They are often used to manage runoff direct from roofs, i.e. runoff that is not considered as highly polluted, however they can also be used on larger scales (but in conjunction with other SuDS to deliver water quality improvement).

1.2 Impact of climate change and urban creep

The management of surface water is a significant challenge in the face of increasing urbanisation and increasing rainfall due to climate change (Kelly, 2014; Holman *et al*., 2016; Miller and Hutchins 2017; Consumer Scotland 2022). Given the current state of climate change, it is critical to comprehend and measure any potential effects on the ecosystem.

Urban creep is the "conversion of gardens, and other vegetated areas (which help soak up rain), to built-up surfaces (which are impervious), for example by building conservatories in back gardens, or paving over front gardens for car parking spaces" (Rowland *et al*., 2019). Development control regulates extension of properties and the hard paving of front gardens. Whilst paving of front gardens must use either porous surface (infiltration by porous asphalt or paving) or drain to a porous area within the garden, building extensions will increase roof area that will discharge to the surface water sewer. According to modelling studies, urbanisation and increased rainfall intensity will raise drainage overflow volumes, which will cause more frequent and severe pluvial floods as well as a notable 10% and 20% uplift to the 0.5% Annual Exceedance Probability (AEP) event (Miller and Hutchins, 2017).

Estimating climate change allowances, which forecast the expected changes in important elements like peak river flow, peak rainfall volume, and sea level rise, is an important part of this undertaking. According to the Scottish Environment Protection Agency (SEPA) a useful tool for understanding these anticipated changes and laying the groundwork for mitigation and strategic planning is the UK Climate Projections 2018 report (SEPA, 2024b). Corresponding to UK Climate Projections 2018, an estimate of the expected shift in peak river flow, peak rainfall amount, or sea level rise due to future climate change is known as a climate change allowance. SEPA (2024b), based on Future Drainage (JBA Consulting, 2021), has the approximate peak rainfall intensity for 2050, 30-year return, as shown in Table A1.11.

According to a 2011 study on urban creep in Edinburgh by Wright *et al*., (2011) the impact on flood risk and water quality by installing impermeable hardstanding in Scotland is sufficiently widespread to justify measures to discourage such development. The authors discovered that whilst public opinion supported mitigation (the use of SuDS) to lessen the impact of urban creep, they would generally be unwilling to reinstate previously porous areas that had been paved over (to form driveways) and that in order to promote use of porous hardstanding a combination of legislative change, guidance and education would be necessary. Kelly (2016) investigated the impact of paved front gardens on current and future urban flooding. This study showed that the modelled increases in runoff are directly proportional to increases in impermeable cover and that the contribution of existing paved gardens to the overall drainage burden is substantial. The study also suggested that this problem is very likely to be exacerbated by climate change, with increased rainfall generating more runoff from paved areas. Policies aimed at reducing urban creep could have a substantial benefit to reducing surface water runoff, both at current levels of rainfall and in the future where rainfall intensity, frequency and duration is expected to increase.

Table A1.11. Peak Rainfall Intensity - data taken from tables 9 and 20 of SEPA (2024b)		
River Basin Region	For peak rainfall intensity: Total change (%) to the 2050s (using the 50th percentile)	For peak rainfall intensity: Total change (%) to the year 2080 (using the 95th percentile)
Argyll	33	65
Clyde	30	57
Forth	29	55
North-East Scotland	29	55
North Highland	30	62
Orkney	30	63
Shetland	Use Orkney PRA	Use Orkney PRA
Solway	29	52
Tay	30	55
Tweed	26	50
Western Isles	35	69
West Highland	35	69

A study of the changing rate of urban creep in Newcastle upon Tyne's Ouseburn catchment (Mcdonnell and Motta, 2021) showed that between 1945 and 2018 there was a 120% increase in total impervious area; 54% of the increase in impervious areas was attributed to urban creep alone, with the rest of the growth being attributed to urban expansion. Mcdonnell and Motta (2021) concluded that whilst urban creep is increasing the rate is slowing following the peak in the mid 1990s until the early 2000s. The Rowland *et al*., (2019) study of Edinburgh investigated changes in hardstanding, investigating four categories of change: urban creep, urban extension, urban reduction (decrease in the amount of impervious surface), and the construction of new roadways. The study, over a 25-year period (1990-2015), showed an increase of 4.81 ha/year for urban expansion and an increase of 6.44 ha/year for urban creep. The relative change between the time periods of 1990-2005 and 2005-2015 indicate a decrease in urban expansion from 5.45 ha/year to 2.20 ha/year and an increase in urban creep from 4.41 ha/year to 8.19 ha/year. Changes in the areas of urban reduction (impermeable areas returned to vegetated spaces) and areas of new road, have had considerably less impact than urban expansion and urban creep, with a change of 1.11ha/year and 1.13 ha/year respectively.

Current requirements for surface water sewer design include a 10% uplift for urban creep and 30% uplift for climate change (Scottish Water, 2018). Studies on urban creep have demonstrated that areas with increased urban creep exhibit faster hydrological response times (Mcdonnell and Motta, 2022), whilst more frequent and intense rainfall is being driven by climate change. This combination presents an increased risk of flooding to urban environments that have high percentages of impermeable surfaces within catchments. SEPA's assessment of climate change allowances for flood risk assessment in land use planning have identified that the standard uplift may not be suitable to mitigate for new development. The increases in climate change and urban creep will need to be adjusted to cater for future flood risk protection; this will mean a volumetric increase in SuDS design to future proof new development. Use of runoff storage/disposal techniques at property level can be used to offset increases in urban creep and climate change and reduce the volume of storage used at site and regional level.

Increases in rainfall intensity, duration and frequency is a well-recognised implication of climate change. Studies have indicated that climate change will result in a large uplift and steepening of intensity-duration-frequency curves over Northern Europe which will result in much more frequent, intense rainfall (Hosseinzadehtalaei *et al*., 2020). These studies show that rainfall will become more intense and more frequent even in climate scenarios which do not represent the worst-case scenario. More intense, more frequent rainfall is likely to impact how drainage systems perform. This, coupled with increased urbanisation, has a significant impact on the effectiveness of different surface water management solutions (Kourtis and Tsihrintzis, 2021).

Studies on long-term performance predictions of sustainable drainage systems due to climate change are limited. Most studies focus on the uplift that would be required to increase sizes of drainage systems to cope with increased rainfall, or on the applicability of nature-based solutions in general as a mitigation against increased surface water runoff compared to hard-engineered solutions. There are, however, some studies on the performance of sustainable drainage solutions such as green roofs. There was a study conducted by Hamouz *et al.*, (2020) which analysed the performance of green roofs based on different rainfall intensities from 0.8 to 2.5 mm/min for periods of 30 minutes to 90 minutes. The study assessed the performance of green roofs in different locations in Norway under extreme precipitation, with the intensities chosen to represent exceedance of a 20-year return period in current and future conditions. This study found that the performance of the green roof was more sensitive to initial conditions, in particular soil moisture content, than the shape of the hyetograph, where green roofs with lower initial moisture contents showed longer runoff detention. However, hyetograph shape was also a factor in the overall performance. Hyetographs with later peaks performed poorly compared to an earlier peak, which also reinforces the more significant influence of water content.

Koiv-Vainik *et al.*, (2022) conducted a review of different SuDS solutions to understand the impact of different climates on water retention. This study separated regions into cold and dry, cold and wet, warm and wet, and warm and dry based on Koppen-Geiger classifications. In the review, there was no discernible pattern between climate conditions and water retention, and the performance of a number of different SuDS technique was variable across different climate conditions. This suggests that it is very difficult to make predictions about how SuDS will perform in the more intense rainfall which occurs as a result of climate change.

1.3 Policy and Governance

With the increase of climate-change caused flooding events, development of appropriate policy to manage flooding and minimise associated risk has become increasingly crucial. Policy documents for flood resilience and management provide the basis upon which SuDS are used at all scales of development, from regional to site and source control.

Governance for flooding within Scotland lies with a range of organisations and legislative frameworks as identified in Water-Resilient Places (The Scottish Government, 2021):

1. The Scottish Government: responsible for national policy on planning and flood risk management including flood protection, natural flood management and flood warning. This includes A-class trunk roads and motorways (under the responsibility of Transport Scotland).
2. The Scottish Environment Protection Agency (SEPA): Scotland's national flood forecasting, flood warning authority and strategic flood risk management authority. SEPA produces Scotland's Flood Risk Management Plans
3. Scottish Water: responsible for removing surface water from within property curtilages on connection to the public sewer.
4. Local Authorities: responsible for the drainage of local roads and public highways and for providing flood protection and maintaining watercourses.

1.3.1 Policy

The Scottish Government has overall responsibility for policy on flood management (Scottish Government, 2018). It works with other organisations (SEPA, Scottish Water & Local Authorities) to reduce risk of flooding. Policy relevant to water management includes:

The Water Framework Directive (Directive EU, 2000) is transposed into Scots law by the Water Environment and Water Services (WEWS) (Scotland) Act 2003 and regulated under the Water Environment (Controlled Activities) (Scotland) Regulations 2011 – more commonly known as the Controlled Activity Regulations, or CAR (SEPA, 2024).

This legislative change introduced two key changes:

- A requirement for SuDS to be used for all new development.
- Revision of the legal definition of sewer, to include sustainable drainage.

The latter placed the obligation on Scottish Water to adopt SuDS that conformed to Sewers for Scotland (Scottish Water, 2018).

The Flood Risk Management (Scotland) Act 2009 promotes sustainable surface water management and recognises that functioning above and below ground drainage system are necessary to deliver benefits of flood risk management (Scottish Government, 2020). This is supported by the Scottish Governments' aim of using blue green infrastructure (e.g., SuDS) for drainage and flood management (Scottish Government, 2021). Accordingly, since

2020, policy improvement has been considered in Scotland to improve surface water management and reduce the burden on drainage systems, lessen the impact of floods and increase the uptake of blue-green actions (Scottish Government, 2020). The importance of using blue green infrastructure is evident in the 21 recommendations provided by the Scottish Government on the delivery of water resilient places in Scotland (Scottish Government, 2021, Figure A1).

The Scottish Environment Protection Agency (SEPA) is Scotland's national flood forecasting, flood warning authority and strategic flood risk management authority (Scottish Government, 2021). SEPA is responsible for supporting the Scottish Government in the implementation of the Flood Risk Management Act, supporting development of plans to manage the risk of flooding in Scotland, encouraging and facilitating participation from the public and interested organisations, and prioritising sustainable measures (Scottish Water, 2018).

Local Authorities under the Flood Risk Management Act are responsible authorities for the preparation and implementation of Local Flood Risk Management Plans, jointly with the other Responsible Authorities. Local Authorities have powers to promote new flood alleviation schemes where these can be justified and funding is available and are responsible for managing flood risk in their area through activities such as maintaining road gullies, carrying out clearance and repair works and working with emergency services in response to severe flooding. Local Authorities are responsible for producing surface water management plans

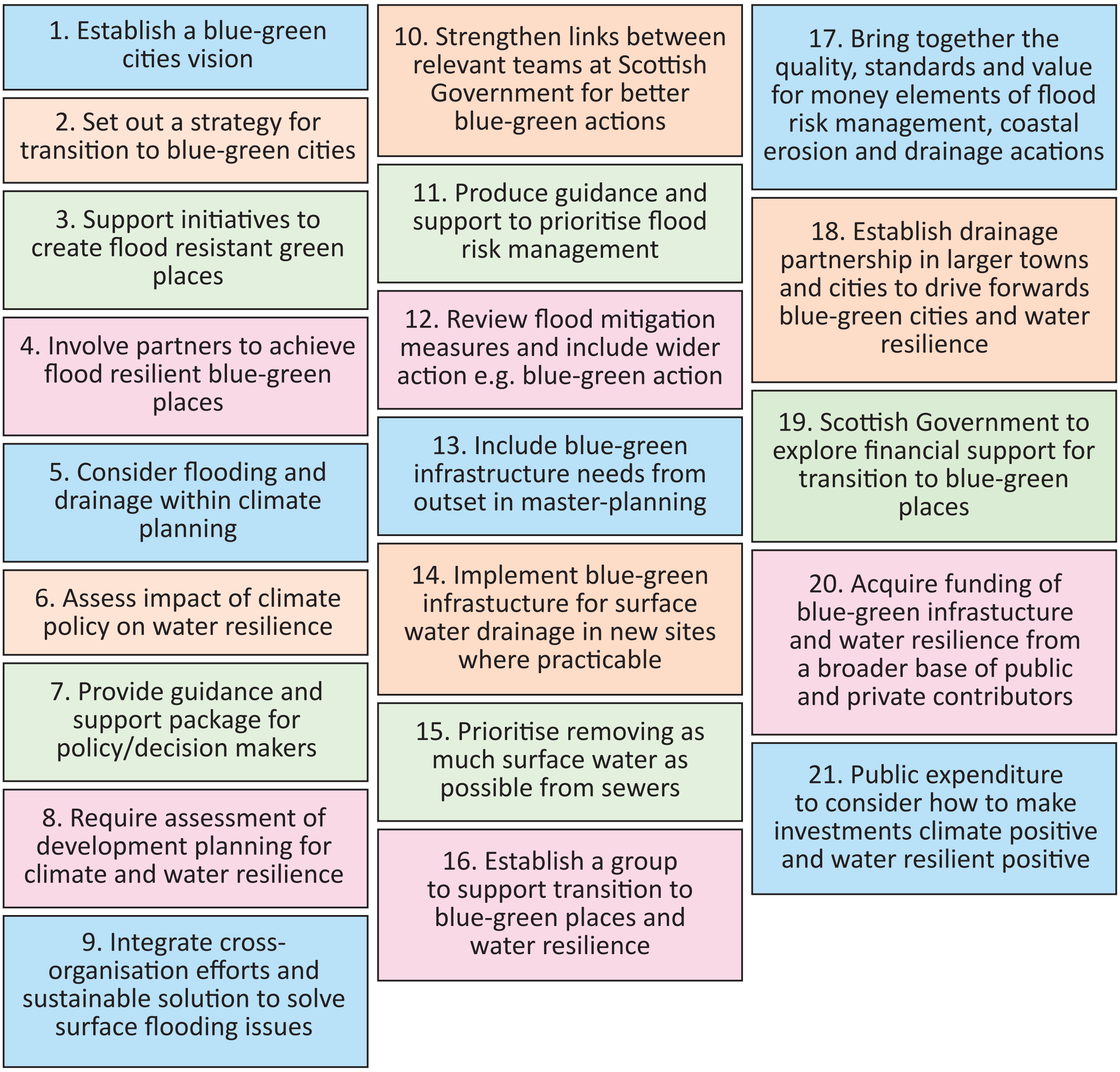

Figure A1. Recommendations on delivery of water resilient places in Scotland (Scottish Government 2021).

aimed at managing overland flooding, caused by the build-up of water on land following heavy rainfall or by a high-water table causing ponding of standing water in low lying areas. The plans will then be implemented by the responsible authorities, as appropriate (Scottish Water, 2018). In addition, the Roads (Scotland) Act 1984 stipulates that Local Authorities are responsible for managing flood risk within local road networks (HMG, 1984). Appendix 6 of the Surface water management planning: guidance (2018) provides additional guidance to responsible authorities in the preparation of Surface Water Management Plans, specifically in relation to the consideration of future flood risks. These risks include climate change, urban creep, and any demographic changes.

In National Planning Framework 4, Scottish Government's Local Development Plans (LDPs) are to describe planning for adaptation measures and to identify opportunities to implement improvements to the water environment through natural flood risk management and blue green infrastructure as a flood risk and water management plan, to strengthen community resilience to the current and future impact of climate change (Scottish Government, 2023). SuDS form part of the mitigation of flooding and are required for new development within National Planning Framework 4, and Planning Advice Notes on Flooding, Sustainable Urban Drainage Systems, Water and Drainage and Designing Streets (Scottish Government (2021). Planning authorities have the power to direct developers to implement design and maintenance requirements. National Planning Framework 4 (NPF4) stipulates that all rain and surface water should be managed through SuDS. In addition, the Framework requires SuDS systems to integrate with existing and future blue-green infrastructures (Scottish Government, 2023). Within National Planning Framework 4 (NPF4) and underpinning Planning Advice Notes (PANs), SuDS must be used for new development, specifically at an early stage in project design in order to determine its applicability. Planning Advice Note 61 (PAN 61) also highlights the importance of planning process to co-ordinate provision of SuDS in new developments and suggests setting out clearly the expected role for SuDS in significant new development masterplans, so that as developers begin to work within the framework of the master plan, they are fully aware of these expectations (Scottish Government, 2001).

Flood Risk Planning Advice (2015) highlights that in urban areas, identifying appropriate SuDS can be done through an understanding of sources and pathways of flooding (Scottish Government, 2015). In relation to development sites, the Planning Advice requires consideration of SuDS requirements from the outset of a development proposal to minimise impacts and maximise opportunities such as delivering high quality places and green infrastructure. Planning Advice Note 79 Water and Drainage (PAN 79) highlights the important role of SuDS in freeing capacity for wastewater and reducing emergency overflows by keeping surface water out of the combined system in new development, and the removal of surface water from combined systems in areas being redeveloped (Scottish Executive, 2006).

According to PAN 61, within the curtilage of private properties, responsibility for surface water drainage lies with the owner. Out with private properties, (unless the site is served by a private sewer) statutory responsibility for surface water drainage is split between roads authorities, responsible for the drainage of adopted roads, and water authorities, responsible for drainage of other land (Scottish Government, 2001). PAN 61 reports that local authorities are responsible for the maintenance of public above ground SuDS (including swales, ponds, or other ground depression features) and water authorities are responsible for below ground SuDS (Scottish Government, 2001). For the implementation of SuDS on the ground, the Advice Note also highlights the central role of planners in the development of control process, from pre-application discussions through to decisions, in bringing together the parties and guiding them to solutions which can make a significant contribution to sustainable development (Scottish Government, 2001).

Property curtilage drainage must meet the requirements of the Building Standards Technical Handbooks, as explained in the domestic and non-domestic buildings handbooks. The domestic and non-domestic buildings technical handbooks explain that surface water discharged from a building and a hard surface within the curtilage of a building, should be carried to a point of disposal that will not endanger the building, environment or the health and safety of people around the building (Scottish Government, 2024, 2024b). The technical handbooks describe the construction of a soakaway as a method to discharge surface water. However, to prevent damage to the stability of the building (particularly foundations), soakaways should be located at least 5 m from a building and from a boundary in order that an adjoining plot is not inhibited from its full development potential (Scottish Government, 2024, 2024b). The technical handbooks also highlight the important role of SuDS in the control or management of surface water and refers to The SuDS Manual (Woods Ballard *et al.*, 2015) for comprehensive advice on initial drainage design assessments and best practice guidance on the planning, design, construction, operation and maintenance of SuDS (Scottish Government, 2024, 2024b).

Scottish Water under the Sewerage (Scotland) Act 1968 has a duty to provide public drainage and is responsible for the drainage of rainwater runoff (surface water) from roofs and any paved ground surface within the property boundary for normal rainfall events. Scottish Water, the national water and sewerage undertaker for Scotland manages the surface water runoff from within property curtilage, i.e. roofs and hardstanding. Sewers for Scotland (currently in 4th edition) stipulates the requirements for the design and implementation of surface water networks (including SuDS) for assets to be vested within Scottish Water. Sewers for Scotland (SfS) enables the adoption (vesting) of site control SuDS, however in-curtilage drainage (including source control) remains the responsibility of the landowner/individual:

Landowners are responsible for the management of surface water on their land and must ensure that runoff from their curtilage does not cause flooding problems to their neighbours.

Individuals are responsible for managing their own flood risk and protecting themselves, their family, property, or business (Scottish Water, 2018 and Scottish Government, 2021).

1.4 Cost Benefit Analysis (CBA) of runoff retention solutions

Implementing SuDS in practice requires a clear overview of the costs and benefits valuation (Van Oijstaeijen *et al.*, 2020). Andersson *et al.*, (2014) identified that SuDS require an evolution in urban design principles and urban governance, where methods and tools are required to bridge planning, financial and implementation (Wild *et al.*, 2017). Van Oijstaeijen *et al.*, (2020) notes that in contrast to grey infrastructure, where added value is much more tangible, the main challenge for local authorities when implementing SuDS is the development of credible business cases to support informed decision-making. Often multiple benefits are valued notionally and are difficult to include in funding proposals (O'Donnell *et al.*, 2018) and not equivalent to what is common practice in grey infrastructure investment. Consumer Scotland (2023) explored the barriers to the adoption of SuDS which offer a range of benefits to consumers and the wider environment. SuDS contributes to the reduction of pluvial flooding risks and incidents by reducing runoff load. Water barrels and rainwater harvesting provide an alternative source for non-potable water, attenuation offers opportunity for additional water recharge, enhancement of biodiversity and reduce urban heat island effect (EA, 2007). Consumer Scotland (2023) also recognised the important role consumers have in supporting the maintenance of SuDS and the role they have in delivering their own blue-green interventions at a household scale. Challenges to widespread adoption are the identification and assessment of the multiple benefits (O'Donnell *et al.*, 2017) and the engagement across a range of stakeholders, where understanding their drivers could be used as part of a business case to partnership funding SuDS delivery and maintenance.

1.4.1 Cost Analysis

Decision makers commonly use cost comparison as a method to understand the cost and options for infrastructure provision (EPA,2023). Whole Life Cost (WLC) includes the consideration of planning, design, installation, operation and maintenance, and replacement. Important decisions in the process of preparing WLC estimates are around the time period and the discount rate to be included in the analysis. This accounts for the low perceived value of future maintenance and cost vs capital investment at the start of the project. Treasury guidance provides rates for project appraisal (HM Treasury, 2022) although how the funding is comprised will lead to alternative discount rates related to different stakeholders. WLC provides an understanding of cost to provide drainage requirements of different approaches rather than optimising benefits (Lamond, 2016). Analysing cost alone ignores the difference in performance between SuDS and grey infrastructure. As a result, they provide an incomplete basis for decision-making. (EPA, 2023).

1.4.2 CBA and monetising benefits

CBA is a systematic approach that enables a clear monetary comparison of the costs and benefits of the installation of blue-green infrastructure, thereby facilitating the decision-making process and providing an appreciation of the cost effectiveness of the range of alternative solutions (Oluwayemi *et al.*, 2019). CBA has been used in a range of drainage and infrastructure studies, for example Joseph *et al*. (2014) successfully applied the CBA concept to property level flood adaptation measures, incorporating the recognition of the intangible benefits.

CBA requires the calculation of Net Present Value (NPV), to enable justification of initial capital investment. Benefits identified can be evaluated using cost substitution through stated preference methods, hedonic pricing or benefit transfer (HM Treasury, 2011). Effective application of CBA can determine whether a project or proposal represents a worthwhile (efficient) investment where the benefits outweigh the costs. In CBA, Benefit Cost Ratio (BCR) is an indicator of the overall value for money of an option. BCR is the ratio of the discounted present value benefits of a project or proposal, expressed in monetary terms, relative to its discounted present value costs, also expressed in monetary terms (Water UK, 2017). Used to compare alternatives, CBA can help select between different projects or proposals, increasing understanding of wider (e.g. environmental and social) costs and benefits in an informed decision-making process.

The benefits of SuDS can be grouped into tangible benefits (monetary) and intangible benefits (non-monetary) (Ashley *et al*., 2018a)). Bozman *et al.* (2015) described tangible benefits as quantifiable especially monetarily; these are identified as reduced cost of infrastructure, improved aesthetic value, flood risk reduction and improved market value of the property. It should be noted that the benefits associated with flood risk reduction can also be achieved through the implementation of grey infrastructure. Foster *et al*. (2011) acknowledged SuDS as providing additional benefits that grey infrastructure cannot, such as counteracting urban heat island effects, reducing energy costs, creating community amenities, and improving habitats. Multiple benefits of adopting SuDS also involve evaluating the relative significance of benefits in context specific locations (Morgan and Fenner, 2019). The intangible benefits are subdivided into the benefits accrued by the property owner and the benefits accrued by the wider community (Oluwayemi *et al*., 2019) as shown in Table A1.12.

Monetised benefits included indirect capital and operations savings that might result for deferring expenditure on the current drainage system and reductions in the cost of pluvial flooding incidents (EA, 2007). The intangible benefits of SuDS can be evaluated by using one of the stated preference methods of valuation. Discounting future benefits and converting them to their equivalent value today, or present value is an important stage in CBA. Ackerman and Heinzerling (2001) described discounting as a tool used in CBA to compare the present costs and benefits and the implication for the future. CBA eliciting time preferences will account for individuals and organisations preference related to receiving benefits or incurring costs. Charness *et al*. (2013) reflect the advantage of discounting is that it enforces consistency, and it makes the assumptions explicit, and as such supports the decision-making process.

Water UK (2017) outlines some important implications of discounting in the analysis of environmental and social benefits. The higher the discount rate used, the lower the importance placed on future costs and benefits. At any positive discount rate, benefits that accrue more than 50 years into the future will have a very small present value. At a rate of 3.5%, benefits occurring in 25 years will have only 42% of the value of those occurring today. Hence, schemes with benefits occurring well into the future are less likely to be favoured than those with near-term benefits (Water UK, 2017).

Table A1.12 Overview Benefits of SuDS – adapted from Oluwayemi *et al*. 2019.

Monetary (Tangible Benefit)	Non-Monetary (Intangible Benefits)	
	Property Owner	Wider Community
• Reduced cost of infrastructure • Improved Aesthetic Value • Improved market value of the property	• Rainwater harvesting and amenity • Increased property protection • Reduction in energy usage	• Economic improvements • Air and water quality • Reduced loss of ecological and cultural values • Reduction/elimination of depression • Reduction of G.P. visits • Habitat for wildlife

1.4.3 Valuation toolkits

A number of tools can support benefit valuations (EPA, 2023). Green Infrastructure Cost-Benefit valuation toolkits have been evaluated by a number of authors (O'Connell *et al*,. 2018; Morgan and Fenner, 2019; Van Oijstaeijen *et al*., (2020); Ferrans, 2022), these take different forms, based on spatial and non-spatial data such as webtools, textual guides, computer programs and spreadsheets. Van Oijstaeijen *et al*., (2020) presents an overview of toolkits designed to contribute to calculating an economic value of green infrastructure elements and aim at the valuation of a wide range of benefits as shown in Table A1.13.

Table A1.13. Valuation toolkits (Van Oijstaeijen *et al*., 2020).

	Developer	Objective	Last version**	Literature references
Nature Value Explorer (NVE)	VITO, BE	Demonstrate the impact of various land use scenarios on the value and generation of ecosystem services	2018	(De Valck *et al*., 2019; Liekens *et al*., 2013)
i-Tree eco	USDA Forest Service, US	Uses field data from trees and air pollution and meteorological data to quantify environmental effects and value to society	2019	(Blair *et al*., 2017; Kim *et al*., 2018; Ozdemiroglu *et al*., 2013)
Green infrastructure valuation toolkit (GI-Val)	The Mersey Forest, UK	Establish the value of existing green assets or proposed green investments, using a set of calculator tools	2015	(Jayasooriya and Ng, 2014; Ozdemiroglu *et al.*, 2013)
A guide to value Green Infrastructure	Centre for Neighbourhood Technology (CNT), US	To inform decision-makers and planners about green infrastructure benefits and guide them in valuing potential green infrastructure investments	2011	Ozdemiroglu *et al.* (2013)
Toolkit for Ecosystem Service Site-based Assessment (TESSA)	Birdlife int., UK	Guidance on how to evaluate the benefits human receive from particular natural sites, generating information to support decision making	2017	(Birch *et al*., 2014; Liu *et al*., 2017; Martino and Muenzel, 2018)
Integrated Valuation of Ecosytem Services and Tradeoffs (InVEST)	Natural Capital Project - Stanford University, UK	Facilitate quantification of trade-offs associated with different management choices and investments enhance development and conservation	2018	(Arcidiacono *et al*., 2016; Isely *et al*., 2010; Ozdemiroglu *et al*., 2013; von Essen *et al*., 2019)
EcoPLAN Scenario Evaluator (SE)	University of Antwerp, BE	Evaluate the supply of ecosystem services to alternative scenarios in spatial development projects	2017	Maebe *et al.* (2019)
Green Infrastructure Benefits Valuation Tool	Earth Economics, US	A quick, screening assessment of the potential costs and benefits of different green infrastructure investment options	2018	(Toledo *et al*., 2018)*
Capital Asset Value of Amenity Trees (CAVAT)	London Tree Officers Association (LTOA), UK	A strategic tool and support for decision making when the value of the tree stock, or of a single tree needs to be expressed in monetary terms	2018	Ozdemiroglu *et al.* (2013)
Benefits Estimation Tool (B£ST)	Construction Industry Research and Information Association (CIRIA), UK	Evaluate and monetize economic, social and environmental benefits of blue-green infrastructure to support investment decisions and identify stakeholders for potential funding routes.	2019	(R. Ashley *et al*., 2018a, 2018b)

1.4.4 B£ST – Benefits of SuDS Tool

Benefits of SuDS Tool – a tool developed by CIRIA (Construction Industry Research and Information Association), provides a structured approach to identifying and valuing a wide range of benefits associated with SuDS. B£ST offers monetisation, qualitative evaluation of several intangible benefits and the ability to calculate benefit accrual over time. The benefits are considered over a specific time frame (specified by the user), providing insight into how benefits may accrue over time and at different rates. A wide range of benefits are first screened and those likely to generate significant benefits are identified for further detailed assessment (O' Donnell *et al.*, 2018). Van Oijstaeijen *et al.*, (2020) provides a critique of valuation tools (Table 2.13) and concludes that only B£ST really elaborates on developing the economic case for green infrastructure. B£ST provides the ability to produce benefit cost ratio output to support decision-making (Ashley, *et al.*, 2018). Providing a guided example of cost calculation, depreciation and discounting regarding urban green infrastructure can aid stakeholders in developing a credible business case, equivalent to what is common practice in grey infrastructure investments (Van Oijstaeijen *et al.*, 2020). Table A1.14 provides a summary of the B£ST evaluation tool.

Table A1.14. Summary of the B£ST evaluation tool (O' Donnell *et al.*, 2018).

Benefit categories of B£ST	Tool Inputs	Tool Outputs
Air quality Amenity Biodiversity and ecology Building temperature Carbon reduction and sequestration Crime Economic growth Education Enabling development Flexible infrastructure (under development) Flooding Groundwater recharge Health Pumping wastewater Rainwater harvesting Recreation Tourism Traffic calming Treating wastewater Water quality User-defined benefits	Type and size of SuDS Present value of impacts (if this has already been calculated) A wide range of data, including flood inundation data or flood risk assessments, environmental data (e.g. water quality status, habitat type), health impacts (e.g. views over greenspace), socio-economic data (e.g. number of residents living in area, house prices), drainage data (e.g. total reduction in water use) Confidence level in calculated method and valuation Evaluation time frame	Monetised summary of outputs (pre and post confidence) Summary of qualitative outputs Summary results – ecosystem service categories (pie chart, bar charts) Summary results – triple bottom line categories (pie chart, bar charts) Benefit–cost ratio Flexibility scores Sensitivity analysis

1.5 Literature review conclusion

Increases in rainfall intensity, duration and frequency is a well-recognised implication of climate change. Studies have indicated that climate change will result in a large uplift and steepening of intensity-duration-frequency curves over Northern Europe which will result in much more frequent, intense rainfall. More intense and more frequent rainfall is likely to impact how drainage systems perform which highlights the crucial role of sustainable systems in flood management. However, studies investigating the technical performance of sustainable drainage under the conditions anticipated in the future are limited, with a single study on green roofs performance under more intense rainfall showing that there is likely to be an impact on performance as a result of climate changed-induced increases in rainfall intensity and duration. It is anticipated that other types of sustainable drainage systems will also be impacted, with routine maintenance becoming more critical to ensure efficiency of performance.

Table A1.15 outlines a summary of available sustainable drainage techniques and their performance, scalability, relative capital costs, maintenance costs, and applicability for retrofit based on an assessment of the available literature. The literature review of different techniques shows that some systems have been more thoroughly researched (green roofs in particular have been much more widely studied than most other solutions, for example, with Koiv-Vainik *et al.* (2022) showing 144 papers referencing green roofs compared to the next highest raingardens which had only 37 references) and contain much more data on their performance in terms of surface water attenuation, reducing runoff, and providing treatment.

The Scottish Government, as responsible authority for policy on flood management works closely with SEPA, Scottish Water and Local Authorities to reduce risk for flooding. SEPA as Scotland's national flood forecasting, flood warning authority and strategic flood risk management authority supports the Scottish Government in areas such as implementing the Flood Risk Management Act and supporting development of plans to manage the risk of flooding in Scotland. Scottish Water has a duty to provide public drainage and is responsible for the drainage of rainwater runoff (surface water) from roofs and any paved ground surface within the property boundary for normal rainfall events. Local authorities are responsible authorities for the preparation and implementation of Local Flood Risk Management Plans jointly with the other Responsible Authorities and producing surface water management plans aimed at managing overland flooding, caused by the build-up of water on land following heavy rainfall or by a high-water table causing ponding of standing water in low lying areas.

The combined work of organisations responsible for surface water management provide a mechanism for policy formation, implementation and monitoring which has resulted in appropriate management of surface water runoff, flood protection, natural flood management and flood warning. An example of policy formation, implementation and monitoring is requirement for soakaways to be located at least 5 m from a building and from a boundary, in order that an adjoining plot is not inhibited from its full development potential, and as a method to prevent damage to the stability of the building, particularly foundations. Section 7 of the Sewerage (Scotland) Act 1968 has enabled agreement between Scottish Water and local authorities to share responsibility for a single combined surface water system, thus eliminating the need and over-design of a two-pipe surface water sewer system. The key benefit of this process is bringing the responsibility of SuDS within regulatory bodies and defining the ongoing operation and maintenance obligations.

Use of in-curtilage source controls is low within Scotland and the rest of the UK, and there are a number of challenges to wide scale use. From a volumetric perspective, where site control SuDS will be vested with Scottish Water, in-curtilage source controls are not included within the hydraulic design for the site as their future operation cannot be safeguarded. This is contradictory to design principles where attenuation volume is managed throughout the management train at source, site, and regional levels. This is driven by the concern that source controls may not be maintained or removed (e.g., removal of porous surfaces or downpipe disconnection devices in raingardens and water barrels). Responsibility for in-curtilage source control remains with the owner of the property, and regulation of in-curtilage construction and ongoing standards is the responsibility of the local authority. Regulation of individual property level source controls would be extremely challenging based solely on the number of properties, not to mention the variety, types and detailing of source control used.

Benefits can be subdivided into the benefits accrued by the property owner and the benefits accrued by the wider community. Addressing flood risk is often the initial primary driver for action, however successful implementation of SuDS can lead to solutions where the flood risk reduction element becomes small in comparison to the other benefits. Understanding and articulating the benefits of implementing SuDS could lead to stakeholders implementing some of these solutions for other reasons other than flooding.

The critique of valuation tools concludes that only B£ST really elaborates on developing the economic case for green infrastructure. B£ST provides the ability to produce benefit cost ratio output to support decision-making. Providing a guided example of cost calculation, depreciation and discounting regarding urban green infrastructure can aid stakeholders in developing a credible business case, equivalent to what is common practice in grey infrastructure investments. The useability of the tool in different cases is important to understand. The case studies in Section 3 of the main body of the report and Appendix B support the literature review findings to further explore sustainable drainage techniques and their performance, scalability, and applicability for retrofit. They will also indicate relative capital costs, maintenance costs and which evaluation tools are most appropriate for which circumstance and scale of development.

Table A1.15. Summary of surface water management techniques.

SuDS technique	Property/ Community level suitability	Suitability for retrofit (5 (easy) to1 (challenging))	Relative water retention capacity	Relative treatment performance (1 (low) to 5 (high))	Relative capital costs (5 (low) to 1 (high))	Relative maintenance costs (5 (low) to1 (high))
Green roofs	Both	2	3	2	2	4
Raingardens	Both	4	3	3	4	5
Permeable surfaces	Both	3	4	3	3	3
Rainwater harvesting	Property	5	5	1	5	5
Soakaways	Both	2	5	4	2	3
Swales	Community	2	3	2	4	4
Trenches	Both	3	3	3	4	3
Trees	Community	1	2	5	1	2
Proprietary SuDS	Property	Varies	5	1	Varies	Varies

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Appendix B – Case Studies

B1 Case Studies – Residential Source Control: Retrofit In-curtilage

The following case studies are a composite of retrofit options that have been implemented at property level in the UK and further afield.

The key driver for all examples is the removal of surface water runoff from the sewer. By doing so this has reduced capacity issues and incidence of local flooding.

Case Study B1.1 De-paving and Attenuation, Southwell Road, London

Introduction

This case study demonstrates options available for high-density residential retrofit. Additional benefits of the retrofit include enhanced placemaking, community cohesion and development of previously little used communal area. The location of the flats is in the catchment of a culverted river, the River Effra, which is a tributary to the River Thames running through South London. The area is susceptible to localised flooding due to the combined sewer being close to capacity and unable to deal with heavy rainfall events.

The main concept of the case study is the benefits of de-paving an existing area to reduce capacity issues within the sewer and incidences of localised flooding.

The partners for the project were:

- London Wildlife Trust
- Loughborough Farm
- Loughborough Junction Action Group
- Lambeth Council.

Case study location

The case study focuses on an existing block of residential flats located on the Southwell Road, Lambeth, London. Available space to retrofit surface water management systems within densely urbanised areas can be challenging. The Southwell Road flats had an existing area of hardstanding (i.e. a paved over area) to the rear that was lacking in social character and not achieving its potential for useable space. This area was identified as an opportunity to de-pave in order to divert water from the sewer as well as provide a wider series of benefits.

SuDS techniques used were:

- De-paving an area of 330m², replaced with a gravel base layer, overlain with woodchip.
- Two 1000 litre water barrels.
- Green roofs added to two adjacent garages (26m²).

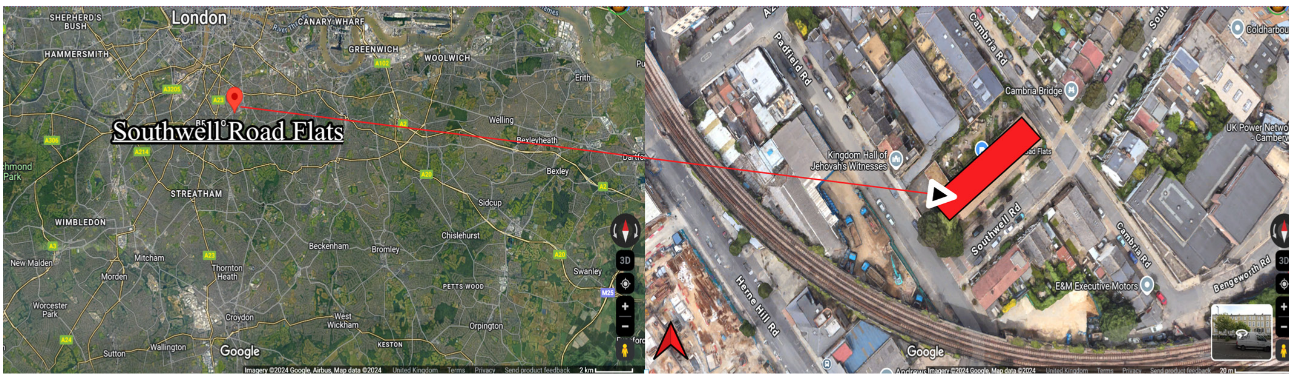


Figure B1.1. Case study location. Image source: Google Maps.

Technical Review

All measures were introduced within privately owned curtilage of the buildings.

The de-paving of the existing asphalt surface and introduction of a porous surface and the retrofitting of green roofs to the two garages has effectively reduced surface runoff entering the sewer. The green roof was studied by University College London students in 2017 who found that the roof retains 73% of the rainwater that falls on the roof, significantly reducing runoff.

Construction of planters for vegetables and visually engaging plants have helped to create an attractive and usable space for the residents. The two 1000 litre water barrels are used as a source for watering the planters, reducing demand on potable water supply. Removing an impervious area of 330m^2 and returning to porous surface has helped to reduce capacity issues within the combined sewer, whilst the introduction of the porous surface has "softened" the area, increased infiltration into the ground and reduced noise from users of the space. By introducing rain barrels, water has been removed from the sewer and can be used to water the vegetable planters – the latter is important as the vegetables do not require the use of a treated (and metered) water supply.

Evaluation of Benefits and Costs

Table B1.1 below provides an overview of the costs and benefits of the surface water management interventions used in this case study, based on the findings from the literature review.

The previously underused area to the rear of the flats is now a visually engaging area that is used to grow fruit and vegetables by the residents and a community gardening group. The space has been successfully transformed from hardstanding to a biodiverse, rich public space. A Coarse Assessment was undertaken for this case study using the CIRIA B£ST tool (Horton *et al.,* 2019). The Coarse Assessment is a simplified assessment of benefits which provides an indicative range of benefits and benefit values that are provided by the scheme. The lower, central, and higher bound value estimations are based on assumptions built into the tool's calculation and are fixed values. The Coarse Assessment is shown in Figure B1.4.

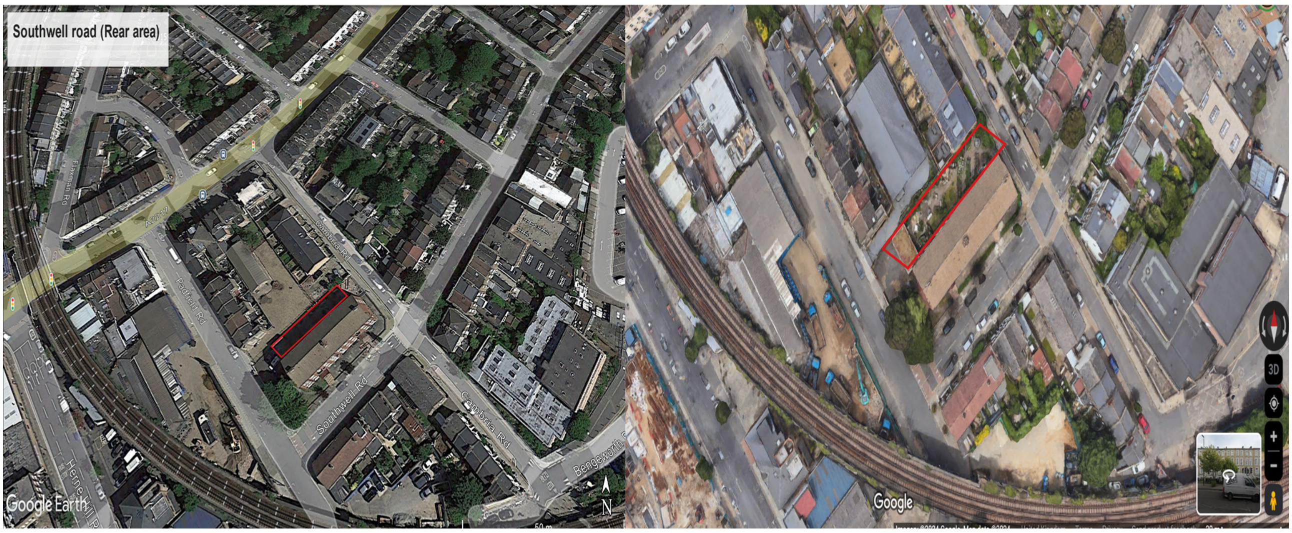


Figure B1.2. Area to the rear of Southwell Road Flats before retrofit (left) and after retrofit (right). Image source: Google Maps

Figure B1.3 Southwell Road Flats before retrofit (left) and after retrofit (right). Image source: susdrain 2024, courtesy of Lambeth Council *et al*..

In this assessment the largest benefit value comes from the reduction in flood risk. The questions and answers for the Coarse Assessment in this case study are shown in Table B1.2.

The tool provides recommendations for the estimated quantities to be selected in each question. For example, in the case of estimating amenity value, the tool recommends calculating the number of people within a 500m radius of the site. However, as this location is situated in a densely populated area of London, the number of people within 500m was too high since the number of people who will directly benefit from this scheme is much smaller given that the area is not accessible to the public. For this amenity benefit evaluation, it was therefore assumed that only residents in the block of flats would benefit and so a quantity of 32 was used (assuming 2 occupants per flat on average). For the other benefits, the assumptions that underpin the course assessment through the upper, lower, and central estimate via the screening questions is provided in Appendix C of the B£ST Guidance document (Horton *et al.,* 2019).

Similarly, it was decided that only the flats on the ground floor would benefit from any flood risk reduction. It is not known if these properties were at risk of flooding before these measures were implemented, although this is still likely to be an underestimate as flooding is within the network area (unknown at time of our research) and not directly to the block of flats itself. Also, removing rainfall runoff to the combined sewer helps to reduce capacity issues and incidence of flood. Consequently, this resulted in the flood risk reduction benefit significantly outweighing other benefits.

The assessment showed the benefits value provided significantly outweighed the construction costs identified from the online Susdrain case study. The total cost in 2015 was £25,774 although there is no detailed breakdown of costs, so it is unclear whether this is represents construction costs or solely material costs. There are some cost savings for reuse of materials (e.g. paving slabs) and favourable contractor rates through a local authority framework agreement.

To ensure the costs and the benefits are being compared using 2024 values, an average inflation rate of 3.5% has been considered for the costs and used in the benefit-cost ratio below. The benefit-cost ratio using the central benefit? estimate and estimated costs is provided below:

$$\frac{Benefits}{Costs} = \frac{£118{,}016}{£35{,}127.32} = 3.36$$

Table B1.1. Benefits and costs overview based on literature review.

	Category	Relative score (1 (low) to 5 (high))
Benefit	Water retention capacity	4
	Treatment performance	3
	Amenity	5
	Biodiversity	5
Cost	Relative capital costs	3
	Relative maintenance costs	3

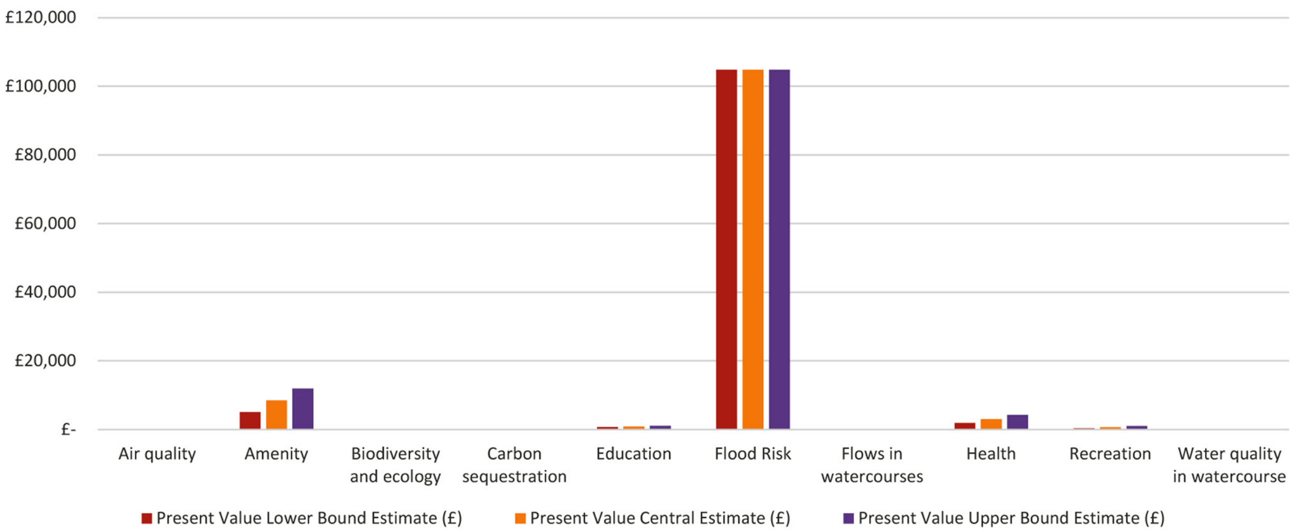


Figure B1.4. Coarse Assessment using B£ST tool.

Lessons learnt

De-paving existing areas of hardstanding is particularly beneficial in high density areas where there is little space to retrofit, or where space is valuable for other uses. The main benefit is for flood risk management.

Social benefits to residents and users of the space are the main additional benefits. The retrofit has created useable space for allotments (highly valued in dense urban areas) and created an attractive space for social interaction. The initial design was augmented to ensure privacy for the residents on the ground floor was maintained.

Ground investigation is necessary for infiltration techniques, particularly near building foundations. When retrofitting in dense urban areas, full infiltration is always the aim, however, ground conditions may not permit this or there may be risk to foundations. In such cases it may be necessary to line the system, effectively creating a tank below the existing ground level.

Table B1.2. Coarse Assessment questions for benefit evaluation using B£ST tool.

Question	Estimate quantity	Reasons/evidence for the estimated quantity
How many trees are being planted in urban and suburban areas (not as woodland)? Insert the number of trees to be planted.	0	
How many trees are being planted as woodland? Insert the area of woodland in hectacres	0	
How many people will benefit from the imprbovements to green space? Insert the number of people who live or work within 500 m of the green space improvement.	32	*The green space will primarily benefit those who live in the block of flats, so this is all that has been considered. 16 flats in the block, assumed on average 2 occupants per flat.*
How many properties are likely to flood less requently/ severely? Insert the number of properties	4	*Only flats on the ground floor have been considered for flood risk reduction.*
What area of land is being enhanced that improves biodiversity? Insert the area of land in hectacres that is enhanced.	0.035	*This value represents the areas of hardstanding converted to a permeable surface and the green roofs.*
What length of watercourse (km) or area of water (km^2) is being improved? Insert the length or area (1km also equals $1km^2$) which will potentially change in ecological (WFD) status.	0	

Case Study B1.2 Smart Rain Barrel Retrofit

Introduction

Rain barrels have historically been used to collect rainwater for reuse. As a SuDS technique, rain barrels are only effective if they have sufficient capacity to store rain, i.e. that they are not full at time of the rainfall event. Leaky rain barrels that slowly drain down to a designated level can be used (leaving some water for reuse) however these can still result in inadequate storage volume to collect rainfall, or insufficient reuse volume in the warmer seasons. This case study investigates the use of smart rain barrels – these are rain barrels that incorporate a mini-computer that receives weather forecast data to control the volume that drained from the barrels in advance of the forecast rainfall event.

Partners involved in the case study are:

- SDS Water
- Local Authorities in Kent, Devon & Lancashire

Case study location

This case study illustrates the use of smart rain barrels being retrofitted to residential properties in England.

The drivers for use have been to remove surface water from the sewers to improve capacity issues, and to reduce metered water use. The smart rain barrels are low footprint solutions that have been retrofitted to properties at the position of the existing downpipe. They are particularly suitable as an option where space is limited.

Technical Review

The smart rain barrel receives data from the weather forecast and calculates how much water to release back into the sewer, in advance of the storm, so that sufficient storage is available. This method reduces peak flow in the sewer and consequently, incidence of flood.

The smart rain barrels can be connected to the mains power supply, solar panels or an incorporated long-life battery. To reduce the maintenance frequency a leaf litter trap or litter guard should be installed to limit accumulation of organic matter/debris within the rain barrel.

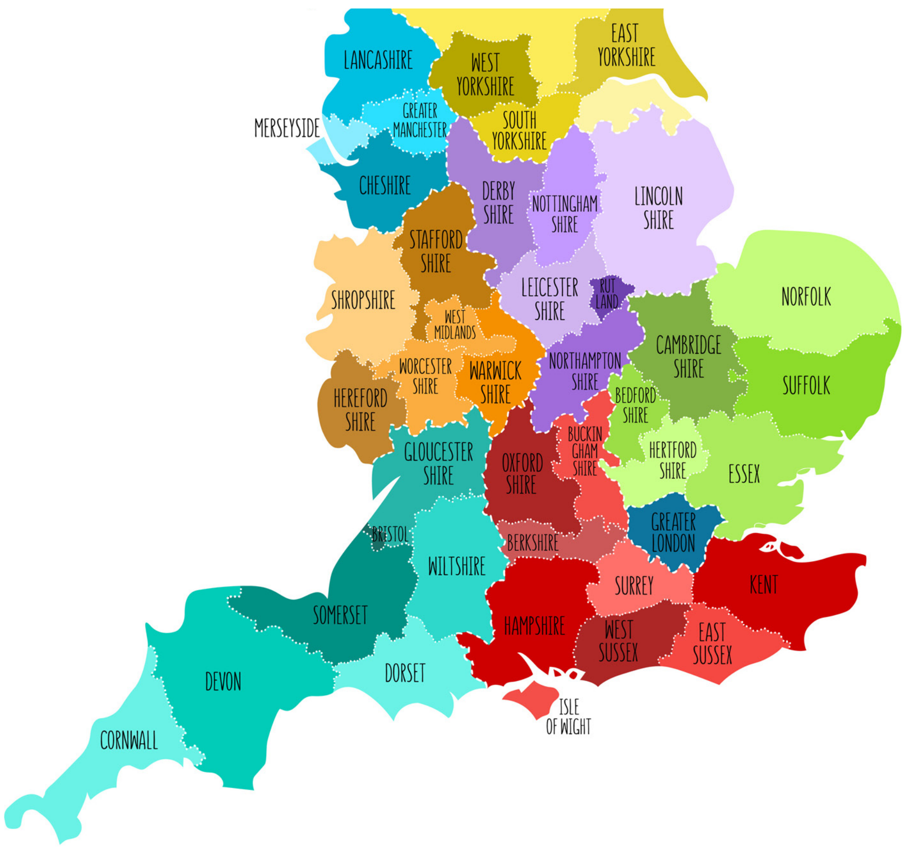


Figure B1.5. Case study locations: Lancashire, Devon and Kent, England. Image source: Lara Fields (adobe stock Licensed)

Figure B1.6. Intelligent rain barrel with mains supply (left) and with solar panel (right). Image source: SDS Water.

Table B1.3. Benefits and cost overview based on literature review.		
	Category	**Relative score (1 (low) to 5 (high))**
Benefit	Water retention capacity	5
	Treatment performance	1
	Amenity	1
	Biodiversity	1
Cost	Relative capital costs	3
	Relative maintenance costs	1

Evaluation of Benefits and Costs

Table B1.3 provides an overview of the costs and benefits of the surface water management interventions used in this case study, based on the findings from the literature review.

At the site in Combe Martin, North Devon, 34 tanks were installed. Data showed that the barrels discharged an amount of water 19 times greater than the volume of the tanks; ensuring that the rain barrels had sufficient capacity to store subsequent rainfall events. Over the period of a year, it was shown that each rain barrel could remove just over 5,000 litres from the sewer, a total of 108m^3 for the site.

The locations where the smart rain barrels were used were all areas that had existing flooding, and the retrofit was driven by the local authority – this meant that the rain barrels and installation was not paid for by the homeowner.

The B£ST tool has been used to provide an evaluation of the likely benefits of retrofitting rain barrels. In this case, a single property has been used for the evaluation despite 34 tanks being installed in total. This is because, typically, retrofitting of rain barrels would be paid for by a homeowner, and so the benefits value should also be considered on a property-by-property basis. The Coarse Assessment output is shown in Figure B1.7. Single rain barrels are unlikely to provide much flood risk reduction benefit from the single property where the rain barrel has been installed so the benefit values provided by the B£ST tool in this case is likely to be misleading, as is the benefit-cost ratio to the homeowner. However, the combined effort of all the barrels installed could remove 5,000 litres from the sewer network which is likely to have an impact on flood risk reduction further downstream in the sewer network so there will be some flood risk reduction benefit.

The benefit value is focused entirely on reduction of flood risk to the single property where the rain barrel has been installed. This is because rain barrels provide no amenity benefit, or other benefits assessed by the B£ST tool. Assuming the upper range of rain barrel costs, according to the Environment Agency's report into the costs of sustainable drainage systems (Environment Agency, 2015), the benefit-cost ratio has been calculated below. Note that no actual costs were available for this specific case study meaning that this benefit-cost estimation is highly uncertain in this case.

$$\frac{Benefit}{Costs} = \frac{£26{,}205}{£6{,}000} = 4.37$$

Lessons learnt

Rain barrels require a small footprint and are easily retrofitted source control options. Traditional rain barrels may offer limited benefit as they must be drained to allow storage of rainfall events – this can be challenging in the winter when there is a lower requirement for rainwater reuse (e.g. watering plant or washing vehicles).

Use of rain barrels on a larger scale within a development can remove a significant volume of plot runoff from the sewer to help capacity issues. Use on a small scale, for example one or two properties, will offer limited benefit to sewer volumes. Reuse of rainwater will reduce demand on treated water supply which, cumulatively, can reduce demand on potable supply.

Smart rain barrels can overcome the capacity issue by using weather forecast data to drain the barrel in advance of the storm. Smart rain barrels are still a relatively new concept in the UK and are not yet used extensively.

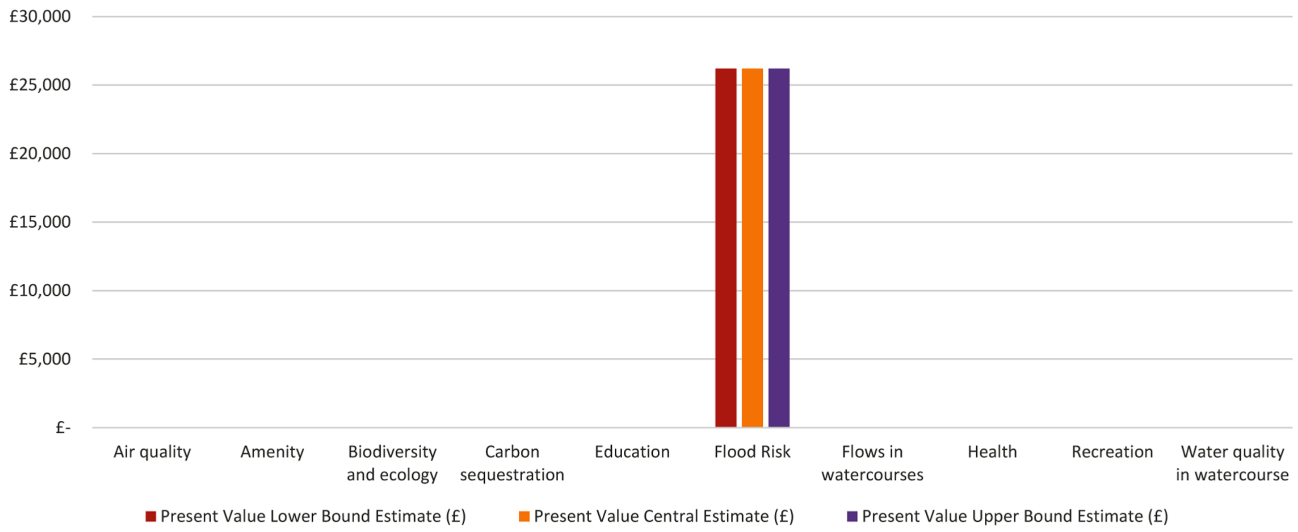


Figure B1.7. Coarse Assessment summary using B£ST tool.

Case Study B1.3 Downpipe Disconnection

Introduction

This case study is located in Craigie Street in the Hilltown area of Dundee. The key driver for the retrofit was to remove water from the combined sewer.

Partners in the project were:

- Stobswell Forum Community Group
- Sustrans Scotland
- Dundee City Council
- Scottish Water

Case study location

The project forms part of the *Sustrans Scotland* funded Pocket Places programme that is designed to improve local areas by creating attractive places that promote active travel. The Craigie Street Pocket Place was designed in consultation with the local residents and business owners, and this has helped to shape the layout and design.

Craigie Street was previously a dead-end street that permitted pedestrian access to Albert Street. It was identified as an area of opportunity to redevelop and improve the placemaking of the area and, in the process, drainage improvements were also included. The project was the winner of the Scotland Loves Local Streets and Spaces Award 2023.

The case study used two techniques; disconnection of adjacent property downpipes and altering of road levels to manage run-off to street raingardens and permeable paving.

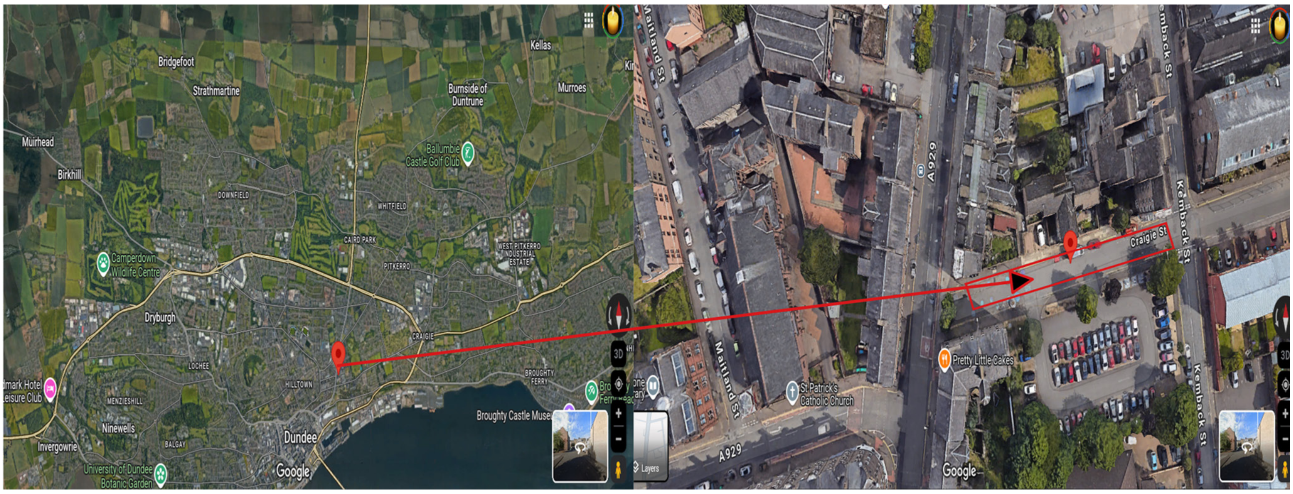


Figure B1.8. Case study location. Image source: Google Maps

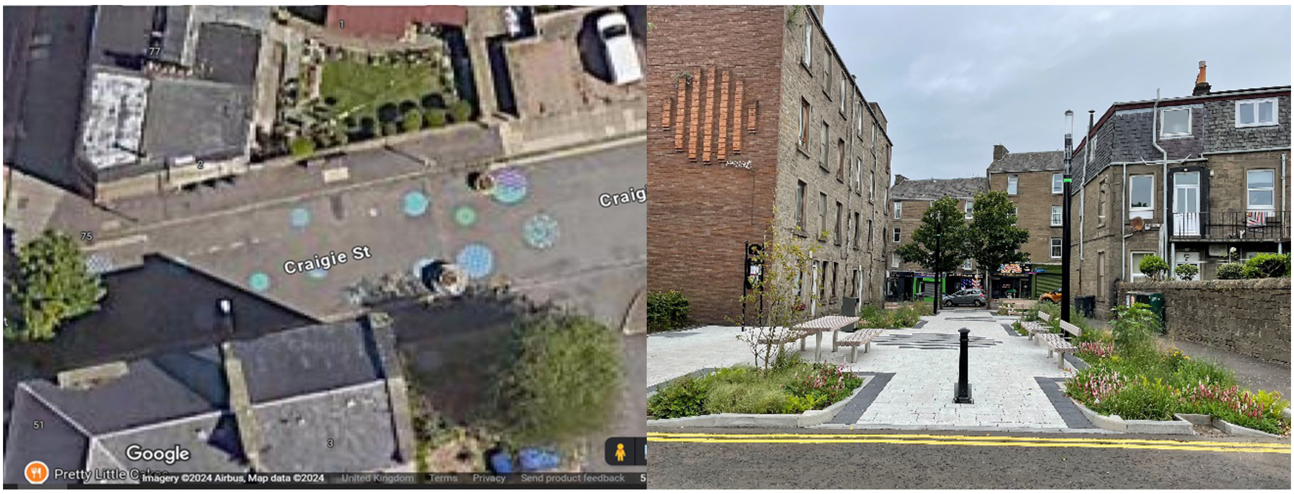


Figure B1.9. Craigie Street before retrofit (left) and after retrofit (right). Image source: Google Maps (left) and Abertay University (right).

Technical Review

The rain gardens were formed as part of the streetscape, with porous paving in-between used for pedestrian/cycle access.

Marshall Priora porous paving was used for the scheme, which has a shallow sub-base designed to attenuate runoff (this is a lined, or tanked, system not an infiltration system). Outfall from the porous pavement is throttled to the existing surface water sewer.

The downpipes from the existing buildings (Figure B1.10) were disconnected from the combined sewer and now discharge into the raingardens. Road runoff was disconnected from the combined sewer and the road geometry was changed so that rainfall runoff flow enters the raingardens as sheet-flow. Constructed silt traps were used at entry points from the road, promoting settlement of sediment and debris that can be easily monitored and removed, and importantly not pass onto the surface of the engineered soil and reduce infiltration.

Once in the raingardens, the runoff percolates through the engineered soil, removing pollutants and improving the quality of water discharged. Runoff re-enters the combined sewer at a controlled rate. The raingardens reduce the volume of water (plant uptake and evaporation) and the rate at which it enters the sewer (by providing attenuation and slowing the flow), thus reducing sewer capacity issues.

Use of raingardens is a relatively new concept in Dundee and design has been influenced from other projects in the UK. The raingardens were completed in July 2023 and review by the designers of the performance has highlighted adaptations that will benefit the future schemes. This includes variation of the planting specification so that there is more greenery all year round and increasing the size of the silt traps to lower the frequency of maintenance (removal of deposited sediment/silt).

Maintenance of the raingardens is carried out by Dundee City Council. Maintenance is relatively simple, requiring litter picking, removal of sediments at inlet traps, weeding and replanting. Like most above ground SuDS additional maintenance is necessary in the Autumn – Winter season to remove leaf litter trapped in the vegetation.

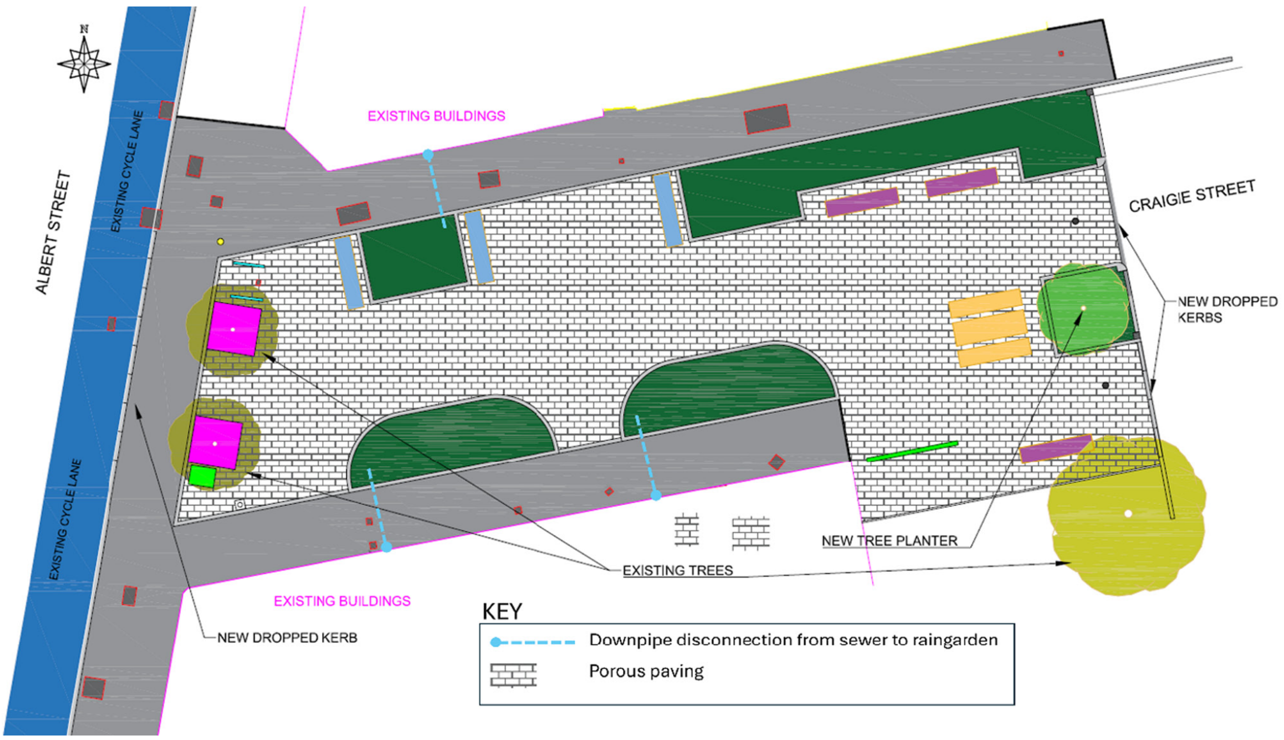


Figure B1.10. Craigie Street raingardens (dark green hatching) and downpipes disconnected from the combined sewer to the raingardens (light blue as shown in the Key) and porous pavement (grey hatching). Source: Dundee City Council.

Figure B1.11. Construction of the raingardens (left). Downpipe disconnection into the raingarden (right). Image source: Stobswell Forum SCIO (left) and Abertay University (right).

Figure B1.12. Street furniture, community noticeboard and painted paving. Image source: Stobswell Forum SCIO.

Figure B1.13. Autumn: leaf litter trapped within the raingarden. Image source: Stobswell Forum SCIO.

Evaluation of Benefits and Costs

Table B1.4 below provides an overview of the costs and benefits of the surface water management interventions used in this case study, based on the findings from the literature review.

The retrofitted pocket place has proven popular with locals, with the seated area being used by the community for lunch and social gatherings. The paving has been designed so that it is flush with the existing roadway to promote pedestrian and cycle access. The Coarse Assessment summary is shown in Figure B1.14.

This scheme provides a wide range of benefits outwith flood risk reduction. The amenity benefits are significant, and this is because the amenity benefit values were specifically considered in the design and development of the scheme. There is some benefit to flood risk which is actually likely to have been underestimated in this assessment since the flow of surface water drainage from Craigie Street to the main combined sewer on Albert Street has been slowed significantly with the inclusion of in-ground raingardens and porous pavement. This provides extra capacity in the combined sewer, which is not accounted for in this assessment.

It is likely that the reduction in the number of properties at risk of flooding is significantly under-estimated as more properties downstream will be at reduced risk of flooding given the additional capacity created in the combined sewer, however, this would require more complex flood modelling to understand the true number of properties at reduced risk of flooding. Exact costs were provided by stakeholders in the pocket park project, and these have been used in the benefit-cost ratio.

The estimated values and justification for the estimated values is shown in Table B1.5.

The benefit-cost ratio is shown below.

$$\frac{Benefit}{Costs} = \frac{£1,001,695.00}{£162,688.80} = 6.16$$

This ratio likely underestimates the flood risk reduction benefit as only the disconnected properties have been considered, but what has been demonstrated in this case study is the benefit value of the other amenity benefits associated with the inclusion of nature-based solutions that are of amenity value to the local community, particularly in dense urban areas where there may be a lack of available green spaces.

Table B1.4. Benefits and cost overview based on literature review.

	Category	Relative score (1 (low) to 5 (high))
Benefit	Water retention capacity	3
	Treatment performance	3
	Amenity	4
	Biodiversity	3
Cost	Relative capital costs	4
	Relative maintenance costs	1

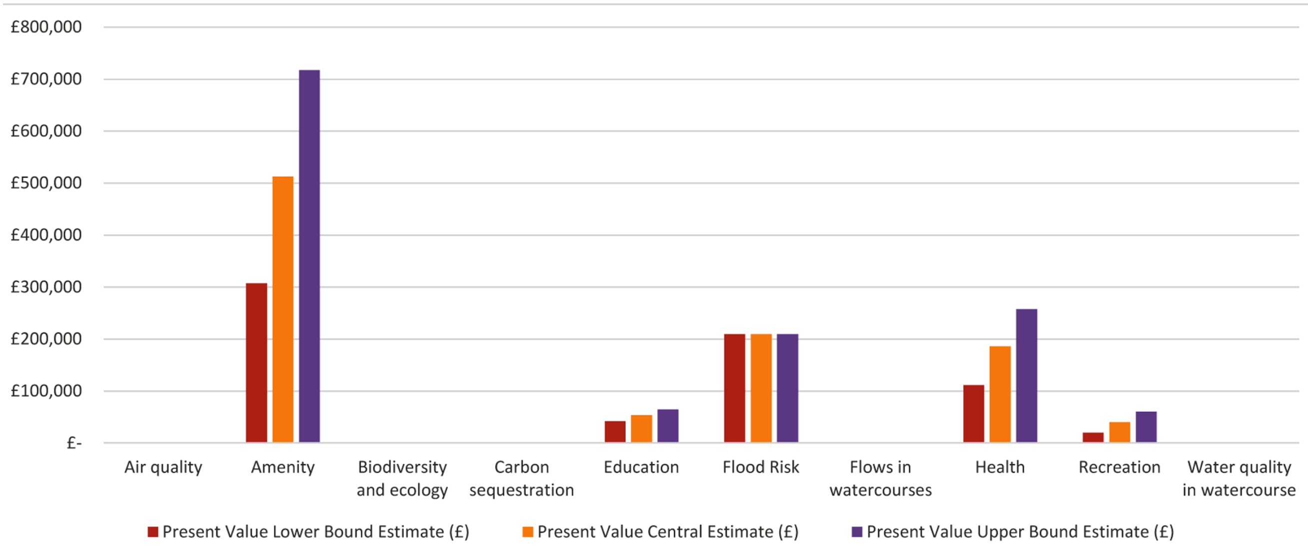


Figure B1.14. Coarse Assessment summary using B£ST tool.

Lessons learnt

The raingardens and porous pavement have successfully reduced the volume and rate of runoff that enters the combined sewer, helping capacity issues.

The project has been well received by the residents and the area is popular as a space to socialise. Engaging with the local community from the design stage has helped to drive community ownership. Consultation included a public open day; a hand-delivered consultation; door-knocking of local residences and businesses; and an online survey.

The pocket places project has been successful in improving areas of the city, greening previously paved areas, and providing welcoming social spaces. Artwork and interesting design have been a key feature of the pocket park, and it used painted paving to mirror the brickwork detail on the adjacent tenement. High specification and visually interesting seating and benching have been included in the space to encourage use.

The pocket places project has provided a successful range of benefits to the community, improving not only drainage but also the streetscape and community value of the Stobswell area.

Table B1.5. Coarse Assessment input using B£ST tool.

Question	Estimate quantity	Reasons/evidence for the estimated quantity
How many trees are being planted in urban and suburban areas (not as woodland)? Insert the number of trees to be planted.	0	
How many trees are being planted as woodland? Insert the area of woodland in hectacres	0	
How many people will benefit from the improbvements to green space? Insert the number of people who live or work within 500 m of the green space improvement.	1925	*The green space will primarily benefit those who live in the block of flats, so this is all that has been considered. 16 flats in the block, assumed on average 2 occupants per flat.*
How many properties are likely to flood less requently/ severely? Insert the number of properties	0	*Only flats on the ground floor have been considered for flood risk reduction.*
What area of land is being enhanced that improves biodiversity? Insert the area of land in hectacres that is enhanced.	0 .005	*This value represents the areas of hardstanding converted to a permeable surface and the green roofs.*
What length of watercourse (km) or area of water (km^2) is being improved? Insert the length or area (1km also equals $1km^2$) which will potentially change in ecological (WFD) status.	0	

Case Study B1.4 10,000 Raingardens, Melbourne, Australia

Introduction

This case study is from Melbourne, Australia. The project intended to encourage residents to build their own raingardens to reduce demand on water supply (for watering gardens) and reduce pollution entering watercourses. Melbourne Water delivered the project which ran for five years and exceeded the target of 10,000 raingardens.

Partners in the project were:

- Melbourne Water
- Victorian Government
- Community

Case study location

The location of the case study is city-wide within Melbourne, Australia.

Water scarcity and flooding are impacts of extreme weather events that the state of Victoria faces. Melbourne Water (owned by the Victorian State Government) has a programme of measures to counter these challenges, including raingarden use. Raingardens had already been used in public spaces throughout the city to manage rainfall, and this concept was extended to residential properties.

Within the scope of the project, raingardens were defined as any vegetated area that runoff from roofs, paths and drives could be diverted to.

The 10,000 Raingardens project produced a series of guidance documents to assist homeowners, who were then asked to register their raingarden so that

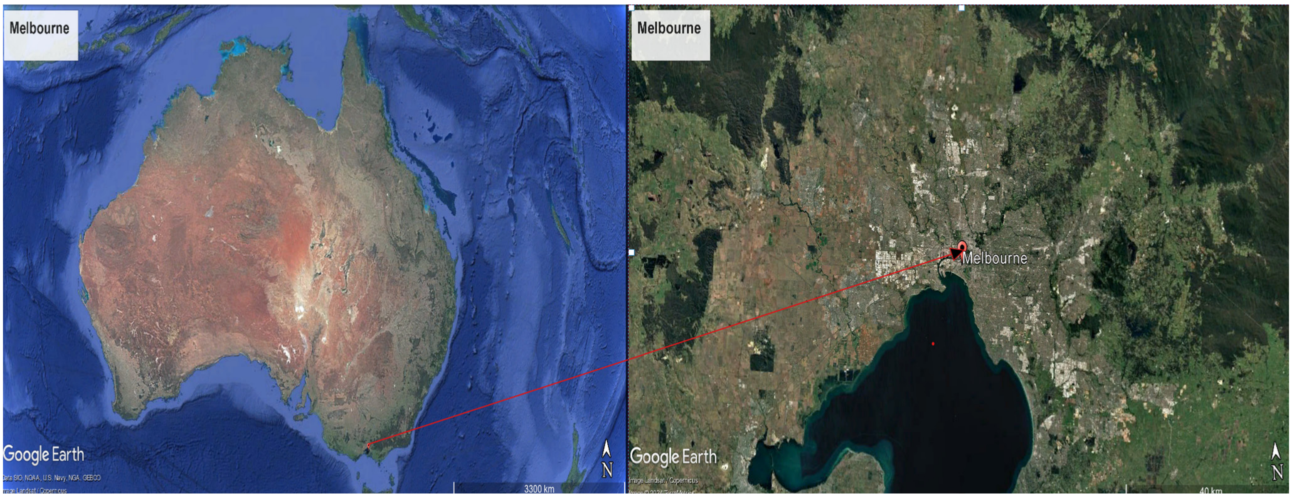


Figure B1.15. Case study location. Image source: Google Maps.

Figure B1.16. Boxed raingardens. Guidance schematic (left) and property level installation (right). Image source: Melbourne Water.

the community could reach the target number of 10,000.

Whilst the driver in this case study was predominantly reducing demand on water supply, the principles are the same for managing runoff from residential areas by disconnecting downpipes and redirecting runoff from hardstanding to vegetated attenuation devices (raingardens).

The project was promoted by local in-person events, online, and in local media. It included a seeded postcard (that could be planted to start your raingarden) that won the national Australian Postcard of the Year Award.

This case study demonstrates how homeowners can easily create their own raingarden.

Technical Review

Guidance for the design and construction of raingardens was produced which illustrated different methods to divert and reuse rainfall runoff. Importantly, the guidance included an aide memoire to calculate raingarden size based on the roof and/or hardstanding area being drained.

Measures implemented varied, depending on a number of factors:

- Where space was limited, boxed raingardens were a popular option.
- Where space was not restricted, disconnection of the downpipe and local shaping of the ground was commonly used to divert rainwater to vegetable/planted areas.
- Cost and availability of materials: the project promoted an innovative approach to raingardens and there were many low-cost designs, including re-use of existing materials including old baths as raingardens.
- Planting – raingardens were planted with a wide variety of plants – vegetables, pollinators, texture/colour based and scent – participants were encouraged to do their own thing.

The project offered rewards for innovative and interesting raingardens and encouraged owners to not only register their raingarden but also to upload a photograph. These were judged, and awards issued.

Figure B1.17. Award winning seeded postcard of the year design front (left) and back (right). Image source: Melbourne Water.

Figure B1.18. Inground raingardens. Guidance schematic (left) and property level installation (right). Image source: Melbourne Water.

Evaluation of Benefits and Costs

Table B1.6 below provides an overview of the costs and benefits of the surface water management interventions used in this case study, based on the findings from the literature review.

No evaluation has been conducted using the B£ST tool due to the lack of information available and the likely variety of raingarden solutions across the project. Any assessment would require more information about specific raingardens used.

Lessons learnt

The project was highly successful in reducing demand on the water supply whilst capturing rainfall that could cause flooding. Placing the focus on promoting the benefit of raingardens as self-watering vegetable gardens helped to overcome the perception that raingardens do not offer the homeowner any tangible benefits.

Media promotion and local events helped to raise awareness of the project, which was driven by a sense of "doing-our-bit" to help neighbours, the community, and the city as a whole.

Retrofit of raingardens was a relatively simple task that could be achieved by most homeowners. Freely available factsheets on how to design and build different types of raingardens also encouraged the retrofit of raingardens. Use of an aide memoire to calculate the size of the raingarden required (based on roof area) was a very handy tool and allowed homeowners to confidently design their raingardens.

The use of a website to show the progress towards the target of 10,000 raingardens, and the ability to register your own, helped keep the project in the public eye.

Table B1.6. Benefits and cost overview based on literature review.

	Category	Relative score (1 (low) to 5 (high))
Benefit	Water retention capacity	3
	Treatment performance	3
	Amenity	4
	Biodiversity	4
Cost	Relative capital costs	3
	Relative maintenance costs	3

B2 Case Studies – Residential Source Control: Design and Build by Developer In-Curtilage

Case Study B2.1 Holytown, Motherwell

Introduction

This case study is an example of how developer driven in-curtilage source control can be used for new build residential development.

Partners in the project were:

- Taylor Wimpey
- C&D Associates
- Abertay University

Case study location

The case study is located in Holytown, Motherwell, and is a new residential development by Taylor Wimpey.

The show home for the development was fitted with four different in-curtilage source control devices as a demonstration of options that could be made available to purchasers of new-build properties. The techniques offered a range of options from highly visible green measures to non-visible underground measures. These included:

- Raised (boxed) raingarden
- In-ground raingarden
- Underground attenuation device
- Rain barrel

Figure B2.1. The Taylor Wimpey showhome location (highlighted in red) at the Holytown site. Image source: Google Maps.

Technical Review

The raised (boxed) raingarden was connected to the roof downpipe at the rear of the property in the back garden. Flow from the pipe is diverted into the raingarden, which is constructed as a series of modules that the runoff passes through and is then slowly released back into the downpipe.

The boxed raingarden has been constructed within a timber box and located to the rear next to the kitchen so that it can be used to plant herbs for cooking.

The in-ground raingarden is a shallow unlined depression, filled with engineered soil (increased infiltration capacity) and planted with visually engaging plant species. The raingarden received runoff as sheet flow across the surface of the plot, however it is also possible to disconnect the roof downpipe to the in-ground raingarden.

To comply with building regulations, the in-ground raingarden was located more than five metres from the building foundation. Overflow from then raingarden was to an area of vegetated open space to the rear of the plot.

The underground attenuation device was a device being trialled by Abertay University to attenuate roof and drive runoff using a tank and a complex flow control (a multi-orifice control plate).

The attenuation device manages roof water (and can also manage runoff from the drive) by storing and slowly releasing runoff into the surface water sewer. The device was located to the front of the property so that it could be connected to the surface water sewer on the road.

It was designed to attenuate the 1:30 year return period storm – the level of protection that adopted sewers are designed to. However it was tested to determine if it could manage the 1:200-year return period storm at plot level. The testing demonstrated that it was possible to manage the 1:200-year return period within the plot.

A proprietary gully guard sack was installed before the attenuation tank to trap debris. Maintenance of the gully guard is straightforward. It can be removed and washed, then reinstalled.

Figure B2.2. Boxed raingarden at the show home (left) and the disconnection of the downpipe into the multi-cell box (right). Image source: James Travers.

Figure B2.3. In-ground raingarden at the show home. Image source: James Travers.

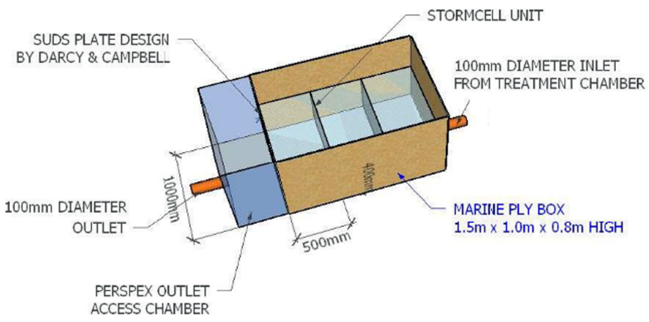


Figure B2.4. In-ground attenuation device design (left) gully guard sack (right). Image source: James Travers.

The rain barrel used was a standard off-the-shelf rain barrel which offered limited benefit unless drained to a lower level for rainfall events. A low-cost option to improve the function of the barrel would be to install a leaky draw-down system, so that the barrel slowly drains to a lower level.

Figure B2.5. Rain barrel fitted at the show home. Image source: James Travers.

Evaluation of Benefits and Costs

Table B2.1 below provides an overview of the costs and benefits of the surface water management interventions used in this case study, based on the findings from the literature review.

The Coarse Assessment summary using the B£ST tool is shown in Figure B2.6.

The benefit value in these surface water management techniques is primarily in the flood risk reduction for the property. The single property flood risk reduction is likely to be misleading since the single property is unlikely to be at a significantly reduced risk of flooding. However, the removal of surface water from the sewer network is likely to lead to increased capacity in the local sewer network which can have significant benefits for properties downstream which are likely to be

Table B2.1. Benefits and cost overview based on literature review.

	Category	Relative score (1 (low) to 5 (high))
Benefit	Water retention capacity	3
	Treatment performance	3
	Amenity	4
	Biodiversity	4
Cost	Relative capital costs	2
	Relative maintenance costs	1

at a reduced risk of flooding. The amenity value calculated is relatively low, because the number of people benefitting is lower. An average property size has been assumed, which is a household including 2.4 people (according to the Office for National Statistics, the average in England and Wales was 2.4 in 2021 (ONS, 2021) which has been used to estimate the number of people who will benefit from these surface water management interventions). With no cost information available for the proprietary attenuation device, this has not been included in the benefit-cost assessment. The assessment includes estimated indicative costs only for the rain gardens and rain barrel based on Abertay University's database of costs, accounting for an average yearly inflation of 3.5%. There are no construction drawings available showing the size of the rain garden, but these have also been assumed based on aerial imagery. The benefit-cost ratio is shown below:

$$\frac{Benefit}{Costs} = \frac{£27{,}443.00}{£3{,}299.92} = 8.32$$

Including the cost of the proprietary device would likely increase the cost in the ratio above and reduce the overall ratio.

Lessons learnt

Both the boxed and in-ground raingardens provide effective management of runoff and are well suited for residential property. They can be used to grow a range of plant species; however, tolerance of wet and dry conditions (particularly for in-ground raingardens) must be considered.

Use of standard rain barrels is a cheap option but offers limited benefit, particularly in the winter season when they are likely to be full and offer little or no attenuation. Fitting the barrels with a slow drain down will improve their use at low cost, however the hydraulic benefit is not quantified, and this would likely preclude their approval as source control devices for new-build development (smart rain barrels may be suitable but this required further study and analysis).

The in-ground attenuation device offered an unobtrusive means to attenuate runoff and discharge at a controlled rate into the surface water sewer. It could be used to receive runoff from downpipes or in conjunction with a porous surface for a driveway.

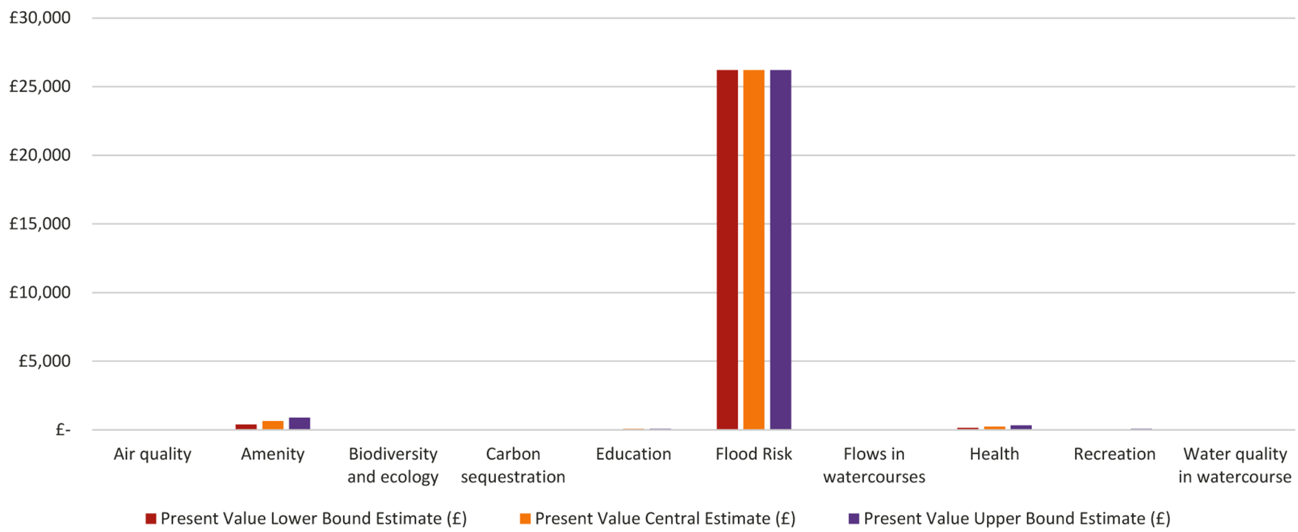


Figure B2.6. Coarse Assessment summary using the B£ST tool.

Case Study B2.2 New-build residential in-curtilage SuDS, Dunbar

Introduction

This case study demonstrates how in curtilage source control can be included within new build residential streets.

The key driver for the SuDS design was providing source control to reduce forward flow into the existing sewer.

Partners in the project were:

- Hallhill Developments Limited
- Civic Engineers

Case study location

The site is a residential development in Dunbar, East Lothian. It comprises of 37 house plots and is the final phase of a larger development. The development phase used permeable pavement on the driveway for managing flow from the hardstanding and roof.

Figure B2.7. Case study location outlined in red (left), the last phase of a larger development (right). Image source: Google Maps (left) and Civic Engineers (right).

Technical Review

The initial site design (circa 2015) used a single end-of-pipe detention basin for all phases. The case study is the final phase of the development and is still being built as of 2024.

Due to flooding issues within the catchment, the drainage for the last phase has been adapted to use in-curtilage source control to manage the 1:200-year storm event within that phase, before discharging into the existing 225mm diameter surface water sewer. The hydraulic design has been modelled to current rainfall intensity (increased from the original 2015 design).

Each house plot has a permeable pavement, with a stone aggregate sub-base to attenuate and treat runoff from the drive and roof of the house (the roof downpipe is connected into the permeable pavement). The permeable pavement is connected by a pipe to a proprietary Oriflo chamber.

The Oriflo chamber is used to initially disconnect the plot drainage from the surface water sewer and uses a 30mm diameter orifice to throttle flow, which releases the attenuated water into the surface water sewer slowly to avoid capacity issues. This diameter of orifice is compliant with Sewers for Scotland 4th Ed (Scottish Water, 2019).

The design for water quality is good as it manages the main source of pollution from the plot (the motor vehicle that is parked on the permeable surface) and provides effective removal of hydrocarbons and heavy metals.

Evaluation of Benefits and Costs

Table B2.2 provides an overview of the costs and benefits of the surface water management interventions used in this case study, based on the findings from the literature review.

The Coarse Assessment summary using the B£ST tool is shown in Figure B2.10.

In this assessment, only flood risk reduction is considered to provide benefit value, given the low amenity value of the surface water management solutions used in this case study. This assumption is based on the findings of the literature review which suggests that whilst permeable paving solutions provide high volumetric capacity and high treatment capacity, the amenity value is low. Also, the Coarse Assessment questions only account for amenity value related to green infrastructure, which does not include permeable paving although there is no amenity value to be gained from permeable paving. A single property, like other case studies on single properties in these assessments, are not likely to be at a significantly reduced risk

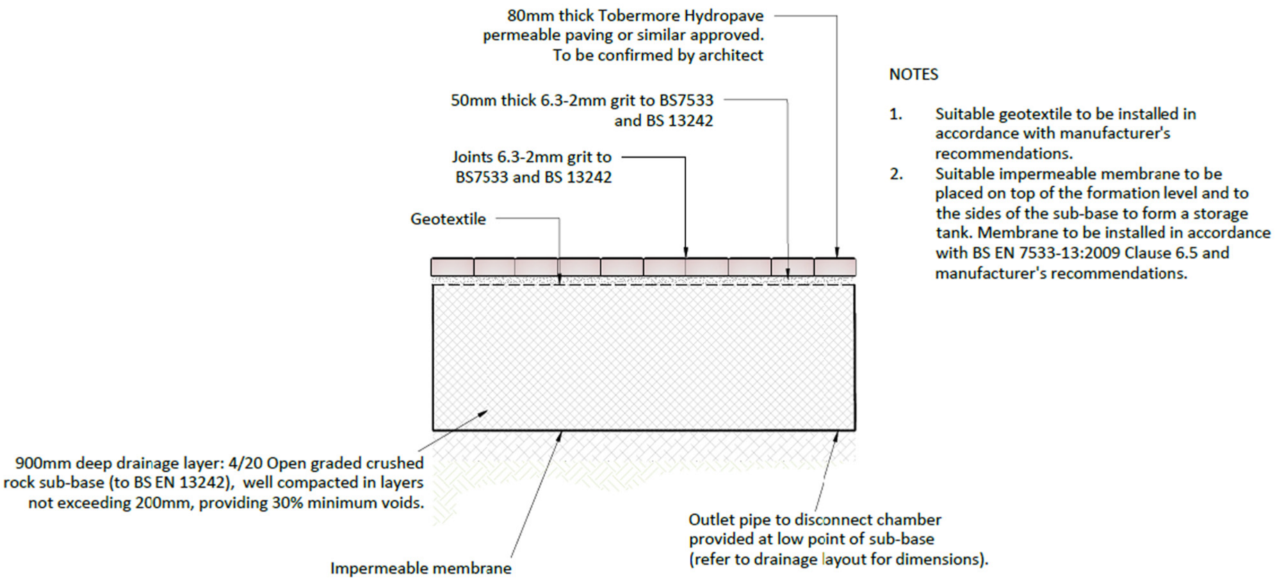


Figure B2.8. Porous block paving typical section. Image source: Civic Engineers.

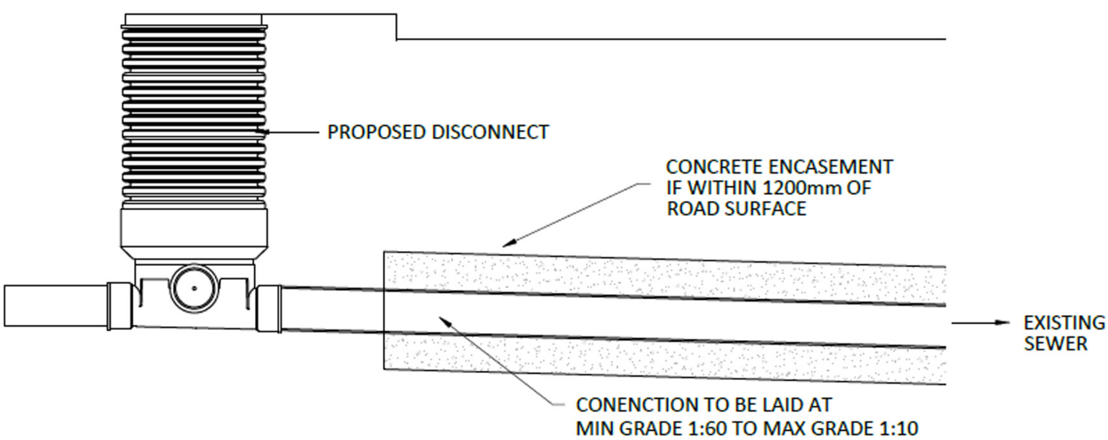


Figure B2.9. Typical section through the Oriflo disconnect to surface water sewer. Image source: Civic Engineers.

of flooding using these surface water management techniques alone. However, using source control and removing/slowing down the runoff into the main drainage network increases additional capacity in the local network which is likely to have a flood risk reduction benefit downstream. The total cost should include the cost for permeable paving and the proprietary device, but no costs have been provided for the proprietary device and therefore this cannot be included in any benefit-cost ratio. Instead, an estimated indicative cost for the permeable paving only has been included and a double car driveway has also been assumed with a typical size of 27.5m^2. The costs are taken from Abertay University's cost database and a yearly inflation of 3.5% has been assumed. The benefit-cost ratio is shown below:

$$\frac{Benefit}{Costs} = \frac{£26{,}205.00}{£5{,}002.56} = 5.24$$

Including the costs of the proprietary system and the associated pipework would increase the costs and therefore decrease the benefit-cost ratio shown for this case study.

Lessons learnt

Managing the 1:200-year storm event within the property curtilage is possible, and consequently can reduce the sizing of the site control SuDS.

The Oriflo chamber provides a combined disconnection point to the surface water sewer, incorporates an approved flow control and provides access for maintenance and inspection. The Oriflo chamber can be adapted to use a variety of different orifice sizes.

Use of permeable pavement on the driveway can be incorporated within the plot to manage the design rainfall event, without sacrificing useable space for drainage.

Table B2.2. Benefits and cost overview based on literature review.

	Category	Relative score (1 (low) to 5 (high))
Benefit	Water retention capacity	4
	Treatment performance	3
	Amenity	1
	Biodiversity	1
Cost	Relative capital costs	3
	Relative maintenance costs	3

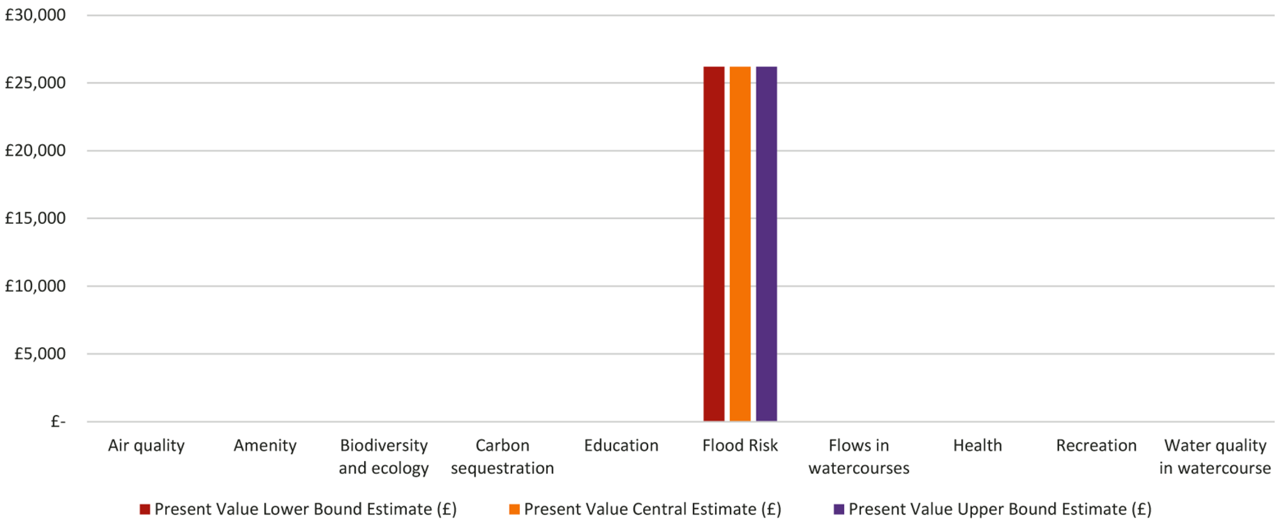


Figure B2.10. Coarse Assessment summary using the B£ST tool.

B3 Case Study – Community Level Source Control: Partnership Delivery of Source Control

Case Study B3.1 Douglas Community Park

Overview

This case study illustrates the benefits of partnership working amongst stakeholders working together to fund, design, and implement retrofit SuDS as part of a multiple benefits project. In addition to removing rainwater from combined sewers, this case study demonstrates how redevelopment of open spaces can achieve placemaking objectives.

Introduction

The local community in Douglas secured funding from the National Lottery to develop a brownfield site, formerly school grounds, to the north of Balunie Avenue. The project delivered a park to provide a new landscaped space for the community to come together, grow, play, exercise and relax.

Following a successful collaboration elsewhere in Dundee, Dundee City Council approached Scottish Water to investigate the potential to incorporate surface water management into the design of the new open space. The park's creation provided an opportunity to retrofit blue-green infrastructure measures to drain the adjacent roads and roofs to allow for disconnection from the combined sewer. This project triggered the development of a wider drainage strategy for Douglas, enabling future social housing development and further disconnection from the combined sewer.

Key Stakeholders involved in the community park retrofit are:

- Douglas Community Spaces Group.
- Dundee City Council.
- Scottish Water.

Future projects planned to follow the successful completion of this project will include more key stakeholders in addition to those listed above, namely:

- SEPA
- Caledonia Housing Association.

Case study location

This case study location is to the north of Balunie Avenue, Dundee. Balunie Avenue is the main route through the Douglas area in the east of Dundee. The site is bounded to the north by Balmoral Terrace, to the east by Balmoral Place and Douglas Community & Library Centre, and to the west by Balcarres Terrace.

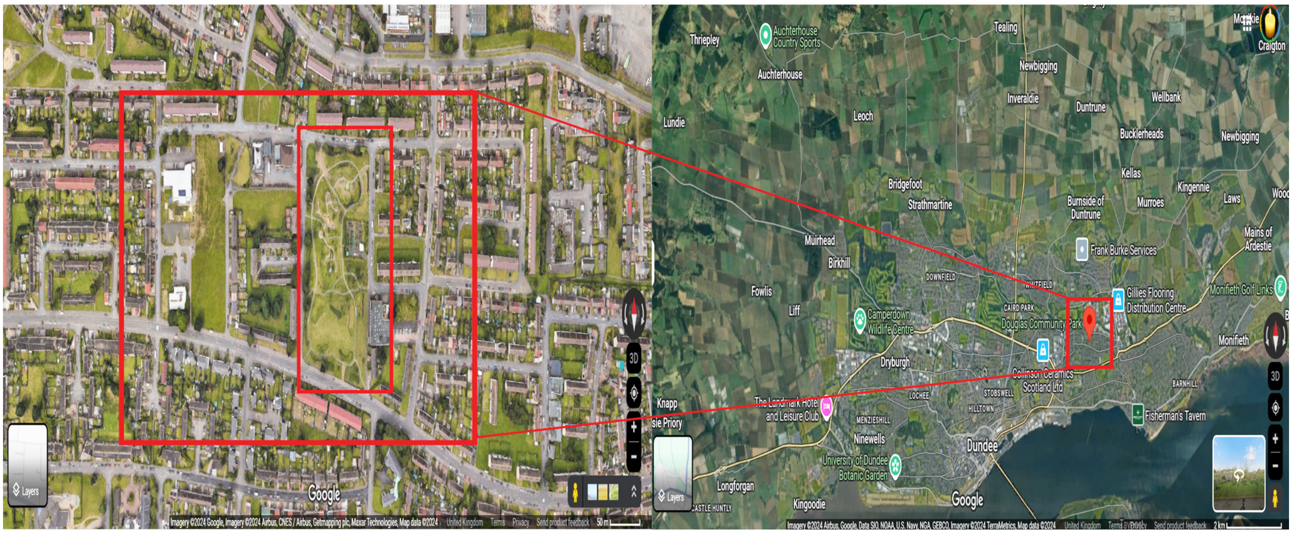


Figure B3.1. Location of Douglas Community Park. Image source: Google Maps.

Figure B3.2. A bird's eye view of Douglas Community Park. Image source: Google Maps.

The site was previously a brownfield site approximately 19,800m^2 and prior to the completion of the park, laid empty as a green space with low amenity value. Figure B3.2 provides a bird's eye view of the new Community Park that replaced it.

The primary purpose of the park is to provide amenity value for the local residents. This has been delivered through the construction of playgrounds, a basketball court, footpaths, benches, allotments, and flower beds. The secondary purpose of the park was to disconnect roof and road drainage from the local combined sewer network (roof drainage is the responsibility of Scottish Water and road drainage is the responsibility of Dundee City Council).

Technical Review

The roof and road drainage are conveyed to the Community Park through conduits from the road surface that pass underneath the public footpaths on each of the carriageways surrounding the park (Figure B3.3 (a)). The local community have been involved in the park throughout the entire project. This included volunteers and local primary schools being involved in tree planting as shown in Figure B3.3 (b).

The Community Park provides source control and conveyance of surface water through permeable paving (the surface of the basketball court is paved with permeable paving) and swales (Figure B3.4(a) and (b)). Combined, the surface water management solutions provide a total of 833m^3 of storage.

The park includes accessible play equipment, picnic benches with shelters, and a growing area which is managed by local volunteers. This includes an orchard and polytunnel. The park has played host to family fun days, which have been organised by the local Empowerment Team, and a summer festival which involved local community groups who were asked to perform. Local primary schools have been invited to seasonal treasure trails and scavenger hunts, and there are also plans for an educational 'Earth Walk' which will include a guided walk through the park.

This case study illustrates the benefits of partnership working amongst stakeholders working together to fund, design, and implement retrofit SuDS as part of a multiple benefits project. In addition to removing rainwater from combined sewers, this case study demonstrates how redevelopment of open spaces can achieve placemaking objectives whilst providing high amenity value to the local residents. The district plan presented in Figure B3.5 illustrates the integrated thinking and partnership approach required.

The design of the park was led by Dundee City Council Landscape Architects. Dundee City Council engineers were responsible for the design of the drainage system, whilst Scottish Water provided details for the connection to the combined sewer. Scottish Water are responsible for maintenance and are also monitoring the efficiency of the drainage system.

Figure B3.3. (a) Drainage conduit from public carriageway into Community Park. (b). Local primary schools planting trees in the Community Park. Image source: Scottish Water, courtesy of Claypotts Primary School, Dundee.

Figure B3.4. Community Park surface water management solutions: (a) permeable paving surface to basketball court; and (b) swales. Image source: Scottish Water.

Evaluation of Benefits and Costs

Table B3.1 below provides an overview of the costs and benefits of the surface water management interventions used in this case study, based on the findings from the literature review.

The Coarse Assessment summary is shown in Figure B3.6.

Interestingly, whilst the main drivers for the scheme were for the amenity benefit, the benefit value of the flood risk reduction is considered to be greater by the B£ST tool. This value is so high because of the number of properties disconnected from the combined sewer system which has created additional capacity for storm events. In reality, it is likely that the benefits to flood risk are underestimated because the number of properties at reduced risk of flooding downstream of the park has not been quantified. For a true estimate of the number of properties at reduced risk of flooding, flood modelling would be required which is beyond the scope of this study. It was therefore decided to use the number of properties disconnected to provide a very conservative estimate for use in this assessment. The park itself also provides storage volume which also increases the flood risk

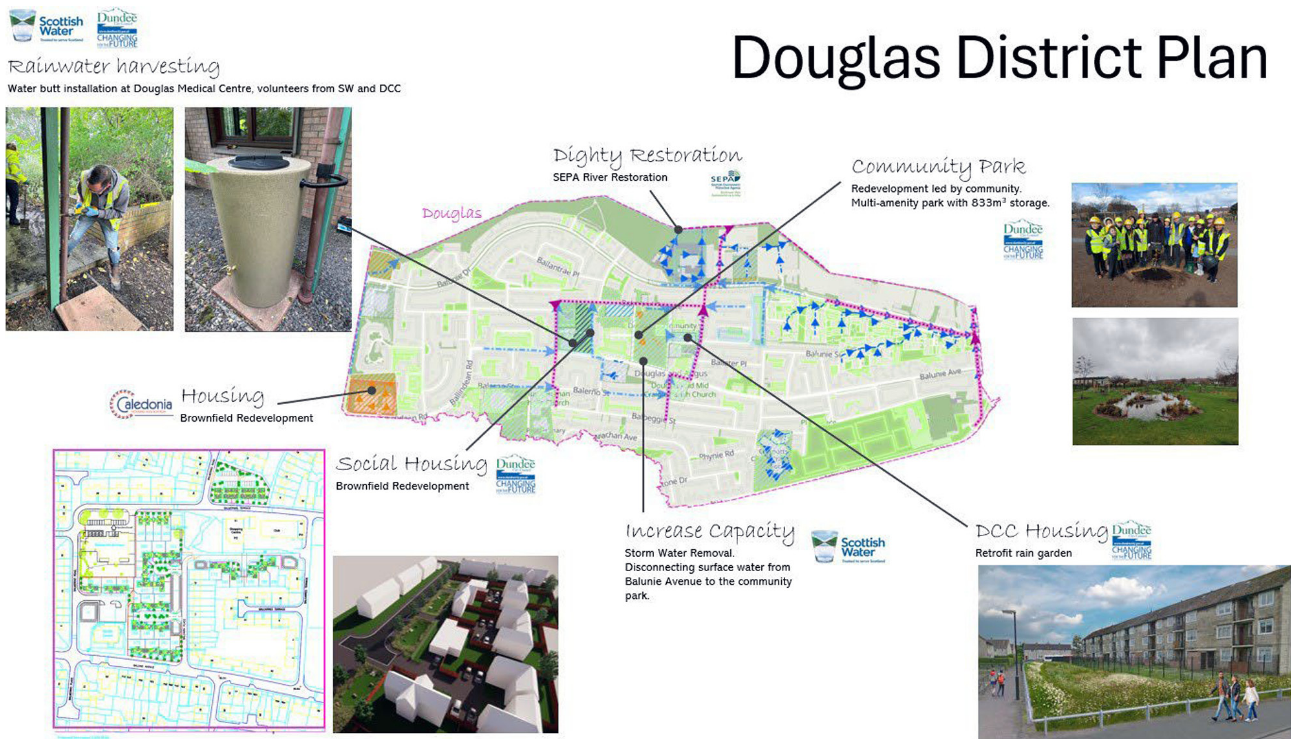


Figure B3.5. Douglas District Plan. Image source: Scottish Water.

Table B3.1. Benefits and cost overview based on literature review.		
	Category	**Relative score (1 (low) to 5 (high))**
Benefit	Water retention capacity	5
	Treatment performance	4
	Amenity	5
	Biodiversity	3
Cost	Relative capital costs	3
	Relative maintenance costs	3

reduction benefit. The amenity value, however, is still significant and there is a wide range of additional benefits linked with the creation of the park which are shown with the B£ST tool. The benefit-cost ratio using the central estimates is shown below:

$$\frac{Benefit}{Costs} = \frac{£3,333,175.00}{£450,000.00} = 7.40$$

Table B3.2 shows the input used to generate the benefit values for this case study assessment. The benefit-cost ratio calculated in this case study is high and shows the benefits in including additional benefits in sustainable drainage systems to enhance the overall value of the benefits.

Lessons learnt

This is an example of a very successful project, which has arisen through partnership and willingness to work together, out with the normal framework, to pool resources and deliver multiple benefits.

The park provides significant amenity value to the local community, particularly when compared with what was on the site previously.

The creation of the park was driven primarily by the local community, and this has helped encourage further regeneration of other, similar sites throughout Douglas and the wider community in Dundee.

By disconnecting the road and roof surface water surrounding the park from the combined sewer and providing 833m^3 of storage capacity, the park also makes this area of Douglas more resilient to flooding issues.

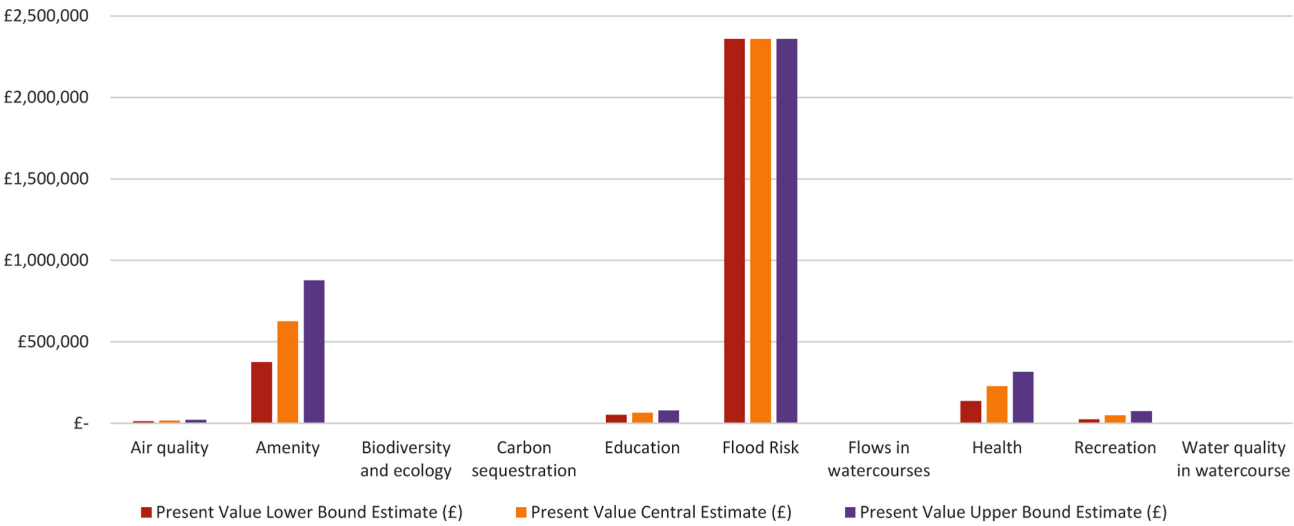


Figure B3.6. Coarse Assessment summary using B£ST tool.

Table B3.2. Coarse Assessment input using B£ST tool.

Question	Estimate quantity	Reasons/evidence for the estimated quantity
How many trees are being planted in urban and suburban areas (not as woodland)? Insert the number of trees to be planted.	25	*The value has been estimated from the construction photographs.*
How many trees are being planted as woodland? Insert the area of woodland in hectacres	0	
How many people will benefit from the improbvements to green space? Insert the number of people who live or work within 500 m of the green space improvement.	2353	*According to the latest census information, the population density of the EastEnd ward of Dundee is 3017 per square km. This value has been used to determine the number of people within a 500m radius of the park who will benefit from it.*
How many properties are likely to flood less requently/ severely? Insert the number of properties	90	*90 properties have been disconnected from the combined sewer and are drained through the park.*
What area of land is being enhanced that improves biodiversity? Insert the area of land in hectacres that is enhanced.	1.98	*The size of the community park is approximately 19800 square metres. This value has been used to determine the size of the land enhancing biodiverisy.*
What length of watercourse (km) or area of water (km^2) is being improved? Insert the length or area (1km also equals 1km^2) which will potentially change in ecological (WFD) status.	0	

B4 Case Study – Community Level Source Control: Community Engagement and Stewardship

Case Study B4.1 Coppermill Community Rain Gardens

Introduction

This case study is an example of how community engagement can enable retrofit solutions and provide a basis for ongoing stewardship.

The case study looks at the area in and around Coppermill Lane and St James Park in the Waltham Forest Borough Council, London. Waltham Forest Council successfully applied for funding through the Transport for London's Liveable Neighbourhoods scheme. The scheme was designed to reduce traffic and encourage use of more sustainable transport/ active travel. The scheme involved retrofitting of raingardens into the existing streetscape.

Partners involved in the project were:

- Waltham Forest Council
- Transport for London
- What If: Projects
- Meristem Design

Case study location

The location of the case study is the Coppermill area in Walthamstow, London. The project is an example of co-design and community engagement, from the initial consultation, through to implementation and aftercare.

Raingardens were selected as the source control technique as they are a small footprint technique that fit within the streetscape and provide multiple benefits. These benefits include greening of previously grey (paved) areas and biodiversity gain which can help in developing placemaking objectives.

Technical Review

Consultation with the local community included co-design workshops, consultation sessions, leaflet drops and online meetings. This early stage of consultation allowed the community to feel part of the project and express their ideas for design and impart knowledge of local issues, e.g. where there were existing problems with surface ponding. The consultation helped to influence the design and location of the raingardens.

Retrofit of raingardens within the streetscape reduced the number of car parking spaces, which can be a contentious issue in densely populated areas. Fortunately, this loss of car parking space was not an issue in the Coppermill area, where levels of existing parking were good and there was a focus on sustainable transport, with many residents having given up car ownership.

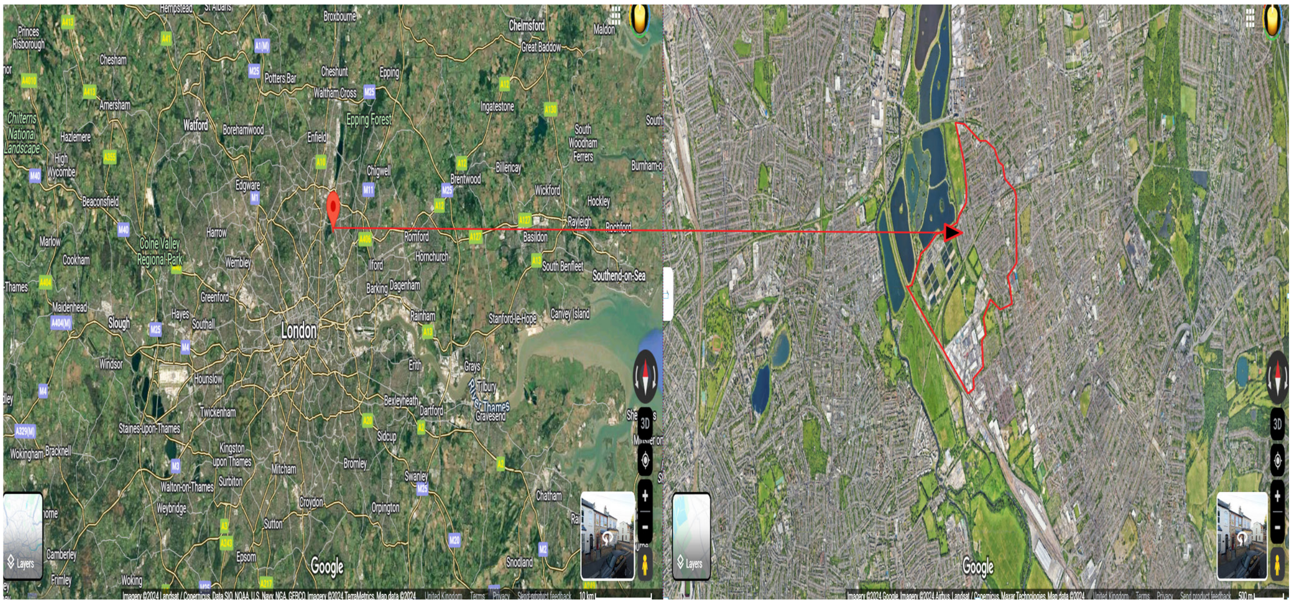


Figure B4.1. Case study location – London Borough of Waltham Forest (left) and the Coppermill Liveable Neighbourhood area within the Borough (right). Image source: Google Maps.

The raingarden locations were predominantly driven by road geometry, ensuring they were located at low points where the runoff would enter as sheet flow across the road surface.

To engage the community and help to develop knowledge and understanding, the local community were involved with the initial planting following the raingardens installation, and during the one-year maintenance period.

After the initial maintenance period the raingardens were maintained by the community, with designated "owners" for each raingarden. This did require a level of community cohesion, and the raingardens have been well maintained with a good level of buy-in.

The raingardens have performed well, however there are some opportunities to improve. There are minor discrepancies in levels/road geometry and areas of surface ponding on the road.

The soil specification was quite rich, and the raingardens could be quickly overwhelmed with grass/weeds. Residents contacted a local tree surgeon to source free woodchip to mulch the raingardens surface.

Figure B4.2. Community planting of the raingardens (left) and plants designed for interest and colour (right). Image source: Tom Fewins.

Figure B4.3. Excavation for raingardens (left) and variety of plant species for colour and texture incorporated in the raingardens (right). Image source: Tom Fewins.

Evaluation of Benefits and Costs

Table B4.1 below provides an overview of the costs and benefits of the surface water management interventions used in this case study, based on the findings from the literature review.

The raingardens installation has been a success, they have enhanced the streetscape, increased biodiversity, and reduced flow into the combined sewer. The Coarse Assessment is shown in Figure B4.4.

In this coarse assessment, the reduction in flood risk provides the highest benefit value, because there is a significant number of properties in the local area now at a reduced risk of flooding as a result of the raingardens being installed in strategic locations. The amenity benefit is also significant in benefit value. In total, this project has provided £28,506,765,00 in benefit value, being driven primarily by the reduced flood risk. The number of properties at a reduced risk of flooding is just an estimate based on an assessment of how many properties are in the local area. The inclusion of raingardens in strategic locations to provide attenuation will slow the flow of runoff into the combined sewer network which creates additional capacity during storm events, reducing the likelihood of flooding. The estimated indicative cost and benefit values have been assumed based on 280m^2 of raingardens. This has been taken from information on the designer's website showing previous completed projects (https://www.meristemdesign.co.uk/community-rain-gardens-waltham-forest). Costs have been taken from Abertay University's cost database and an average yearly inflation of 3.5% has been assumed.

The responses to the questions used to generate the coarse assessment is shown in Table B4.2. Google Maps was used to estimate the number of properties at reduced risk of flooding by counting properties in the area using aerial imagery. The area of land where biodiversity has been enhanced was chosen based on the overall area of raingardens built.

The benefit-cost ratio is shown below:

$$\frac{Benefit}{Costs} = \frac{£28{,}506{,}765.00}{£110{,}552.50} = 257{,}86$$

Table B4.1. Benefits and cost overview based on literature review.		
	Category	**Relative score (1 (low) to 5 (high))**
Benefit	Water retention capacity	3
	Treatment performance	3
	Amenity	3
	Biodiversity	3
Cost	Relative capital costs	2
	Relative maintenance costs	1

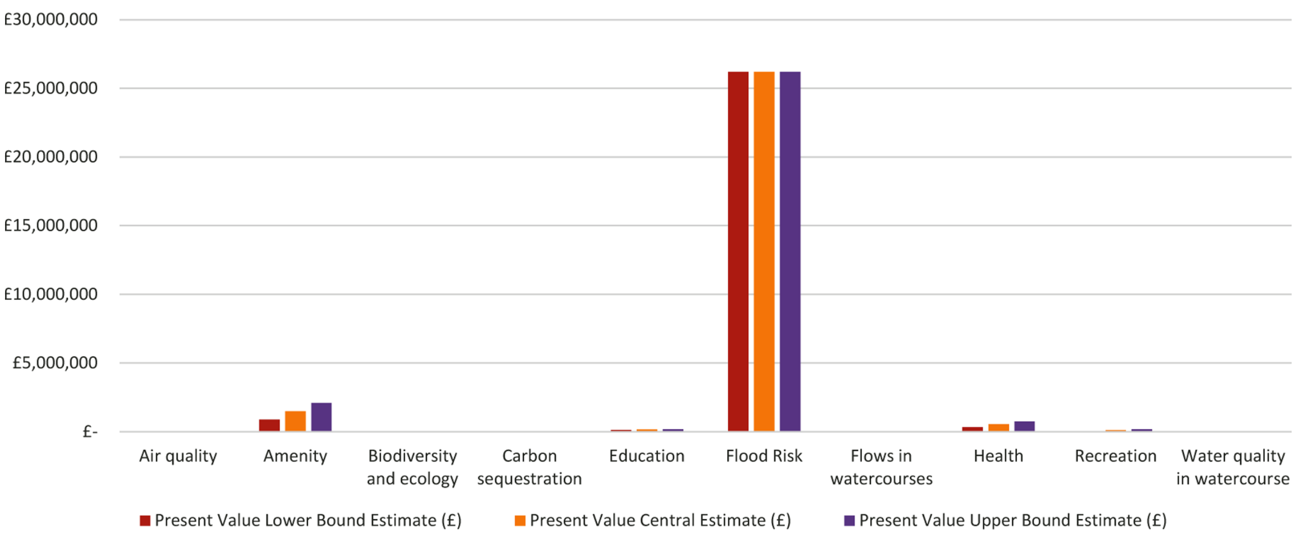


Figure B4.4. Coarse Assessment summary using B£ST tool.

This benefit-cost ratio is skewed by the high benefit value of flood risk reduction which is being driven primarily by the number of properties assumed to be at a reduced risk. As mentioned, above, the number of properties was assumed based on a crude estimate based on aerial imagery. For an accurate estimate, flood modelling would be required, which is beyond the scope of this study. This case study demonstrates an example of the coarse assessment, using the B£ST tool, not being fit-for-purpose since the benefit-cost ratio is likely to be significantly higher than any value that would be obtained from a more complex analysis that included flood modelling to obtain the actual number of properties at a reduced risk of flooding, and to what extent that flood risk has been reduced to.

Lessons learnt

Community engagement from an early stage is highly beneficial. Understanding of what raingardens are and how they function was an initial barrier. This was overcome by the open days and consultations. Once there was a better understanding of the issues, the community asked for more raingardens than were initially designed. Raingarden installation, however, can result in loss of parking and thus engagement with the community at the early stages can help reassure residents (?) and broaden their knowledge of the benefits of sustainable transport and active travel.

Involvement of the community in the initial planting and aftercare period has helped understanding of maintenance requirements and developed a sense of ownership and pride.

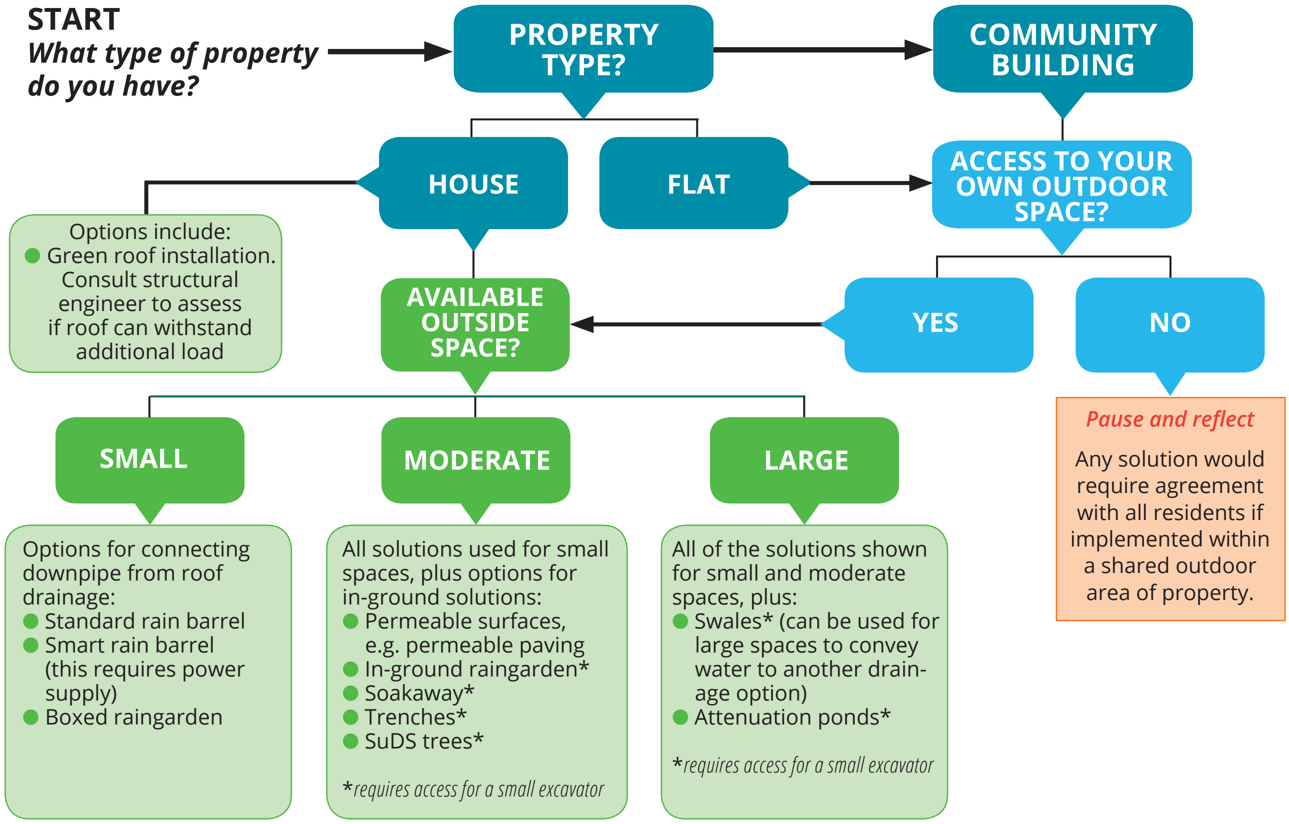
Raingarden "ownership" has tended to reside with a small group within the community. This could be improved by appointing a (local authority) volunteer coordinator – a person that has sufficient time and resource to work with the community to increase the number of active volunteers to share the workload amongst a larger group within the community.

Table B4.2. Coarse Assessment question responses.

Question	Estimate quantity	Reasons/evidence for the estimated quantity
How many trees are being planted in urban and suburban areas (not as woodland)? Insert the number of trees to be planted.	0	
How many trees are being planted as woodland? Insert the area of woodland in hectacres	0	
How many people will benefit from the improbvements to green space? Insert the number of people who live or work within 500 m of the green space improvement.	5,594	*Based on population density of Waltham Forest Council.*
How many properties are likely to flood less requently/ severely? Insert the number of properties	1,000	*Estimated using Google maps.*
What area of land is being enhanced that improves biodiversity? Insert the area of land in hectacres that is enhanced.	0.03	*Estimated using Google maps.*
What length of watercourse (km) or area of water (km^2) is being improved? Insert the length or area (1km also equals $1km^2$) which will potentially change in ecological (WFD) status.	0	

Appendix C – Infographics

Sustainable Drainage System (SuDS) Choose your most suitable option



What are the costs and benefits?

SuDS technique	Challenges to retrofit	Relative capital costs	Relative maintenance costs	Water quality	Water quantity	Amenity	Biodiversity	Cooling effect	Air quality
	1 (low) to 5 (high)			x means benefit relevant to SuDS technique					
Green roofs	4	4	2	x	x	x	x	x	x
Raingardens – boxed	2	2	2	x	x	x	x		x
Raingardens – in-ground	3	3	2	x	x	x	x		x
Permeable surfaces – pavement	3	3	3	x	x				
Permeable surfaces – other (gravel, woodchip etc.)	3	3	2	x	x				
Rainwater harvesting – standard rain barrel	1	1	1		x				
Rainwater harvesting – smart rain barrel	3	3	2		x				
Soakaways	4	4	3	x	x				
Swales	4	2	2	x	x				
Trenches	3	2	3	x	x				
SuDS Trees	4	4	3	x	x	x	x	x	x
Attenuation pond	5	5	4	x	x	x	x		x

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Types of Sustainable Drainage Systems (SuDS)


Rainwater Harvesting
(standard rain barrel)


SuDS Tree


Raingarden (boxed)


Soakaway


Raingarden (in-ground)


Trench


Permeable Surface


Swale


Green Roof


Rainwater Harvesting
(smart rain barrel, running on mains)


Attenuation Pond

CREW CENTRE OF EXPERTISE FOR WATERS

Abertay University

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