centre of expertise for waters

A rapid review of the background to source control

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EXECUTIVE SUMMARY

Background to research

The start of the 21st Century witnessed a revolution in drainage practices with the implementation of sustainable drainage systems (SUDS). Prior to 2000, rainfall was managed by directing it away as quickly as possible in underground pipes. Increasing pressures such as watercourse pollution, stricter environmental laws, climate change and urbanisation called for a paradigm shift with Scotland leading the way for implementing SUDS. SUDS are designed to mimic natural drainage processes, managing rainfall in stages as it drains from a development. Collectively this process is called the stormwater treatment train. The first stage is source control, with stages two and three being site and regional controls respectively. Source control principally controls and treats polluted runoff at source (where the rain falls) and if designed and implemented correctly, protect watercourses and downstream SUDS through filtration, infiltration and storage. In Scotland, site and regional control SUDS have become business as usual, however uptake of the stormwater treatment train and the use of source control SUDS in practice is less routine than would be expected.

Objectives of research

The SUDS Working Party in Scotland is an interdisciplinary stakeholder platform to discuss issues relating to the SUDS agenda and promote their use. In 2009, a consultation paper on 'Implementing the Water Environment and Water Services (Scotland) Act' set out proposals to improve the sustainable management of Scotland's water resources. The need for increased source control measures for the mitigation of diffuse pollution and climate change effects in urban areas was identified. To assist in this aspiration, the SUDS Working Party commissioned this study via CREW to identify opportunities and barriers to increasing the uptake of source control in Scotland. This report covers phase one of a three-phase study. It focuses on tracking the evolution of source control to gain an insight into enabling factors and obstacles for successful uptake of the systems. A literature review identified source control origins, the techniques available, and options for their application.

Key findings and recommendations

In the UK, research to validate the performance of source control measures began in the early 1990's. This was enabled by stakeholder platforms such as the SUDS Working Party and the Scottish Universities SUDS Monitoring Group. By the mid-1990s, the SUDS concept was developed which included source control and outlined water quality, quantity and biodiversity / amenity benefits of the systems. By 2000, Scottish guidance was developed and by 2006 it became law to implement SUDS in all new developments. This was quickly followed by technical standards in 2007. SUDS for roads networks were addressed in 2010. Currently, many types of source control exist, most of which have been validated by research and are commonplace. The state of the art techniques such as rain gardens, green roofs and rainwater harvesting however, have had limited uptake in Scotland.

It is evident that the enabling factors for the uptake of SUDS have been the result of top down drivers such as environmental initiatives and regulation. However, clarity surrounding the definition and application of source control as part of the stormwater treatment train is becoming a barrier to its uptake by practitioners. Extensive research provided a bottom up driver to validate effectiveness of the technologies for attenuating pollutants, mitigating flooding and creating habitats. Validation of emerging innovative techniques however, such as green roofs and rain gardens for different development types is limited in Scotland and this may prove to be a barrier in the future.

Key words

Sustainable drainage, SUDS, Source control, Stormwater treatment train, Pollution prevention

1.0 INTRODUCTION

The Sustainable Urban Drainage Scottish Working Party via the Centre of Expertise for Waters (CREW) commissioned a project entitled 'Implementation of source control for SUDS in Scotland' CRW2012/27. The project is being carried out by researchers based at Abertay University Dundee.

The project involves three phases:

1. Review of the background to source control including the history, various types, and options.
2. Appraise how source control is being delivered, within the UK and worldwide, and comment on the approach of the responsible organisations and professional groups in Scotland.
3. Design, implement and write up the outputs from a workshop to be held at the next meeting of the SUDs working party on 27th February 2013. The workshop should consider how to progress this area within the remit of the SUDs working party.

This report is the output from Phase 1. Phases 2 and 3 are presented in separate reports.

The transition from traditional, to sustainable, drainage (SUDS) in Scotland began nearly two decades ago. In a short timescale SUDS have become 'business as usual' in most new developments and many re-developments. This is true in the case of SUDS which manage runoff at the site, and at a regional scale. The uptake of source control SUDS are less routine than would be expected.

The SUDS Working Party in Scotland is an interdisciplinary stakeholder platform, established to discuss issues relating to the uptake of the SUDS agenda and promote their use. The group have been instrumental in delivering Scottish guidance for the design of SUDS (CIRIA, 2000), which was subsequently adopted and adapted for national (UK) guidance (CIRIA, 2007). Following a recognition to target and address surface drainage problems and associated high pollutant loading on roads, national guidance for SUDS for Roads have also been developed (SCOTS, 2010). Promotion of sustainable drainage by the group resulted in SUDS being the legally required norm to drain surface run-off from all new developments completed after, or constructed after 1 April 2007 via General Binding Rule 10 of the Controlled Activity Regulations (SEPA, 2006a and D'Arcy et al, 2006).

SUDS are designed to mimic natural drainage processes, managing runoff in stages as it drains from a site. SUDS utilise the treatment train concept that takes account of pollution control for improving water quality. The first level of treatment is source control with levels two and three being site and regional controls such as ponds and basins. Source control measures control and treat polluted runoff at source. If designed and implemented correctly, these protect downstream SUDS and / or watercourses through filtration, infiltration and attenuation. Source control can reduce management costs of downstream SUDS through removal of polluted sediment loads, which also increases the amenity benefits offered by these features. However, there are limited examples across Scotland of the treatment train and the use of emerging or new generation source control techniques such as green roofs and proprietary SUDS at the single plot level and in dense urban areas.

In 2009, a consultation paper on Implementing the Water Environment and Water Services (Scotland) Act 2003, titled: 'Scotland's Water: Future Directions', set out proposals to '*continue to make proportionate and cost effective improvements that will make a real difference for delivering the sustainable management of our water resources*'. Sections six and seven of the consultation identified the need for increased source control measures for the mitigation of diffuse pollution and climate change effects in urban areas (Scottish Government, 2009).

In order to assist Ministerial aspirations for achieving their long-term ambitions for Scotland's water environment, the SUDS Working Party have commissioned this study via CREW to identify the barriers and opportunities to increasing the uptake of source control in Scotland.

2.0 HISTORY OF THE SOURCE CONTROL CONCEPT

Source control SUDS can be defined as '***the management of stormwater as close to source as possible, where source is the point of contact of rainfall with the ground or other surfaces'***.

The early use of the term source control for managing urban stormwater was considered in one of two contexts: water quality or hydrology. The reasons are important for understanding the origins of source control SUDS and why there is confusion for some of the techniques and whether or not they should be considered SUDS. In the early 1990s source control in the UK was a term used by two sets of professionals. Pollution control officials refered to the minimisation of pollution risks from oil and chemicals by control at source, measures now described as "housekeeping". Hydrologists used the term in relation to hydrology – issues such as flooding and groundwater recharge.

Urban stormwater refers to rainfall driven surface water runoff, whether it drains to surface water sewers, to combined sewers, enters a watercourse directly as surface runoff, or infiltrates into soil and groundwater (Ellis *et al* 2004). The reasons behind the origins of innovative approaches to managing stormwater in the built environment in the UK, including source control, are threefold:

1. Water quality issues
2. Groundwater recharge and water shortages
3. River flooding associated with flash floods and latterly pluvial flooding associated with more intensive rainfall in constrained drainage catchments.

Initially three organisations in the UK independently explored more intelligent techniques to manage stormwater in relation to these issues (D'Arcy, 2012). Later a focus on managing stormwater in combined sewer catchments using SUDS also became important (see section 3.4).

The Forth River Purification Board initiated a review of water pollution control issues in 1993, in anticipation of the re-organisation of the Scottish pollution control agencies in 1996 to form SEPA, the Scottish Environment Protection Agency. A finding of the review was that diffuse sources were a hitherto unrecognised, but very significant problem for water quality in the Forth catchment. A diffuse source category of significant cause of poor water quality was urban drainage (FRPB, 1994). **Figure** 11 shows the sources of unsatisfactory quality as determined by chemical and ecological data in relation to discharges and pollution sources.

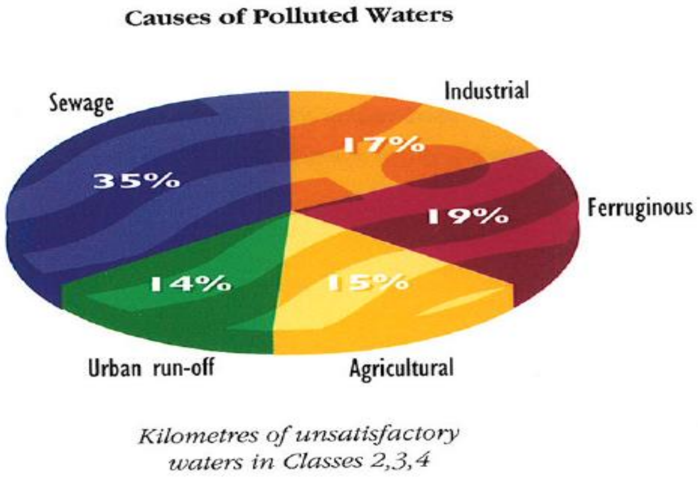

Figure 1 Causes of unsatisfactory river water quality in the Forth Catchment, with reference to a four category classification scheme whereby 1 is the best and 4 the poorest (FRPB, 1994).

There was a growing recognition in parts of the UK that 'foul-into-surface-water' / wrong connections were an important issue. Unpublished surveys in Merseyside showed sewage discharges from surface water drains were a ubiquitous feature of the drainage network, and similar investigations confirmed this as a chronic problem in Scotland. This is still an issue (Boffey, 2012), and a challenge that could be resolved if implementation of source control techniques was more prevalent. The pollution evidence base was extended nationally for Scotland in 1996 and further developed in 2005, (see SEPA 1996 and 1999, Wilson *et al* 2005). The conclusions from these studies established the need for infrastructure to trap and degrade wherever possible the contaminants in urban drainage. This was the basis for water quality drivers and the need for SUDS, including source controls. Initially (1994-96) the term for these measures was taken from the USA: best management practices, or BMPs. The term BMP is derived from the Clean Water Act 1972, which required BMPs to reduce the discharge of pollutants to the maximum extent practicable (Roesner, 1997). BMPs were specific well-defined pollution control techniques and had, at the time, nothing to do with managing flood risk or groundwater recharge.

Independently of the water quality investigations noted above, the NRA (National Rivers Authority) in SE England was concerned with the need to recharge groundwater, allied with interest in reducing flood risks exacerbated by urbanisation (Gardiner *et al* 1994). In parallel, investigations at Coventry University into permeability in the built environment led to interest in permeable pavements (Pratt *et al* 1989 and 1995) as well as soft-engineered technologies for stormwater management. The result of these studies led to a series of documents entitled: *Scope for control of urban runoff* by the Construction Industry Research and Information Association (CIRIA 1992a, CIRIA 1992b, CIRIA 1992c and CIRIA 1992d). The studies, which began in 1989, looked at the legislative and technical background for designing appropriate runoff control measures which also acknowledged the need to incorporate environmental considerations, support conservation and take into consideration the benefits of enhanced water quality and base flow in streams and rivers.

By the mid 1990's, aspirations for stormwater management included (after D'Arcy 2012):

- Capture diffuse sources of pollutants as close to source as possible
- Favour drainage techniques that allow for degradation as well as capture of pollutants
- Encourage drainage infrastructure that minimizes opportunities for wrong connections of foul into surface water drains

- Attenuate peak flows prior to discharge to the water environment
- Recharge groundwater
- Seek to replicate the natural hydrology of the area when providing drainage for the built environment.

Detailed considerations behind those aspirations (driving historical policies / actions in the UK) are set out in **Table 11.**

Table 1 Problem driven stormwater aspirations in UK, mid-1990s in relation to source control

Drivers	Geographic Focus	Example Issues	Environmental Regulator
Water Quality a) Address existing intractable, chronic pollution b) Prevent new problems	Scotland	Separately sewered industrial estates, especially in new towns i.e. Cumbernauld and Glenrothes Major roads and housing developments, and industry and commerce	Forth River Purification Board, FRPB, then from 1996 Scottish Environment Protection Agency, SEPA
Water Quantity a) Address urban flood risks b) Address groundwater recharge	England	Imperviousness a major issue for pluvial flood risks Sealed urban surfaces prevent groundwater recharge	National Rivers Authority, NRA, then environment Agency, EA (England and Wales)
Loss of natural hydrology	UK	Implicated in mobilisation of diffuse pollutants as well as flooding & groundwater recharge	Not a statutory aim for regulators, but key to an integrated philosophy for stormwater in UK

2.1 Developing the infrastructure aspirations for source control

Best Management Practices are defined as techniques to address diffuse sources of pollution and may be procedural or physical structures (Novotny 2003). **Table 11** shows why the BMP concept was recognised in Scotland but not as a driver elsewhere in the UK. Typical urban BMPs include source control techniques such as swales and filter strips, permeable surfaces, and end-of pipe features such as detention basins and retention ponds (Schueler 1987, Ellis 1992, Schueler *et al* 1992). The approach was radical at the time and contrasted with conventional flood risk management solutions such as underground storage tanks and off-line ponds that did not encourage infiltration.

One of the ideas that emerged from the USA as an element in the application of BMPs for managing stormwater was MDCIA, Minimising Directly Connected Impervious Area (Urbonas and Stahre 1993, Urbonas 1999 and Campbell *et al* 2004). This concept was advocated as a basic strategic source control approach to reduce runoff rates and delivery of pollutants to the water environment, by favouring grass/soil infrastructure or permeable surfaces for groundwater recharge and / or slowing runoff and allowing sedimentation/filtration. For the aspirations outlined above it became clear that MDCIA would also eliminate the problem of foul into surface water drains – if the stormwater passed over a lawn and grass filter strip prior to connecting with a public drainage network, any foul drain contamination would very quickly be noticed and resolved (**Figure 22).**

Figure 2 MDCIA exemplified for (a) housing in Berlin and (b) Seattle: roof runoff discharges onto front lawn. Foul connections are not an option.

BMPs were therefore recognised for their primary purpose of addressing diffuse pollution issues, and the more specific concerns with urban drainage, such as wrong connections. Quite independently, the potential of such techniques for allowing recharge of groundwater and more natural hydrology was recognised. Therefore landscape features such as swales and filter drains, or permeable surfaces were advocated as "source controls" in the UK (Ellis 1989, CIRIA 1992b).

The Rio Earth summit (1982) led to the emergence of the sustainable development concept as an idea to be worked into practical actions (Commission of the European Communities 1992). Accordingly, achieving natural hydrological patterns for draining urban areas was seen as more sustainable than conventional techniques as they reduced the environmental impacts of urbanisation (D'Arcy, 1997). The relative lack of concrete in many soft engineering techniques was also seen as a step in the right direction towards sustainable development in practice. The passive basis of treatment and water flows, with minimal maintenance was a defining desirable characteristic.

Thus for some source control techniques, there was a good fit between water quality drivers for BMPs and for the groundwater recharge / flow attenuation at source aspirations for urban drainage infrastructure. Conveyance systems (see section 5) such as swales and filter drains could be adapted to achieve both functions if considered at the outset. But this is not true for all source control techniques. Grass filter strips for example have no storage volume for flow attenuation of flood risk storm events, although they are permeable and allow some recharge of groundwater (Magette *et al*, 1997). It was a feature of many arguments over BMPs that they can have additional environmental benefits such as enhancing urban wildlife / biodiversity and can add to the amenity value of urban landscapes (IAWQ 1996, Stahre 2006, Apostolaki *et al* 2006, Apostolaki and Jefferies 2009). To the problem solving aspirations in **Table 11**, were therefore added desirables, as set out in **Table 22**.

Table 2 UK sustainability aspirations for stormwater management infrastructure that was desirable but not directly problem-driven (after D'Arcy 2012).

Aspirations	Perceived benefit	Examples	Comments
Soft engineering	Less concrete, less CO_2 in production	Swales, ponds, grass filter strips	Fit sought within green landscaping requirements
Passive treatment	No pumping, reduced CO_2 emissions	As above, also permeable pavement	Regulator cannot *require passive* treatment
Biodiversity	Enhancing wildlife interest in urban environment	1). Where source control measures are in place, wildlife in any downstream features such as ponds will be protected from worst pollution impacts (LBAP spp. colonised BMP ponds, e.g. greater crested newts, reed buntings) 2). Source controls can avoid need for kerbs and gullies that trap amphibians	Guidance published, but often not heeded, e.g. Ponds Pools and Lochans (SEPA 2000). Statutory duty for all publicly funded bodies to promote nature conservation (Nature Conservation (Scotland) Act 2004).
Social engagement	Enrich quality of urban life	Green and blue landscapes. Dry feet and no winter ice walking (on permeable surfaces)	Public more interested in dry feet than flow attenuation?
Education	Raise awareness of water and wider environmental issues	Community engagement projects, signs at features, provision of water features in schools	Engagement projects at DEX, signs at M40, Oxford services.
Economics	Potential for cost savings on new developments	Demonstrated in some case studies, e.g. at Motorway services in England	Not achievable if an add-on rather than alternative.
Water as a resource	Reduce demand on centralised distribution network	Rainwater harvesting (i.e. Water Sensitive Urban Design [WSUD] concept) added as an aspiration for stormwater management by Welsh SUDS working party	Waterbutts (rain barrels) provided to customers by several UK water service providers.

2.2 Source control SUDS and the SUDS triangle

The problem driven aspirations to address quality and quantity issues, together with the amenity and biodiversity elements of **Table 22,** were encapsulated in the concept of the sustainable drainage triangle (D'Arcy 1998, Walker et al 2000). This has subsequently become a core defining concept for SUDS, illustrated in **Figure 33**. Consequently, the two very different sets of drivers in **Table 11 (**quality and quantity), plus the wider aspects in **Table 22** were reflected in the term used subsequently in the UK: sustainable urban drainage systems (SUDS). Despite widespread uptake of that term, initial national guidance (e.g. CIRIA 2000) did not seek to set out an integrated approach to stormwater management, on the basis that it was the water quality aims of urban BMPs that were new to the UK, and flood risk measures were already well known. Subsequent guidance has sought to promote a more integrated concept, encompassing the multiple benefits and sustainability aspirations of SUDS. Currently the primary driver for SUDS has switched even in Scotland, increasingly to water quantity issues. Usually a pond is shown in the triangle as the example of a SUDS feature that can tick all the boxes. All aspects can also apply to a green roof or a swale. Even a permeable pavement fits the concept; the amenity function is met by providing dry feet, particularly if stored water is used for watering trees. Road technology without kerbs and gullies also fits the concept, as these features are recognised hazards for amphibians.

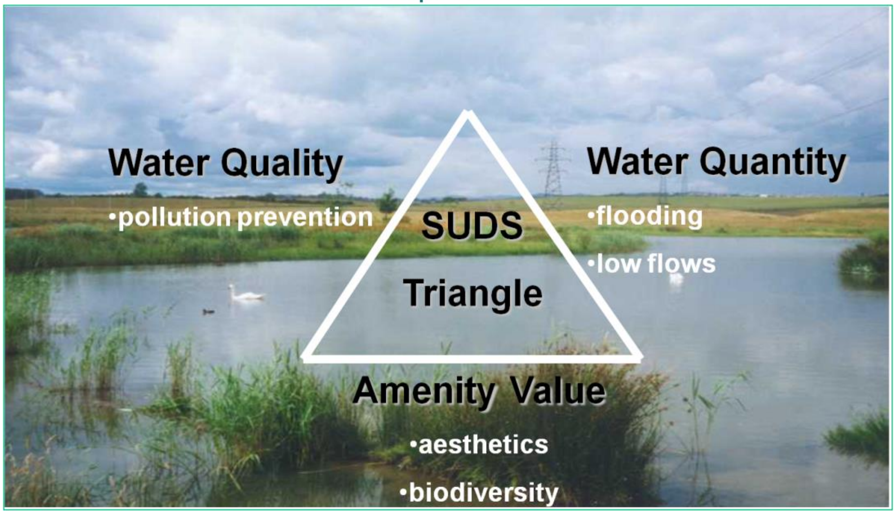

Figure 3 The sustainable drainage triangle (D'Arcy 1998).

2.3 Stormwater management

The SUDS triangle has arguably been a problem when encouraging source control. How to reconcile the more limited scope of some source control options with its "maximise benefits, everything in the one feature" concept? A geocellular plastic storage volume is still a valid technique for flow attenuation, but requires that treatment needs are met elsewhere (on the plot or in the system prior to discharge). A water butt if full at the time of a rainstorm is no different to a downpipe with no butt. Rainwater harvesting for domestic use also has been shown to provide a small reduction in quantity in relation to large rainfall events. Neither should be discarded as options, but require that flow attenuation be provided elsewhere. The plurality of benefits in the SUDS triangle concept should not prevent distributed achievement of its objectives on a site.

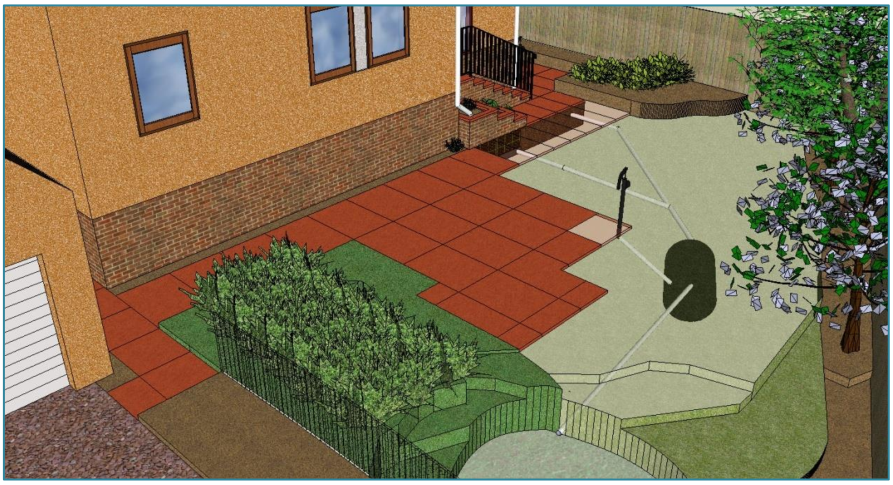

Figure 4 Stormwater management train for a house-plot: roof water is attenuated in an underground rainwater harvesting tank, with overflow to natural raingarden. The driveway uses permeable paving.

That would allow at least partial achievement of source control, if it is seen as the only option, and another part of the system is to be provided elsewhere in the development. In many instances, all aspects could still be provided within a single plot (unit plot SUDS). Alternatively, roof drainage could be attenuated in a geocellular unit beneath a lawn, or attenuated via a water butt fitted with a slow-release pipe, and treatment provided by a permeable pavement area for the driveway or a filter drain.

2.4 Levels of treatment

The original CIRIA SUDS Manual (CIRIA 2000) provided guidance on where and when SUDS techniques could be required. The pollution risks on industrial estates were recognised as greater than other urban areas due to the variety and quantity of pollutants often in use, with traffic, car parking and all the other risks present in housing areas. Thus housekeeping measures at each of the premises on a new industrial estate were advocated, and source controls at each site, followed by SUDS conveyance systems, and a regional control such as a retention pond or stormwater wetland. Those scales of SUDS application became known as three levels of treatment organised as above in a 'treatment train.' Whereby progressively more pollutant is captured cumulatively over the three levels, with highest concentrations anticipated in the close-to-source features, and progressively greater public amenity along the treatment train to the polishing pond last stage.

For trunk roads and motorways, a lower but still important risk was accepted requiring two levels of treatment: a source control feature such as a gravel filter drain (as already standard practice for motorways in Scotland) or swale, followed by a detention basin or pond. The latter (as on an industrial estate) would also serve as a holding pond in the event of an accident involving an oil or chemical spillage.

For housing development only a single level of treatment was required. There was much debate in SUDS Working Party during the preparation of the SUDS manual as to whether a requirement for source control could be established or, if the developer preferred to put in end-of-pipe features should that be acceptable? Either option would be one level of treatment. The level was thus not related to the type of treatment, and how many different processes were provided by one SUDS feature. A point to note is that 'roads' referred to trunk roads or motorways (with greater flows of traffic than a suburban street).

3.0 THE CURRENT ROLE OF SOURCE CONTROL TECHNIQUES

Source control features are listed in **Table 33**, together with indications of conveyance capabilities, functionality for principle statutory drivers, amenity and ecological benefits and suitable application. Source control SUDS can be further sorted by function, for example for pollution control attributes. Laboratory and field evidence has shown that hydrocarbons degrade in soil and in gravel, favouring selection of those types of SUDS (Scholes *et al* 2008, Napier *et al* 2010). Consequently, it is possible to screen source control techniques by type of land-use (and hence predominant pollutants).

Table 3 Source control features: conveyance capability, function and application.

Feature	Conveyance	Function	Application	Comments
Permeable pavement	N	All	All	Stone fill base must have sufficient storage volume
swale	Y	All	H, S, Li, CPL	Filtration. Can absorb soluble pollutants in soil in low flows especially (detergents etc)
Filter strip	N	P, A, E (P, GR: limited)	All	As above. Topsoil is beneficial for pollutant degradation, as is exposure to sunlight.
Biofilter	N	All	R,S, Li, CPL	As above
Rain garden	N	All	R,S, Li, CPL	Large area needed to store water during winter months
soakaway	N	All	R, Li, CPL	By-passes top soil where adsorption & biodegradation optimal. Not suitable for contaminated land.

Waterbutt	N	F	R, Li, I, CPL	zero storage when full
Stormwater storage cells (geocellula)	Y (possible if as under-drained swale)	F, GR	R, S, I, Li, CPL	Can be installed on a plot by plot basis, e.g. beneath lawn or driveway.
Filter drain	Y	All	All	Volume (void space) critical for flow attenuation
Rainwater harvesting	N	F (P: Limited)	R, I, Li, CPL	Limited water quality treatment
Green roof	N	P, A E (F: limited)	R, I, Li, CPL	Limited storage volume
Green wall	N	P, A, E (F: limited)	R, I, LI, CPL	V. Limited storage volume
Tree planters and tree pits	Y (if linked by under-drain)	All	R, S, Li, CPL	Storage volume limited in planter; frontier techniques
Planted rills	Y (?)	All: Limited P, F, GR	R, Li, CPL	Filtration. Can absorb soluble pollutants in soil in low flows; invalidated frontier technique
Infiltration trench	Y	All	All	Ideal where soil conditions favourable / low pollution risk
Schotterasen (gravel turf)	N	P, GR, A, E	R, Li, CPL	Ideal where soil conditions favourable and low pollution risk; frontier technique

Key:
Conveyance: Y = yes; **N** = no. **Function: P** = Pollution control; **F** = Flood risk management; **GR** = Groundwater Recharge; **A** = Amenity; **E**= Ecology. **Application: R** = Residential; **H** = Highway; **S** = Streets; **I** = Industrial; **Li** = Light Industrial; **CPL** = Commercial / Public / Leisure.

3.1 Treatment train: current and future practice

The treatment train concept favours deployment of SUDS in a progressive way within a development, such that at each scale of development (e.g. individual house or business unit, street, entire estate) SUDS features can be used. This allows for progressively increasing percentage capture of pollutants across a development. Whilst the technology can be cost effectively applied across each level, other constraints and developer preferences mean that it is not often accepted on that basis. Consequently, application of successive levels of treatment was reviewed as a policy by SEPA and general minimum requirements on the basis of pollution risks for each type of development were established (**Table 33**).

SEPA policy has avoided being too prescriptive, but the differing characteristics of various SUDS types has required some guidance from SEPA. For example, a road-edge filter drain or swale for motorways and other major highways, followed by a detention basin or pond. Source control measures which deliver treatment and quantity control are adequate for residential areas.

3.2 Stormwater management train

Given some water quality source control SUDS do not have significant stormwater storage capacity (e.g. grass filter strips for pollution control) but are effective for pollutant removal, whilst other features are the converse (e.g. stormwater storage modular box units), requires the achievements of the SUDS aspirations to often be met by a succession of features across a development.

3.3 Proprietary SUDS

Many types of source control SUDS are commercial products, e.g. permeable block paviours, green roofs, water butts, and inlet kerbs to filter trenches. Some of which are included in section 5 of this report as they are accepted (and mostly validated) as effective source control techniques. Additional innovative devices are now available that are targeting the SUDS market. There is an on-going debate amongst professionals and regulators if they should be considered as SUDS. If they are a component of the above, or meet the passive treatment, degradation in situ features of SUDS should they not be considered as SUDS?

Some proprietary techniques may have a role to play in retrofit scenarios and often it will be a combination of soft and hard engineered interventions which will be the most efficient and cost effective solution, particularly in regeneration and re-development situations.

British Water in partnership with the Environment Agency has published two technical guidance documents on proprietary products (British Water, 2005 and 2010). The first was published in 2005 and stemmed from the limited amount of information available to stakeholders on the use of the products available in the market at that time. It was intended to complement existing SUDS guidance to promote their use for the most suitable and appropriate situation (residential, industrial or commercial etc.) to ensure the environment is considered during development. The document covers general guidance and comparative information on the criteria that should be assessed when considering the incorporation and selection of proprietary SUDS products and stresses that every consideration of downstream treatment conditions should be taken into account when selecting the most suitable product. The document refers to each proprietary product and its relationship to the SUDS triangle. The four principle areas of proprietary SUDS solutions include:

- infiltration as the first option to consider (if ground conditions are appropriate) for dealing with runoff at source and a solution which usually requires little or no additional land take.
- storage/attenuation (if infiltration is not an option) to control peak runoffs and mimic the undeveloped process. All methods will require some form of flow control to perform as a storage structure and to satisfy any discharge licences.
- flow control which is generally required to retain or divert flows within the surface water network (source control / SUDS structures) to facilitate required storage volumes.
- treatment of polluted rainfall to protect receiving watercourses.

The updated guidance published in 2010 reviews sustainable drainage and outlines the issues which impact on surface water drainage. It is intended primarily to be a live web based publication so that a greater range of up-to-date information can be provided. It provides detailed descriptions of proprietary technologies to help select the most appropriate to be incorporated into a particular sustainable drainage solution.

3.4 Source control in combined sewer areas (CSOs)

This is an important opportunity and driver for source control SUDS. Disconnection of rainwater using source control can offer an affordable option if the correct technique is selected (as opposed to expensive end-of-pipe solutions), especially in locations which have poorly draining soils or are long distances from available watercourses. Source control techniques could be used to reduce flows by retaining runoff and slowly releasing it back into existing networks to aid flood prevention.

A study undertaken for Yorkshire Water highlighted that CSOs are likely to be required for many years to come. However with increasing pressures to continue to reduce spills, the construction of large storage tanks is unsustainable (Myerscough and Digman, 2008). Although new CSO structures constructed over the last decade have proved reliable and substantially contributed to an overall improvement in urban river water quality in the UK it is unlikely that significant further achievements can be gained using the same approach. One conclusion was that 'through the retrofitting of Best Management Practices, pollution within surface run-off can be tackled' (Heal et al, 2005).

Renfrewshire Council undertook a disconnection study as part of an EU funded programme (Jefferies et al 2008). The study evaluated disconnection options which would be applicable in Renfrewshire, discussed institutional, planning and funding obstacles and presented potential future disconnection targets based on successful experiences in Europe (WSR 2004 and Gemeentle Nijmegen 2007).

3.5 Retrofits

There several examples of retrofit SUDS source control schemes for improving water quality within Scotland. In most cases these have been driven by existing environmental problems, for example quality of receiving waters or flooding of combined systems, or where social regeneration projects are undertaken (Atkins 2004, Heal *et al* 2005). Atkins (2004) assessed retrofit options for ten locations in Ayrshire and Heal *et al* (2005) studied the retrofit example of the Caw Burn Wetland which serves the Houston industrial estate in Livingston. In both situations space was a common driver with scoping studies precluding site control in favour of low footprint source control measures. However, the Atkins scoping study only identified two locations where source control could be retrofitted and although the Cawburn retrofit was successful; its effectiveness is limited due to a lack of source control in the catchment. Whilst there is the on-going question of whether retrofit source controls should be located within the property curtilage or out with in public open space, recent case studies (CIRIA 2012) demonstrate that the latter is commonly the norm.

The regeneration of Craigmillar, Edinburgh is an example of source control incorporated into a large scale regeneration programme (SCOTS, 2010). The criteria which narrowed the scope of options for the development were: small footprint option as space was a premium; two levels of treatment required to protect the environmentally sensitive receiving watercourse; integration of SUDS with the existing infrastructure. The scoping study identified five possible techniques all of which were small footprint options (source control) with porous pavements being the selected option.

In dense inner city areas space is an absolute premium and making use of existing areas is a key focus. A common example is the retrofitting of green roofs in the UK and further afield (see section 5.6). Current uptake of the structures appears to be limited in Scotland but the City of London is pushing for the implementation of green roofs / living walls with a policy statement issued by Ken Livingston (previous Mayor of London) now incorporated into the London Plan (DFL, 2008).

4.0 THE EVIDENCE FOR THE EFFECTIVENESS OF SOURCE CONTROL OPTIONS

Considerable research has been carried out into the performance of SUDS. This has shown that SUDS features including source control are successful in significantly attenuating pollutants such as suspended solids, phosphorus and nitrogen, creating habitat and amenity as well as mitigating the impact of flooding. Scotland has benefitted from a number of SUDS research programmes which have been mainly funded by stakeholders with a role to play in either constructing or owning the structures. The first programme was undertaken by the 'Scottish Universities SUDS Centre of Excellence'. This was a SUDS monitoring group who were part funded by Scottish Water, Yorkshire Water and several other stakeholders, (Jefferies (ed) 2001 and 2004). Results have validated many performance and financial aspects of SUDS including source control (primarily traditional techniques such as filter drains and swales) and played a part in setting national guidelines such as the CIRIA 2000 and 2007 design manuals. It is worth noting that research in Scotland regarding the more novel source control techniques such as green roofs, bioretention / raingardens is limited to date.

The American Society of Civil Engineers (ASCE) has developed a BMP database to record research findings. This database is a long-term project that began in 1994 through the vision of members active in the Urban Water Resources Research Council of ASCE under the leadership of EPA. Funded for many years by EPA, the project is now supported by a coalition of partners including the American Public Works Association (APWA). The database is intended to provide a consistent and scientifically defensible set of data on Best Management Practice (SUDS) designs and related performance. It is updated on an annual basis with the Pollutant Category Summary Addendum for 2012 providing the evidence base most source control types (Leisenring *et al* 2012). The pollutant categories include suspended solids, bacteria, heavy metals and nutrients.

We identified fifteen source control techniques for this study and a brief literature review undertaken. Most of the techniques are validated by research (although not all of them are currently being implemented in Scotland) and a few examples are cited for each. Detailed descriptions of the techniques according to the current national SUDS guidance manual C697 (CIRIA 200) including design drawings, additional images and brief descriptions of the application or option for use can be accessed in the technical report from CREW, the SUDS Working party via SEPA, or Abertay University via the Urban water Technology Centre (uwtc@abertay.ac.uk).

4.1 Swale

In 2004 the SUDS Monitoring Programme stated that 'in many ways the incorporation of swales into drainage systems has been one of the most innovative aspects of source control SUDS in Scotland' (Jefferies 2004). The report provides evidence for the hydrological and water quality performance of roadside swales and describes the design for treatment and conveyance swales throughout Scotland.

Swales can be incorporated into most settings and provide an array of benefits (Highways Agency 2006, CIRIA, 2007, SCOTS 2010, Charlesworth et al 2012, RSPB and WWT 2013).

Figure 5 Trunk road wet swale which conveys and treats runoff, Scotland. Source: Alison Duffy

4.2 Filter Drain /Infiltration trench

Filter drains are linear trenches filled with aggregate, designed to attenuate and treat runoff. They offer a small footprint solution and are commonly used in the road environment. Studies have shown that filter drains can remove up to 75% of total suspended solids from runoff (Schlüter, 2002).

Filter drains are effective attenuation and treatment techniques but can have high failure rates due to wrong siting and be prone to clogging at the top of the trench leaving a redundant storage volume below (McDonald & Jefferies 2003, Lampe et al. 2005, Todd 2007, Hill & Mitchell, 2012, Heal *et al*, 2007).

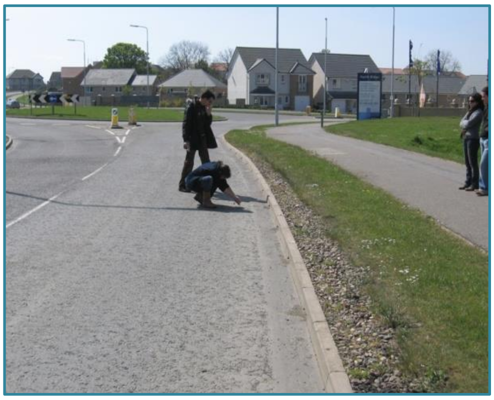

Figure 6 Roadside filter drain, Scotland. Note kerb inlets. Source: Alison Duffy

4.3 Bioretention

A bioretention area is a filtering system which utilizes parking area islands and planting strips for on-site treatment of water quality volume. Surface runoff is directed into shallow, landscaped depressions which are modelled to incorporate many of the pollutant removal mechanisms that operate in forested ecosystems (Claytor, 1996).

Bioretention can be adapted to fit into different development contexts and is designed to capture small storm events or the water quality storage requirement. An overflow or bypass is necessary to pass large storm event flows (TRCA, 2010).

Figure 7 Roadside bioretention in Seattle, USA. Source: Brian D'Arcy

4.4 Rain gardens

Rain gardens capture roof, lawn and driveway runoff from low to medium density residential lots in a shallow depression. These can be simple gardens constructed by the homeowner as a retrofit, or professionally designed into a residential development and may have an underdrain connected to the main storm drain pipe (TRCA, 2010).

Building a raingarden is a simple way to help the environment and the health of local water courses while providing a self-watering garden (Melbourne Water 2010). Owners with raingardens installed on house plots need to be educated on routine maintenance needs (TRCA 2010).

Figure 8 University courtyard, England - Porous paving / rain garden. Source: Alison Duffy

4.5 Permeable pavement

A large number of studies have been undertaken concerning the pollutant removal properties of permeable pavements, their hydraulic functions and the effects of clogging (See Mullaney *et al* 2012).

Coventry University undertook hydrological and water quality field studies on a permeable pavement constructed in 1986 in Nottingham where they showed significant reductions in outflow volumes and water quality parameters for suspended solids and lead (Pratt *et el* 1995).

Figure 9 Lidl car park with maintenance underway Scotland. Source: Alison Duffy

centre of expertise for waters

4.6 Greenroof

Green roofs have the potential to achieve SUDS triangle benefits simultaneously with an opportunity for engineering to work in harmony with natural environmental processes to contribute to sustainable urban environments (Stovin et al 2011).
There are three main types of green roofs: extensive roofs with low growing, low maintenance plants; intensive roofs which are landscaped environments with high amenity benefits and with significant maintenance obligations; simple intensive green roofs with lawns or ground covering plants with regular maintenance required (English Nature 2003, Dunnet 2003, Gedge, 2003).

Figure 10 Garage, Augestenborg, Sweden. Source: Alison Duffy

4.7 Greenwall or Living Walls

Living Walls are relatively new phenomena in the UK, with the first constructed in 2007. Since then, much research and development work has gone into producing walls that are attractive, durable and cost-effective. Living Walls offer design solutions for awkward urban spaces, but they also bring flora and fauna, colour and biodiversity to buildings and urban landscapes.
www.scotscapelivingwalls.net/discover-living-walls.html
Living walls provide environmental benefits in the form of biodiversity, thermal insulation, cooling effects, and noise attenuation. (Design for London (Ed) 2008).

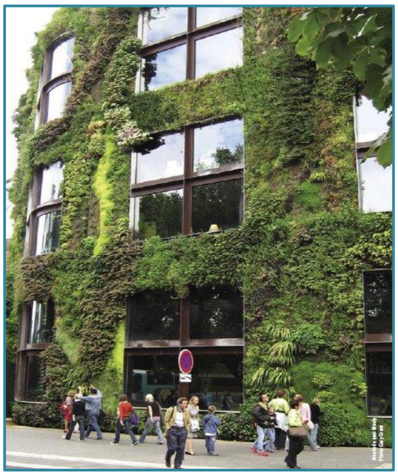

Figure 11 Living Wall, London
Source: Design for London 2008

4.8 Soakaway

In the UK, soakaways are a traditional way to dispose of stormwater from buildings and paved areas remote from public sewer or watercourse (BRE 1991, Jones 2001). They store rapid runoff from a single house or development and allow infiltration into surrounding soil. Drainage from individual properties is often connected to over-size square or rectangular, rubble-filled voids sited beneath lawns without formal provision for access and inspection (CIRIA, 2007).
Pollution danger to the quality of groundwater must be considered. Limited evidence suggests roof run-off does not impact on groundwater quality (BRE, 1991).

Figure 12 Soakaway in residential development, Sweden. Source: Chris Pratt, from Stahre 2006.

4.9 Filter Strip

Filter strips are buffer strips (usually grassed but may also pea-gravel) providing a cost effective first level of treatment at source. Although providing limited hydraulic benefit, they provide good to moderate water quality benefits (Lampe et al. 2005, CIRIA 2007 and 2010). They are best used in conjunction with other source control techniques to provide maximum benefit (Magette et al. 1989).

Dillaha *et al.* (1989) suggest nutrient reductions of up to 37-81% with varying width of vegetative filter strips. They are easily integrated into landscaping, however suitable land must be available for their use (Heal *et al* 2009).

Figure 13 Vehicle lorry park, England. Sheet flow from the car park passes across the filter strip to the filter trench. Source: Fiona Napier

4.10 Geocellular Units

Geocellular units offer little water quality improvement (CIRIA 2007) but can be used in conjunction with other SUDS techniques to deliver both quality and quantity. In standalone form they can be used to attenuate and control forward flow where there are no environmental restrictions or to combined sewer systems (SEPA, 2011).

Geocellular units offer high void attenuation storage with a limited footprint and are particularly useful where space is limited. Location of the cell should consider land use both for access and structural integrity (CIRIA 2008).

Figure 14 Geocellular units under construction. Source: Chris Digman

4.11 Rainwater Harvesting

The pollutant removal capacity of rainwater harvesting systems is directly proportional to the amount of runoff captured. Theoretically, if 100% of runoff is captured and used, no stormwater pollution from the catchment surface will be conveyed downstream (Coombes & Kuczera, 2003; TRCA, 2008c).

Rainwater is likely to contain traces of animal and bird waste, and atmospheric and environmental pollutants. Contaminant level will vary from site to site. Protection against such contaminants must be allowed for in the design of the reuse system. (Scottish Water, 2011).

Figure 15 The Olympic Velodrome, England. RWH was used for toilet flushing and landscape irrigation (learninglegacy.london2012.com)

4.12 Tree Planters and Tree Pits

Tree planters receive runoff from adjacent rooftop downspouts. While they treat small drainage areas, a significant portion of rooftop runoff may be captured and treated this way (TRCA 2010). Tree pits are located within the road and take advantage of the landscaped space between the pavement and street. They are typically designed to be offline, that is when they are full the stormwater will flow to the downstream street inlet (TRCA 2010).

Figure 16 Hydro Filtera tree pit, USA. Source: Hydro International.

4.13 Planted Rills

Planted rills are open surface water channels with hard edges planted to provide water treatment. In dense urban areas where space is a premium they are effective for providing source control acting as pre-treatment to remove silt before water is conveyed downstream. Many schemes use channels in imaginative ways to enhance urban landscapes (RSPB 2013). Planted rills in urbanised areas, can make a visually interesting feature and provide additional wildlife benefit (Cambridge 2010).

Figure 17 Planated rill in residential area Augustenborg, Sweden. Source: Alison Duffy.

4.14 Water butt

A water butt collects rainwater runoff from roofs via an inlet that is connected to the down-pipe. It is normally constructed from polyethylene, which is often sourced from recycled material. They are manufactured in a wide variety of sizes and some models consist of inter-connectable units. During wet periods, water butts are often full, resulting in little or no attenuation or reduction in outflow rates or volumes. However, water butts can be designed to attenuate runoff by using a throttled overflow system. (DEHLG, 2005a and 2005b)

Figure 18 Large scale residential water butt. Source: Chris Digman

4.15 Gravel turf

The vegetation base layer consists of recycling materials or natural gravel mixed with soil. Grasses and herbs are planted on the base layer. It provides habitats for plant, animals and insects, naturally decomposes pollutants and has positive effects on urban microclimates (Florineth 2008).

Figure 19 Gravel turf car park. Source: Florineth

5.0 OPTIONS AND OPPORTUNITIES

Dealing with water when and where it falls can be the cheaper and easier option for many developments by using an appropriate combination of solutions and careful design at the outset. By dealing with runoff at source the volume of water and the potential amount of contamination is less: this is efficient use of space for storage and treatment. This often means the footprint (land take) of downstream SUDS can be reduced (Jones 2001, Heal *et al* 2009).

The minimisation of impermeable areas can be achieved through the use of permeable paving or gravelled surfaces instead of conventional paving/concrete. The diversion of stormwater, such as the first flush of roof run-off or from disconnected downpipes, to infiltration devices such as raingardens and soakaways, reduces the volume of water discharge to receiving waters. Roof water can also be discharged directly to the sub-base of filtration devices if design exceedence can be managed. Maintenance requirements and costs are also low (DEHLG, 2005b).

There are three key categories for the application of source control techniques: unit plot; industrial, commercial and public; and motorways and trunk roads. Following discussions between the project team and SUDS Working Party it was agreed that source control SUDS applied to highways and industrial / commercial developments was well covered in the literature. Indeed the examples in Section 5 illustrate that this is the case in the UK. There is however much scope for application at the unit plot level whether this is in curtilage (house plot) or industrial / commercial units.

5.1 Unit Plot

Novel or frontier systems and applications for each of three categories will be explored in greater detail during Phase 2 of this project. An important but novel conceptual approach for source control implementation is the example of raingardens. Considering the speed of uptake of the systems in Australia are we missing a trick here in the UK? The following is an example of a rain garden initiative.

10,000 Raingardens for Melbourne: "Melbourne Water is a publically owned utility. Melbourne Water's 10,000 Raingardens Program promotes a new, responsible way of gardening so everybody can create their own sustainable garden at home and do their bit to help the environment and protect our rivers. The aim of the program is to encourage people to build raingardens in their own backyards. '*By building a raingarden you will enjoy the benefits of a low maintenance, sustainable garden while also protecting the environment by reducing the amount of pollution that would otherwise wash into our rivers and creeks*'. Until now we have been working with local councils and the community to create raingardens in public spaces such as streets, parks and schools. The raingardens program recently expanded and we are now providing easy, step by step instructions so people can design, build and maintain raingardens in their own homes. Our target is to see 10,000 raingardens built across Melbourne by 2013" http://raingardens.melbournewater.com.au/.

At the time of writing the first draft of this report, the website indicated that 7,872 raingardens had been implemented. By the second draft 8,398 raingardens had been implemented and by the final draft, the target had been exceeded with 10144 raingardens implemented!

It is worth noting at this stage that one of the main concerns and key barriers to unit plot source control within the curtilage of properties in Scotland (and the rest of the UK) is the need for the system to be maintained by the property owner or manager of a property (Ralph, 2011).

6.0 CONCLUSION

This review of the implementation of source control for SUDS in Scotland has highlighted that the catalogue of source control measures has expanded since the early 1990s from the traditional soakaway and infiltration trench to many of the measures detailed in section four. A great deal has been achieved in a short time and the source control toolkit continues to expand on a global scale.

Using a transition management back-casting approach it is evident that the enabling factors for the uptake of SUDS has been the result of top down drivers such as environmental initiatives and regulations which have proved to be the simplest, most effective mechanism for driving improvement. Extensive research in Scotland has provided a bottom up driver in combination with a drive by stakeholders who funded much of the research to validate source control performance. Quantified achievements have been recorded for prevention of pollution and flooding, as well as for amenity and biodiversity befits. However, research into emerging innovative techniques such as green roofs and rain gardens is limited in Scotland and this may prove to be a barrier in the future.

SUDS are a routine area of business in Scotland for all responsible authorities including consultants, developers, planners and SEPA. This is true for SUDS at the site and regional levels but not for source control SUDS. It is apparent that some progress has been made in implementing source control but there are many more options for their use than is currently being applied in Scotland. The need for benefits offered by the systems is becoming more important as future uncertainties in the Scottish urban environment are manifesting in the form of overloaded sewers and repeated combined sewer overflow spills due to climate change impacts, urban creep and the need for new developments.

This review has provided an insight into the barriers for implementing source control with several key factors identified. Firstly, clarity surrounding the definition of source control has become blurred. What is a true source control technique and what is not? E.g. SUDS (including many proprietary mechanisms) which provide conveyance and or flow attenuation but do not offer treatment are not considered SUDS by many water practitioners.

Secondly, Interpretation of the SUDS triangle and confusion with the stormwater treatment train concept appear to have caused a problem surrounding the overall benefits of SUDS and the level of treatment which is required to deal with potential pollutant loading from a specific location. Thirdly, the preference of Scottish Water to adopt site and regional controls has further blurred the boundaries of the treatment train / SUDS triangle concepts. If a SUDS feature such as a pond which maximises all benefits is implemented then practitioners believe that they are providing the level of treatment required across a development AND satisfying the SUDS triangle objectives. This is resulting in above ground drainage systems which are bypassing the first level of treatment – subsequently discouraging source control. However, as long as there is a combination of SUDS which meet all objectives of the SUDS triangle then this will result in a sustainable drainage system.

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