Environment Agency

Rural Sustainable Drainage Systems (RSuDS)

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Author(s):
Dr Lisa M Avery
Catchment Management,
Macaulay Institute

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Environment Agency's Project Manager:
Jamie Letts, Environment and Business

Collaborator(s):
Allerton Research and Educational Trust
Lancaster University
Macaulay Land Use Research Institute
Newcastle University

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Miranda Kavanagh

Director of Evidence

Executive summary

Rural Sustainable Drainage Systems (SuDS) are not a new concept, but they are not widespread in the rural environment and could present many opportunities for improving our management of water at source. They are a collection of physical structures used to mimic natural processes. In rural environments, it is an approach for managing the detrimental impact of rainfall on fields where run-off is a major threat to the flora, fauna and chemical status of our surface waters.

Rural SuDS are tools that help maintain and manage the provision of good water quality. They provide an important role by intercepting run-off and trapping soil before it leaves the field.

Traditional drainage to manage surface water run-off is designed to carry water away quickly, without treatment, and can rapidly transfer pollutants and large volumes of water to streams, rivers, lakes and estuaries. Rural SuDS slow down or prevent the transport of pollutants to watercourses by breaking the delivery pathway between the pollutant source and the receptor. By intercepting run-off and trapping sediment before it leaves the field they help maintain and manage the provision of good water quality by preventing the loss of soil, chemicals, nutrients and faecal organisms. A further benefit is their ability to temporarily capture water and slow down flow. This can reduce localised flooding and provide valuable aquatic habitats in the form of micro-wetlands for farmland wildlife and will encourage the downward movement of water to recharge aquifers.

The report provides a list of existing land management options that fit the definition of sustainable drainage and reviews their cost and effectiveness in helping to meet the objectives of the Water Framework Directive, to reduce flood risk and adapt to climate change. Options explored in the report include trenches, wetlands, retention ponds and buffers and many of these features can be further enhanced by sediment traps as part of the design.

Whilst rural SuDS may be more complex to create compared to a simple buffer strip, this is off-set by a number of additional benefits for the landowner. They can make existing features such as buffer strips, walls and new hedgerows even more effective; they are not demanding on space and by trapping sediment in the field will save a valuable resource.

Rural SuDS are one group of measures that can be created with minimum loss of agricultural production. They should be used as part of a systemic approach to managing run-off, lowering flood risk and increasing water adsorption. They are good examples of being able to deliver multiple benefits but need to be planned and targeted as part of future catchment management.

The measures identified in this report may offer some of the answers towards tackling diffuse pollution to improve the chemical and ecological status of surface water in the short to medium term; whilst in the longer term, they will enable land managers to adapt to intensive rainfall that is more likely with our changing climate.

Acknowledgements

Acknowledgement and thanks to all those who are helping to put science into practice and have developed practical solutions for a very difficult question.

Newcastle University
Lancaster University
Allerton Research and Education Trust
Macaulay Land Use Research Institute
EA Evidence Directorate

Contents

1 Introduction

Man's activities on land, in both the built and rural environment can alter the characteristics of natural soils that can lead to losses of topsoil and increase the flow of water to rivers and lakes. The loss of soil and vegetation can remove an important filtering mechanism for surface water run-off.

Traditional drainage to manage surface water run-off is designed to carry water away quickly, without treatment and can rapidly transfer pollutants and large volumes of water to streams, rivers, lakes and estuaries. While there is no specific legislation to ensure that issues of sustainability are considered with regard to drainage, sustainable drainage systems (SuDS) have been encouraged in the urban environment through local Agenda 21 initiatives and through planning policy PPS25 (England) and TAN 15 (Wales) which directly identify their potential to reduce flooding[(1)]. SuDS mimic the natural drainage characterising the site prior to development. For example, erecting buildings and creating impervious roadways or car parks is likely to remove an area of land which previously allowed infiltration of rainwater and surface run-off. Rather than directing the run-off as rapidly as possible to a receiving water body, sustainable drainage systems seek to minimise the impacts of development on the quality and quantity of run-off, while maximising amenity and biodiversity opportunities[(2)].

Agricultural best practice guidance documents (Defra Good agricultural practice guidance[(3)], EA Best Farming Practices booklet[(4)], SEPA BMPs[(5)], Defra Inventory of DWPA measures[(6)]) make reference to measures which fall within the definition of SuDS and are applicable in the rural environment.

Bringing a suite of SuDS approaches similar to those which are becoming routinely used in the urban areas into rural (frequently but not exclusively agricultural) landscapes could reduce peak storm flow[(7,8)] to receiving waters and associated diffuse pollution, thus helping to prepare for extreme events associated with climate change. Rural SuDS (RSuDS) also have potential to provide additional benefits through increased biodiversity and amenity in farmland catchments.

1.1 Aim of this report

The aim of this report is to list existing land management options that fit the definition of sustainable drainage and to review their effectiveness as a measure to help meet the objectives of the Water Framework Directive, to reduce flood risk and adapt to climate change.

Specific objectives are to:

- create an inventory of SuDS measures that are appropriate for use in agricultural systems;
- review existing relevant studies on the cost-effectiveness of proposed measures;
- review the evidence base to enable the Environment Agency to provide more effective advice to policy makers in Government departments;
- provide the basis for a guidance document for farmers and land managers to install Rural sustainable drainage systems that are effective and beneficial to the environment;
- To communicate the principles of Rural SuDS to Environment Agency staff, key stakeholders and the farming industry.

2 Rural Sustainable Drainage Systems

2.1 Definition of Rural Sustainable Drainage System

RSuDS comprise individual or multiple linked component structures replicating natural processes, designed to attenuate water flow by collecting, storing and improving the quality of run-off water within rural catchments.

The simple definition is that they are measures that primarily intercept run-off or drainage pathways.

2.2 General Description of Rural Sustainable Drainage System

RSuDS are intended to mimic natural hydrological regimes to minimise the impact of human activity on surface water drainage discharges, reducing flooding and pollution of waterways and groundwater. Rural SuDS would be mainly associated with land uses such as farming and forestry.

They involve collection, storage and cleaning processes before allowing water to be released slowly back into the environment. The inclusion of these processes and the presence of a semi-permanent physical structure differentiate RSuDS from other best management practices such as cover crops or soil management.

RSuDS should meet the following criteria:

- Low energy input
- Zero, or only positive environmental impacts
- Low capital and running costs
- Provide additional benefits (habitat and amenity)

2.3 What RSuDS does not include

Providing a specific definition for RSuDS does exclude certain measures by default. For example, some land management measures such as blocking tramlines or creating earth bunds to block the ends of ridges and troughs in potato fields have not been classed as RSuDS because they are a transient rather than semi permanent intervention i.e. occur during particular seasons. Similarly, measures such as moving gateways, providing bridges or fencing livestock away from water courses are not included under the banner of RSuDS because they don't directly involve the collection, storage or cleaning of water. However, these measures are relevant to dealing with run-off in the rural environment and should be considered as land management options which could form part of a train of approaches within a rural catchment.

3 Why control runoff?

3.1 Diffuse pollution

Continuously discharging point sources of pollution within landscapes (for example from manufacturing and sewerage) have been effectively reduced by legislation, being readily identifiable and possible to target with clean-up technology. In contrast, diffuse pollution represents a myriad of smaller, episodic sources that are more difficult to regulate and treat. Hence, diffuse pollution from rural land use (principally agriculture and forestry) has become the major concern for transfer of contaminants from land under rural management to fresh waters.

Land under rural management

The Water Framework Directive (WFD) provides a major legislative driver for maintaining and improving surface and groundwater quality across Europe. Within the timetable for implementation, there is a commitment for a Programme of Measures operational by 2012 to tackle failures in achieving Good Ecological Status. It is likely that these measures will have a new and important focus on tackling diffuse pollution pressures, given the extent of the problem at a national scale (Table 3.1[9]).

Farm tracks and gateways are ideal pathways for run off

Agriculture is major source of diffuse pollution. It is responsible for the majority of silt entering water in England, for over 60% of the nitrate and 28% of phosphate entering surface waters in England and Wales, although this varies between catchments[10]. It is also responsible for reduced bathing water quality due to bacterial contamination from manures, and pesticide pollution.

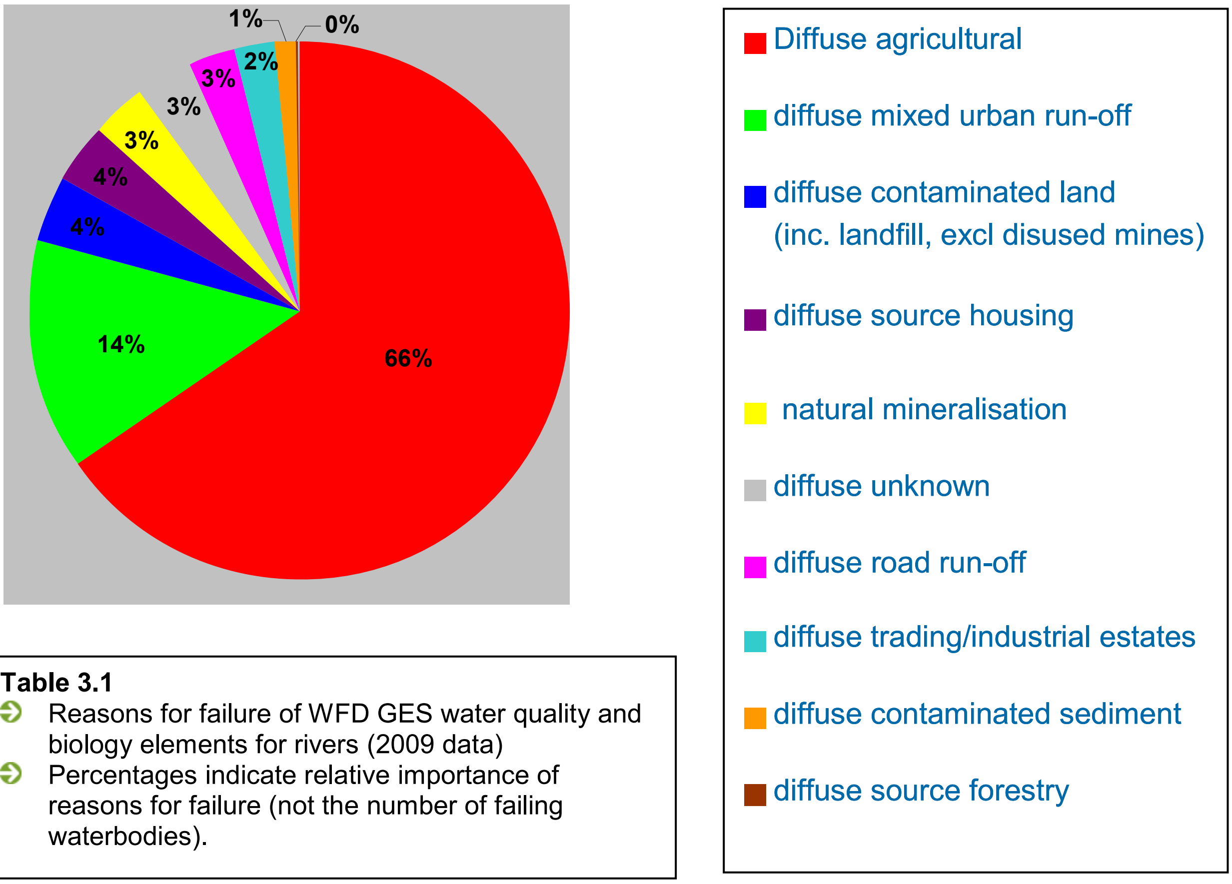


Table 3.1

- Reasons for failure of WFD GES water quality and biology elements for rivers (2009 data)
- Percentages indicate relative importance of reasons for failure (not the number of failing waterbodies).

Activities that contribute to diffuse pollution from farming include:

- Application of inorganic fertilizers to land
- Application of animal manures and organic wastes to land
- Autumn and early spring applications of herbicides.
- Cultivation
- Livestock trampling riverbanks
- Construction and land disturbances

.

According to the 2007 farm practices survey for England, 50 per cent of farmers had experienced some symptom of soil erosion on their land[11]. Other estimates of soil erosion suggest that it affects up to 76% of agricultural land [12]. The agricultural contribution to soil erosion is estimated to range from 75%[13] to 95%[14] so it is a very significant contributor to sediment problems.

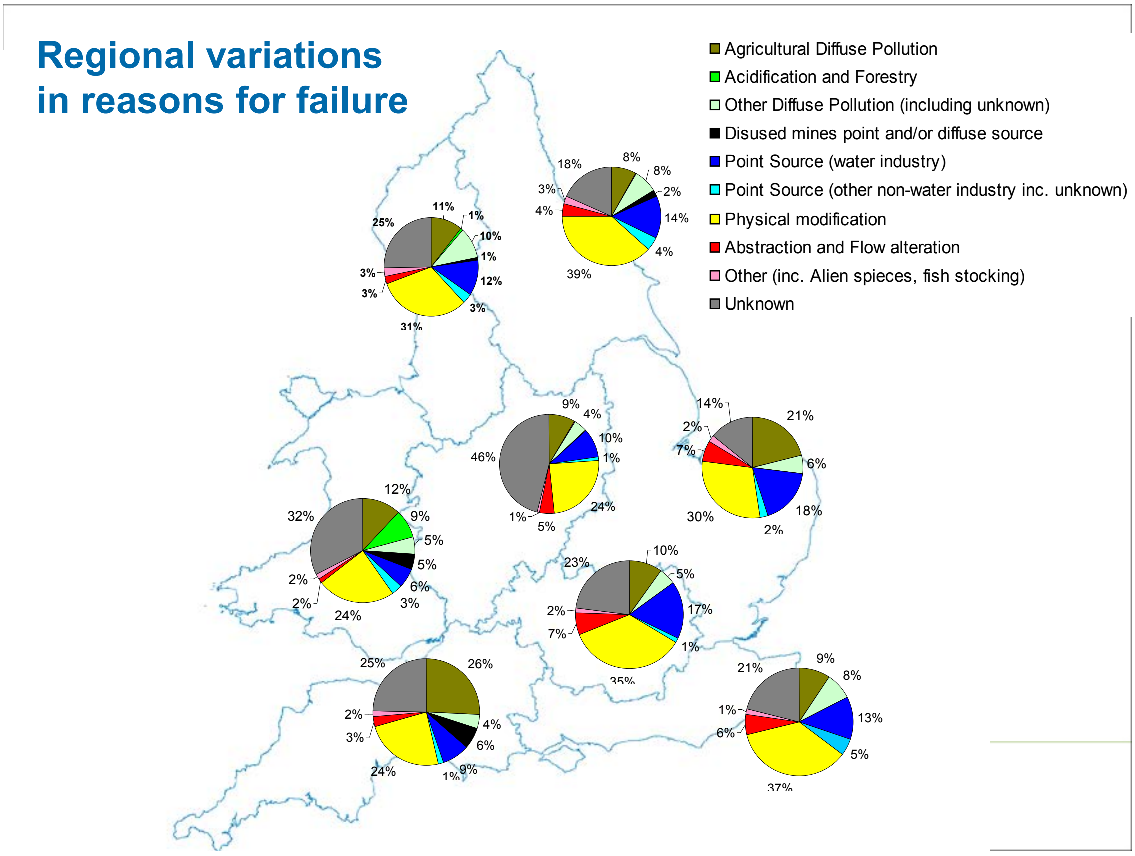
Soil erosion leads to a build up of sediment and associated pollutants in rivers[15]. Specific impacts of excess sediment on river ecology include disruption of food webs, effects on fish health and reproduction, less light penetration and therefore reduced photosynthesis by underwater plants. Trout spawning beds in 57% of reaches surveyed across England have levels of fine sediment at which half the eggs and larvae would be expected to die and more than 40% of freshwater wetland Sites of

Special Scientific Interest (SSSI) in England are in unfavourable condition, with sediment a contributory factor in most cases[16].

Arable and livestock farming systems can also modify soil hydrology by affecting the soil structural conditions, for example through surface crusting, compaction and the loss of soil water storage in the soil profile[15].

The agricultural contribution to phosphorus in surface waters varies widely between river basins, from over 60% in Western Wales to under 10% in Thames[17]. Eutrophication effects from phosphate in fresh water can be locally very significant, for example, Llyn Tegid a SSSI, SAC and Ramsar site, is suffering from eutrophication due to excess phosphate in the water, 90% of which has been attributed to diffuse water pollution from agriculture [18].

Table 3.2[1]



Some crop protection products are still an issue in some localised catchments and more especially where there is abstraction for drinking water. For example, metaldehyde and some oilseed rape herbicides are showing up in samples taken by some water companies. Not all pesticides are mobilised in the same way. Some are water soluble and others have adhere to soil particles.

In general, RSuDS are likely to be most effective at removing particulates and associated contaminants as these will be retained through adsorption, filtration and settling. Soluble contaminants are only likely to be removed effectively in RSuDS where there is a significant retention time for water within the structure allowing microbial break down to occur.

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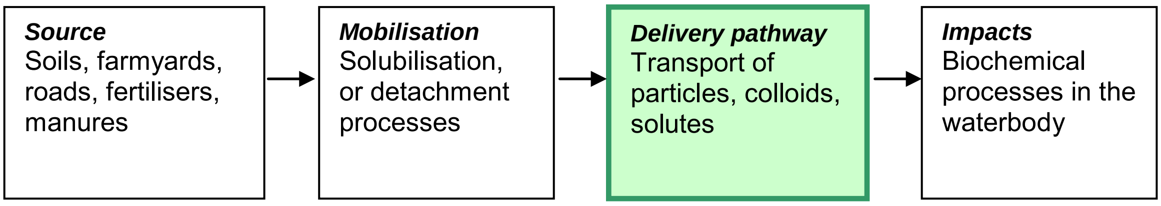
[1] Environment Agency Data 2009

3.2 Diffuse pollution delivery in the landscape

There are many different options for tackling diffuse pollution losses to water bodies. Source controls include reducing the nutrient status of soils or managing manures and slurries. Controls on mobilisation include having a cover crop to stop erosion by rainfall detaching soil particles or not applying nitrate fertilisers in wet weather. Direct controls on impacts *within* major surface waters tend to be less favourable since these may include drastic measures such as dredging a eutrophic lake to remove P-enriched sediments, or adding a chemical flocculant, or complexing agent. Rural SuDS sit within a broad range of measures which can often be successfully applied to control delivery of contaminants between the site of mobilisation and impact. They focus on intercepting the pollutant delivery pathway (Fig 3.1[19]).

Figure 3.1 The P transfer continuum adapted from Haygarth et al.[19]



Since these measures generally involve processes that manage water and the co-transport of contaminants they are highly diverse and subject to specific requirements related to the specific sources, physical transport properties of the pollutants in question and the landscape and climate. For example, the landscape and management of the land is important in terms of: the proximity between critical source areas and the water body; water pathways in terms of drainage ditches, tramlines, soil pipes, gateways and field slopes. Some of the physical factors affecting run-off quantity and quality are indicated in Table 3.2.

Table 3.3 Physical and management influences on run-off quality and quantity (based on Environment Agency[20])

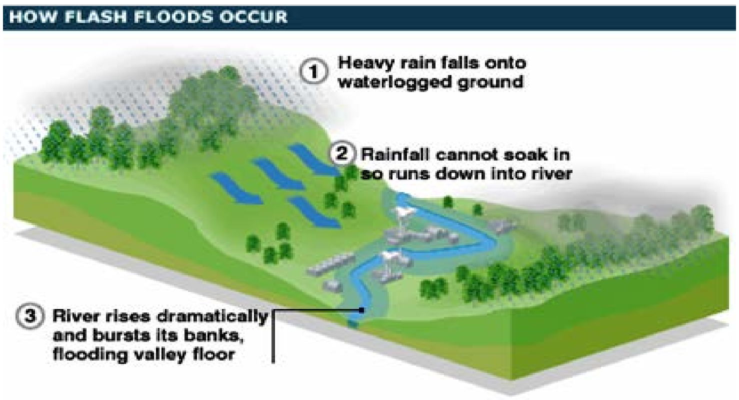
Factor	Properties affected
Soils	Infiltration v run-off, storage potential, bypass flow
Climate	Rainfall frequency, intensity and duration, evaporation, evapo-transpiration
Topography	Slope, shape
Land cover	Vegetation type, surface roughness
Land management	Soil and crop or livestock management activities
Drainage network	Density, hydrological connectivity

3.3 Protection of water resources

There is already substantial pressure on water availability in the UK, in particular in England and Wales[21]. With predicted future population rises and increased housing and infrastructure needs, water supply is a key element of concern, particularly in water stressed areas such as the south-east of England. Currently, there is usually sufficient water to meet the needs of people and wildlife apart from during prolonged periods of dry weather. It is crucial to manage water resources carefully during these dry periods[21] and future climatic changes will increase water stress. Furthermore, water pollution by nutrients, pesticides and dissolved organic carbon presents costly treatment problems for water companies. Limiting this pollution before it enters water bodies from which water is abstracted and treated to become drinking water is more sustainable than additional treatment[22]. RSuDS have the potential to influence both of these aspects by increased retention and treatment of available water.

3.3.1 Flooding

Flooding is the most common natural hazard in Europe and extreme flood events have attracted significant attention over the past few years with widespread flooding across all seasons[23]. In England and Wales alone, it is estimated that over 4 million people and properties valued in excess of £200 billion are potentially at risk from flooding[24]. A holistic, catchment-wide approach which takes into account land-use change and achievement of good ecological status under the WFD may be more favourable than traditional hard-engineering solutions[23]. Rural SuDS could provide structural measures, primarily to control surface run-off, by helping to buffer peak flows and thereby contributing to flood risk management.



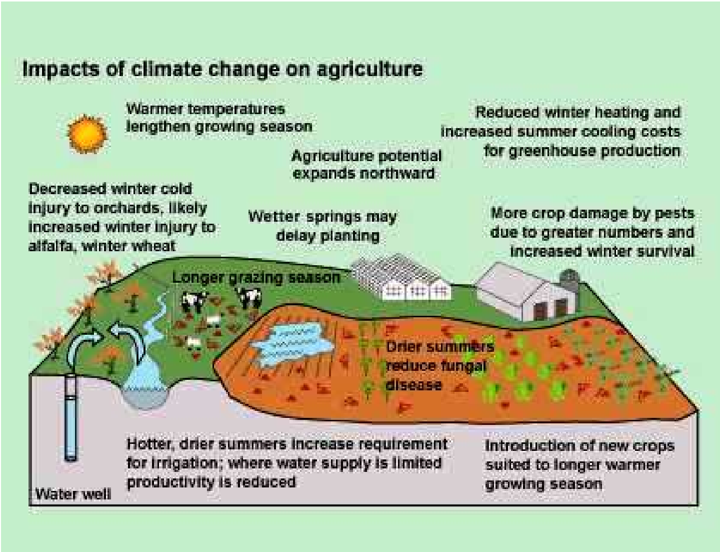
There is substantial evidence of BMPs reducing runoff generation in England and Wales at the local scale[20]. Land management for flood risk reduction is still in its infancy, therefore as part of the Government's “Making Space for Water” initiative, Defra recommended the delivery of “land management changes which have the potential to deliver multiple benefits including flood risk management” rather than with flood risk reduction as the sole driver. Quantitative evidence is still needed to show whether soft engineering to capture runoff at field scale can be effective in a catchment solution.

3.3.2 Climate change

Key predicted climate change effects highlighted in UKCIP02[26] (Table 3.3) include:

- general warming
- hotter, drier summers
- warmer, wetter winters
- greater variability in year-to-year precipitation
- changes in the number of intensive rainfall events
- associated changes in soil moisture and the length of the thermal growing season.

Key impacts upon diffuse pollution are highlighted in red in Table 3.3. Increases in particulate pollution are likely to be greater than on soluble pollutants and primarily driven by rainfall frequency and intensity. This will require an increase in the storage capacity of run-off interception measures. This would be an important consideration when designing RSuDS. Intense rainfall events are also likely to lead to “flushing out” of pollutants from soil and sediment stores[27]. It is clear that climate change effects on diffuse pollution are likely to be complex[28].



However, RsuDS components could be implemented to contribute to control measures to effectively interrupt the delivery of contaminants from source to water body. Some RSuDS, such as retention ponds and wetlands, may have the added benefit of providing water storage for irrigation which would be useful during drier summer

Table 3.4. UK climate change scenarios for the period 2011 to 2040 (UKCIP02) and potential impacts on sustainable rural drainage control measures. Arrows denote relative increase or decrease for each factor. Red shading highlights very strong impacts; orange shading indicates strong impacts - based on expert judgment at MLURI (UKCP09 data would present a wider range of future changes, which would not change the conclusions of the report).

General factor		Changes			Impacts			
		South east England	Other areas England & Wales	Scotland	Particulate diffuse pollution	Solute diffuse pollution	Requirement for increased storage volume for water retention	Possibility of pollutant 'flushing out'
General warming	Annual temp change	1.5°C	1 to 1.5°C	1°C	↑↓	↑	↓↓	↓
Hotter, drier summers	Summer temp change	1.5°C	1 to 1.5°C	0.5 to 1°C	↓	↑	↓↓↓	↓
	Summer precip change	-20%	-10 to -20%	-10%	↑↓		↓↓↓	↓
Warmer, wetter winters	Temp change	1°C	1°C	0.5 to 1°C	↑↓	↑	↓	↓
	Winter precip change	+10%	+10%	no change	↑↑↑	↑	↑↑	↑
Precipitation inter-annual variability	Spring	none	none	none				
	Summer	-5%	-5%	-5%	↓	↓	↓	↓
	Autumn	+5%	0	0	↑↑	↑	↑↓	↑↓
	Winter	+5%	0 to +5%	0 to +5%	↑↑↑	↑	↑↑↑	↑↑
Soil moisture	Spring	0	0 to -10%	0 to +4%	↑	↓	↑↓	↑↓
	Summer	0 to -20%	-10 to -20%	0 to -10%	↓	↓	↓	↓
	Autumn	0 to -20%	-10 to -20%	0 to -10%	↓	↓	↓	↓
	Winter	0 to -10%	0 to +4%	0 to +4%	↑↑↓		↑↑↓	↑
Change in number of intense rainfall days per season	Spring	-0.25 to +0.25	-0.25 to +0.25	-0.25 to +0.25	↑↓	↑↓	↑↓	↑↓
	Summer	-0.25	-0.25	-0.25	↓	↓	↓↓	↓↓
	Autumn	-0.25 to +0.25	-0.25 to +0.25	-0.25 to +0.25	↑↓	↑↓	↑	↑
	Winter	+0.25 to 0.5	+0.25 to 0.5	-0.25 to +0.25	↑↑↑		↑↑↑	↑↑
Change in length of thermal growing season		up to +30 days	up to +30 days	no change				

3.3.3 Biodiversity

As human population pressures and consumption levels increase, biodiversity decreases, making it more difficult for the natural world to continue delivering the goods and services on which humanity ultimately depends[29]. Drainage systems have a biodiversity value which can be considered as a combination of its communities of plants and animals and the connections and interrelationships between them. Different vegetation types support a range of animal communities[30]. Drainage channels also provide valuable 'connectivity' i.e. corridors linking habitats for both aquatic and terrestrial species[30].

Habitats identified within the UK Biodiversity Action Plan (UK BAP) that are particularly associated with the types of watercourses and banks that could be influenced by or incorporated into RSuDS are listed below (adapted from Buisson et al. [30]).

- Rivers and streams (a specific action plan exists for chalk rivers)
- Standing open water and canals
- Oligotrophic and dystrophic Lakes
- Ponds
- Mesotrophic lakes
- Eutrophic standing waters
- Aquifer-fed naturally fluctuating water bodies
- Arable and horticultural arable field margins
- Boundary and linear features
- Hedgerows
- Broadleaved, mixed and yew woodland wet woodland
- Neutral grassland lowland meadows
- Improved grassland coastal and floodplain grazing marsh
- Fen, marsh and swamp lowland fens
- Reedbeds
- Bogs lowland raised bog

SuDS have been successful in reintroducing biodiversity in the urban environment[31] and RSuDs features such as ponds and wetlands have been shown to promote biodiversity in addition to their functions of reducing peak flows and improving water quality[32,33]. Use of RSuDS therefore provides added value in terms of biodiversity. Furthermore, enhancing existing features, for example planting of buffer strips with trees or additional vegetation or using RSuDs components to create wildlife corridors may provide a means of enhancing the biodiversity value of measures implemented through existing agri-environment schemes.

3.4 Amenity

In urban areas, there is a clear belief that SuDS can provide amenity benefits in locality, including walking around ponds and wetland areas[34]. The amenity benefits of RSuDS may be less significant as they would typically be applied on private land. However, where appropriately located, amenity benefits could be taken advantage of through activities such as bird and wildlife watching, walking and picnicking.

4 Existing rural drainage systems

In England and Wales there will be little agricultural land that has not been drained to some extent at sometime in the last 200 years[35]. Earliest forms of drainage involved ridge and furrow, which naturally progressed to the installation of underground channels in the furrows using readily available material such as bricks, stones, straw ropes and hedge trimmings. Ditches were the primary drainage system as more land became enclosed and managed but underground drainage continued to develop. Drainage activity in England and Wales changed significantly in the 1960s, with the use of permeable backfill in durable materials such as gravel increasing and the development of subsoiling as a secondary treatment to assist soil drainage, allowing the effective drainage of low permeability soils[35].

Traditional rural drainage systems can be a major pathway for transfer of soluble and particulate pollutants to water courses during intensive rainfall events[35], and they alter the natural soil water regime giving rise to hydrological impacts[18]. As mentioned previously the integration of RSuDS into these systems has the potential to reduce this impact.

ADAS[35] estimated that 2.0 million hectares of agricultural land in England and Wales are drained by pipe drainage schemes that received grant aid, involving approximately 272,000km of drainage pipe. Data clearly indicate a consistent trend for the concentration of drainage activity in the East of England on clay soils, with the majority of schemes in this area using mole ploughing drainage techniques.(Figure 4.1 and Table 4.1). In addition to soil type/cropping requirement, the rate of grant and prevailing weather conditions, affected farmers' decisions as whether to drain[35].

Figure 4.1 Long-term (1961-90) annual average soil drainage under agricultural land, across England and Wales, calculated by the NEAP-N model (Lord and Anthony, 1999).

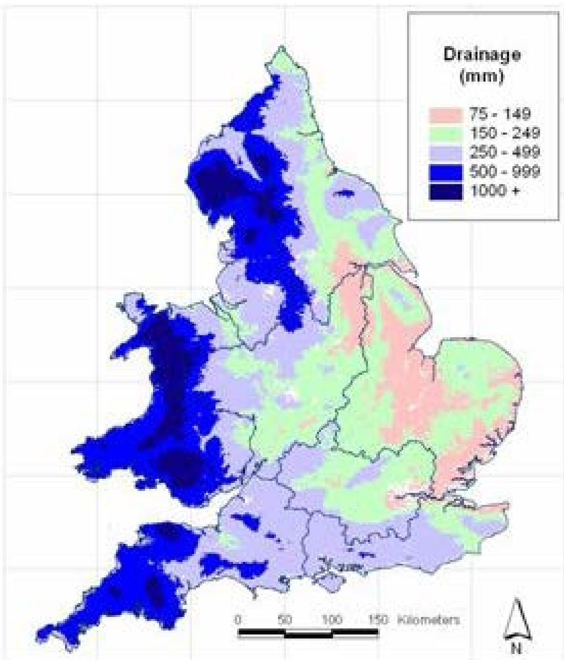


Table 4.1 Maximum area of agricultural land pipe drained with grant-aid, based upon the full database, compared with the estimated area of surviving or non-replacement drainage (minimum area). Data expressed as a percentage of agricultural land (crops and grass, excluding rough grazing) [35]

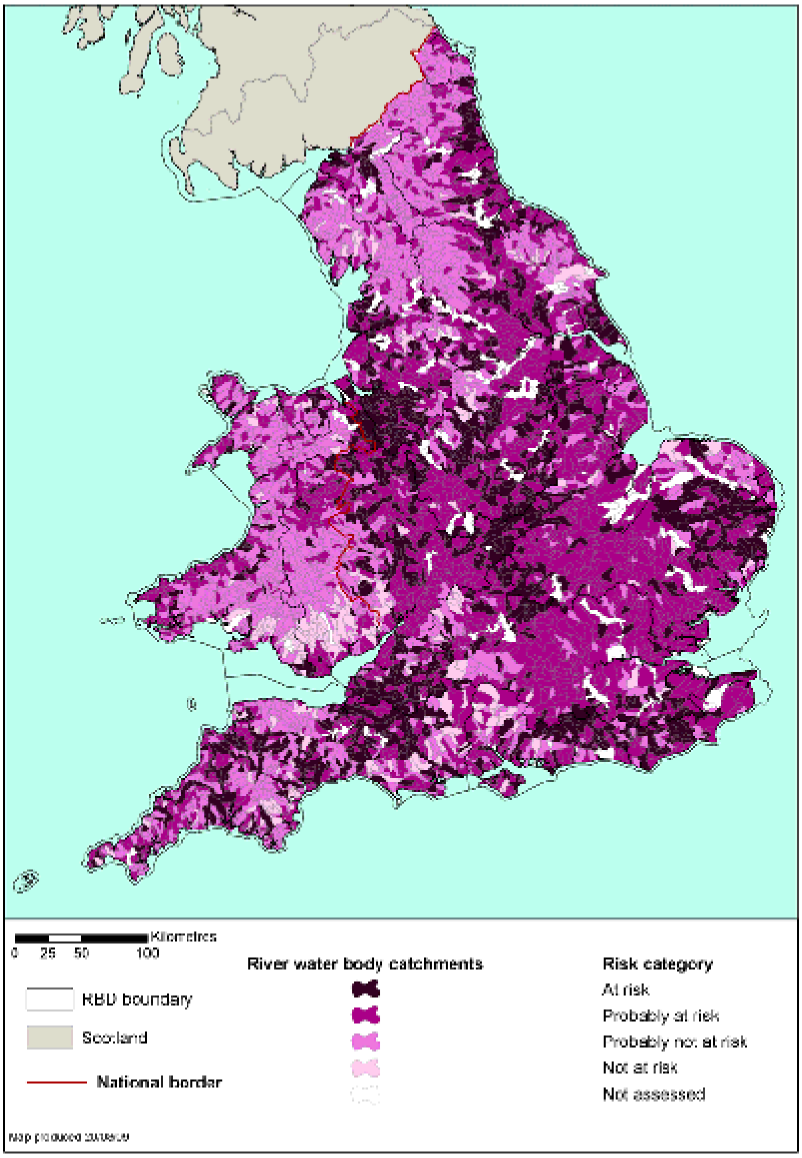
MAFF Region	Crops and grass (Ha)	Maximum drained area (%)	Minimum drained area (%)
East Midlands	1,307,000	39	31
Eastern	1,461,000	50	44
Northern	978,000	17	14
South Eastern	1,216,000	19	17
South Western	1,712,000	10	9
Wales	1,052,000	11	11
West Midlands	1,147,000	19	16
Yorkshire and Lancashire	875,000	27	20

For further information on existing traditional drainage systems within England and Wales please see the Technical Annex.

5 Geographical Application of RSuDS

In simple terms, RSuDS should be implemented in areas where runoff does or could contribute to flooding, erosion and pollution of rivers, streams or lakes. The Environment Agency[36] provides information on catchments at risk from diffuse pollution. For example, Figure 5.1 illustrates rivers and streams at risk from diffuse P pollution.

Figure 5.1 Waterbodies at risk from diffuse agricultural phosphorus pressures [36]



However a number of interacting factors at the local scale would also define where RSuDS should be placed to effectively target run-off. These include physical characteristics, primarily the soils, topography and rainfall, together with the characteristics of the land cover at the soil or ground surface[20]. These are covered in section three on diffuse pollution. Generally, middle to upper parts of main catchments with steeper slopes, higher rainfall and moderate to high soil sensitivity are more sensitive to land use changes and therefore could provide a starting point for advising land owners of RSuDS measures[20]. At the farm scale, diffuse pollution audits highlight areas to be addressed and where Best Management Practices may be applied[5].

6 RSuDS Options

6.1 Assessment category definitions

The effectiveness of RSuDS options is highly variable, both temporally and spatially, depending on numerous factors which are outlined in the summary sheets included within this section. Therefore specific effectiveness figures and costs have not been attributed to each of the options identified. Instead attributes of each option have been awarded qualitative categories defined using the details outlined in the following tables. Life span and site limitations/suitability judgements were not defined but judged qualitatively relative to each other. All figures collated as part of the investigation are available within the accompanying Technical Annex.

Table 6.1 Costs

a) Set up costs

High	Requires significant raw materials, specialist equipment or expert involvement
Medium	Requires some raw materials, specialist equipment and/or expert involvement
Low	Land manager can implement system with minimal advice, equipment and specialist material.

Note: the cost of land take and opportunity costs were not included due to their high variability in time and space

b)Running/maintenance costs

High	Expert advice or equipment required to be brought in frequently (e.g. < 5 yrs)
Medium	Expert advice or equipment required to be brought occasionally (e.g. < 10 yrs)
Low	Mostly involves routine inspections and low grade management which can be undertaken by the land manager.

Table 6.2 Effectiveness

a) Flow

High	Designed to retain and store water
Medium	Decrease water velocity though roughness and encouraging infiltration
Low	Not designed to affect water flow.

b) Water Quality

High	Well designed and sited systems regularly reported to remove greater than 75% of pressure during design condition events.
Medium	Well designed and sited systems regularly reported to remove between 25-75% of pressure during design condition events
Low	Well designed and sited systems regularly reported to remove less than 25% of pressure during design condition events

Note: Text contained within the form will refer to how effectiveness can vary, under different conditions, poor design and poor management. E = performance based on expert opinion

Table 6.3 Additional Benefits

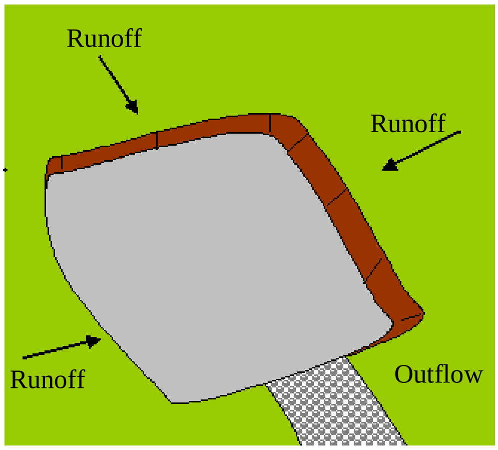
High	Well designed systems have been reported or judged by expert opinion to have the potential to provide significant benefit in this area in the majority of locations.
Medium	Well designed systems have been reported or judged by expert opinion to have the potential to provide some benefit in this area at some locations.
Low	Well designed systems have not been reported or judged by expert opinion to have the potential to provide any benefit in this area at any location.

Table 6.4 Cost effectiveness matrix

		Effectiveness		
		High	**Medium**	**Low**
Cost	**High**			Low value
	Medium		Medium Value	
	Low	High value		

6.2 RSuDS components

6.2.1 Sediment traps

Rural SUDS component	**Sediment trap**	
Summary	A sediment trap is a containment area where sediment-laden runoff is temporarily detained under quiescent conditions, allowing sediment to settle out before the run-off is discharged[1].	
Description	Sediment traps can take a number of different forms. In fact, some of the measures described in this document essentially function as a type of sediment trap, particularly sedimentation boxes, detention and retention ponds. However, many of the RSuDS measures described further in the document benefit from additional sediment trapping before runoff enters them. This can vastly improve the longevity and functioning of other measures. A simple sediment trap can comprise an excavation either with an inlet and outlet, such that it interrupts the flow path to allow particles to settle or collecting drainage from a small surrounding catchment which is allowed to settle and passes out through the outflow. More complex designs may involve covered chambers with manhole access for removal of sediment build up, and/or multiple chambers with "baffles" separating them (see sedimentation boxes). A very simple sediment trap  Diagram modified from California stormwater BMP Handbook[1]	
Cost (£)	**Set up**	***Low*** [1]
	Running/ Maintenance	***Low***[1] Check sediment build up after rainfall events and remove as required e.g. at 1/3rd of trap capacity, check for erosion around outlet, maintain any fencing.
Performance	**Flow**	***Medium***[E] Some attenuation of peak flows due to detention of trap volume but once trap filled, minimal impact on flows.
	Suspended solids	***High***[E] By default, suspended solids will be removed through settling

	Total Phosphorus	***Medium***[E] Particulate P will be retained with sediment
	Total Nitrogen	***Low***[E] Retention time assumed too short for N breakdown
	Pesticides	***Medium***[E] Particle-associated pesticides will be retained with sediment, soluble ones pass through
	Pathogens	***Medium***[E] Particle-associated pathogens will be retained with sediment, others will pass through
Cost effectiveness	***High Value*** [E] *Effective at low cost. Effectiveness will increase with targeting of known run-off sites.*	
Additional Benefits	**Biodiversity**	***Low***[E] No clear benefits as stand alone component, link with high biodiversity value RSuDs component
	Amenity	***Low***[E] No clear benefits as stand alone component, link with high amenity RSuDs component
Common factors affecting performance	Frequency of sediment removal Runoff volumes	
Reliability/ consistency	Dependent on frequency of sediment removal – protects longevity of downstream RSuDS	
Lifespan (years)	Dependent on frequency of sediment removal	
Design guidelines	Small temporary ponding area, often formed by excavation and usually with a gravel outlet. Rocks and vegetation around outlet will protect against erosion[(1)]. Install continuous fencing around open ponding areas of excavations to protect members of the public, children or employees falling as necessary. Restrict basin side slopes to 3:1 or flatter. [(1)] Size depends on soil type, runoff volumes to be intercepted and desired removal efficiency. Generally the larger the basin, the greater the removal efficiency. This is often designed based on a 2 year storm volume and 50m^3 per acre has been suggested in USA although this is site/climate dependent[(1)]. Keep embankments to < 1.3m unless designed by an professional engineer. Locate where a suitable area can be excavated or an embankment can be built across a swale and where access can be provided for maintenance. Design outlet pipe or overspill outlet to accommodate anticipated peak flows.	
Site suitability/ limitations	At site perimeter where sediment laden run-off is discharged[(1)] At multiple locations across site where sediment control is needed[(1)] Around or upslope from inlets to other RSuDs measures[(1)] Requires a large surface area for infiltration and settling[(1)] Less effective at removing fine material[(1)] Suitable for small drainage catchments [(1)]	
Utilisation examples	A sediment trap could be used alone or as a pre-treatment for other RSuDS	
Associated SuDS	e.g. soak-away, infiltration trenches, filter or French drains, constructed wetlands, detention pond, infiltration basin.	
Further Guidance	California stormwater BMP Handbook[(1)] Abbott and Comino-Mateos et al (2003) [(2)] COST 869 - Mitigation options for nutrient reduction in surface water and groundwaters.[(3)] Pandit and Gopatakrishnan (1996)[(4)]	

6.2.2 In ditch options

<table>
<tr><td>Rural SUDS component</td><td colspan="2">Grassed waterways and swales</td></tr>
<tr><td>Summary</td><td colspan="2">Swales are broad and shallow vegetated open channels, designed to convey runoff, reducing its volume and velocity and removing pollutants[1,2].</td></tr>
<tr><td>Description</td><td colspan="2">Swales are broad and shallow channels covered by grass or other suitable vegetation. They are designed to convey runoff, reducing its volume and velocity and trapping particulate pollutants. They can act as conveyance structures to pass runoff between different stages of treatment or they can slow down the rate of runoff or provide temporary storage encouraging infiltration of runoff into the ground, depending on soil and groundwater conditions, and evaporation[1,2]. They treat runoff through filtering by the vegetation, through the subsoil and/or infiltration into the underlying soil.

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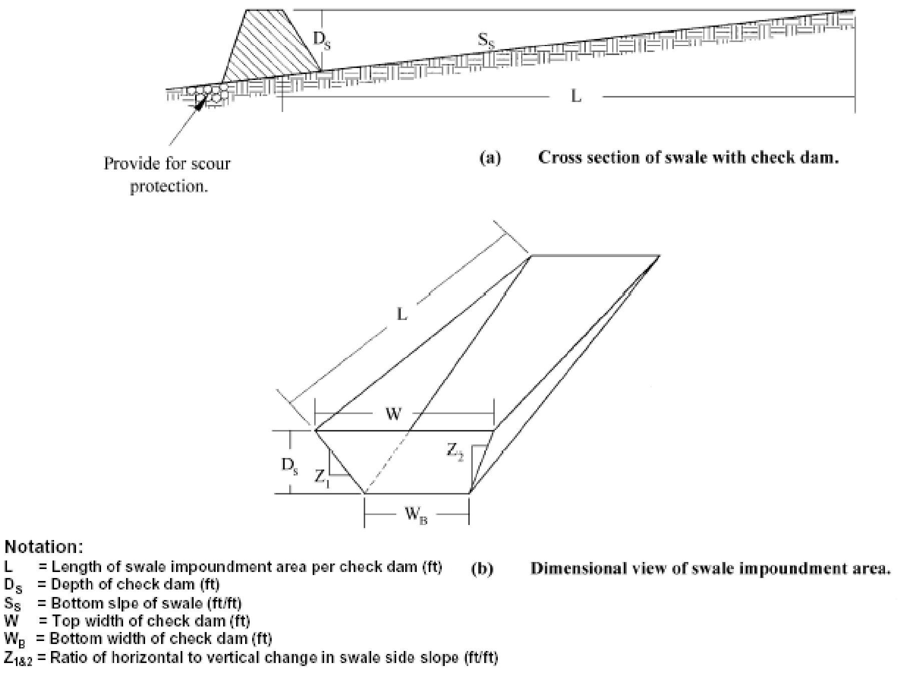
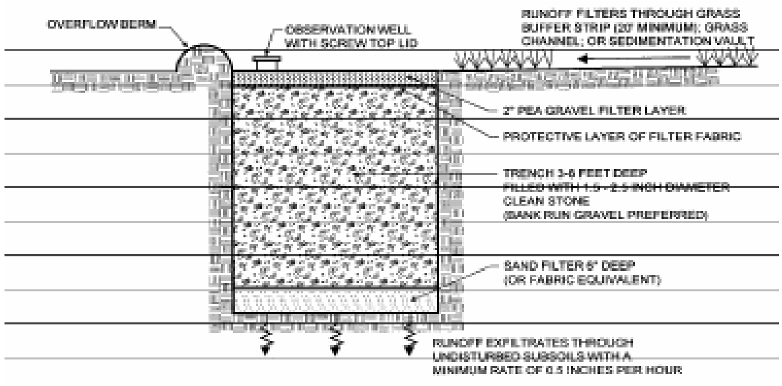
There are three main types of swale[1]:
• Swale
• Enhanced dry swale - swale is kept dry the majority of the time using a filter layer of soil over an underdrain
• Wet swale – where the soil is poorly drained and underdrains are not provided the swale acts as a linear wetland retaining water.
Swales generally remove pollutants for frequent small storm events[3]. For larger less frequent storms of 1 in 2 to 1 in 10 year return period they can act as storage and conveyance mechanism. For larger storm events this may become impractical[1].
Check dams can enhance the performance of swales, maximize the retention time, decrease flow velocities and promote sedimentation. Incorporation of vegetated filter strips parallel to the top of the banks can help treat sheet flow entering the swale[4,5].
Care required to avoid erosion, best used close to source, probably little effect on dissolved pollutants [6,7,8].</td></tr>
<tr><td>Cost (£)</td><td>Set up</td><td>Low, normally limited to cost of establishing the grass and the yield foregone, occasionally earth moving maybe required[2]</td></tr>
<tr><td></td><td>Running/ Maintenance</td><td>Low, monthly inspections and removal of litter, mowing as required (min twice a year), scarifying and spiking, repair damage vegetation and silt removal as required[1,2]</td></tr>
<tr><td>Performance</td><td>Flow</td><td>Medium[9], minimal attenuation due to channel roughness and infiltration.</td></tr>
<tr><td></td><td>Suspended solids</td><td>High,[1,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25] vegetation traps particulate pollution, temporary storage encourages sedimentation[6,7,8].</td></tr>
</table>

	Total Phosphorus	***Medium***[1,10,,11,12,16,17,23,25] traps particulate pollution, probably little effect on dissolved pollutants [6,7,8].
	Total Nitrogen	***Medium***[1,11,12,14,16,17,23,25]minimal effect on dissolved pollutants, some plant uptake [11, 12, 14, 16,17, 20,26, 27]
	Pesticides	***Medium***[9]
	Pathogens	***Medium***[E] ***,*** although data from the one study identified found the swale to be a source of pathogens[10]
Cost effectiveness	***High value,*** low implementation costs and high effectiveness at removing both suspended solids and particulate P, and medium overall means this measure is relatively cost effective, except for flows with high pathogen content.	
Additional Benefits	**Biodiversity**	***High,*** potential considerable benefits to plants, invertebrates and birds through habitat provision[2]
	Amenity	***Medium***, vegetated swales provide improved landscape quality to bare or concrete channels.
Common factors affecting performance	Type e.g. pollutant removal very good for enhanced dry swale[1], swale length and water depth [1,2], seasonal vegetation changes .e.g. SS removal slightly higher in growing season[1]. Reduced performance is caused by compacted soils, short runoff contact time, large storm events, frozen ground, large grass height, steep slopes and high runoff velocities and discharge rates[21]	
Reliability/ consistency	Some studies show swales are more susceptible to failure than other SuDS[5].	
Lifespan (years)	20 yrs plus[22] , very long if maintained[2]	
Design guidelines	Detailed guidance and equations to help design the length and slope of a swale are available from CIRIA (2004)[1]  © California stormwater quality association Key factors taken from CIRIA (2004)[1] unless otherwise stated: • Use manning's equation to design slope, a manning's n value of 0.25 is recommended[5]. • Limit velocities to prevent erosion (typically 1-2m/s depending on soil type) • Maintain flow height below vegetation (typically 100mm) • Minimum length of 30-60m, with a residence time greater than 10 minutes • Minimum base width 0.6m, maximum 2.5-3m unless a flow divider is provided to	

	split the channel in two. • Maximum side slope 1:4, check dams recommended if slope greater than 3% • Infiltration, if required, should not be greater than 10^{-6} m/s [28,29], infiltration tests should be undertaken to comply with regulators policy on soak-aways • Vegetation - mixture of plants including wet and dry area grasses, fine growing grasses maximize filtration[30]. Perennial ryegrass and fescues most suitable in UK. Adding a variety of vegetation is likely to increase biodiversity benefits. • Trapezoidal channels are normal, but other configurations such as parabolic can also provide water quality improvements and maybe easier to maintain[30]. • Minimum retention time of 5min[5].   Photographs courtesy of Georgia BMP manual & Virginia Stormwater Management Handbook
Site suitability/ limitations	Suitable for sites which are not flat or steeply sloping, groundwater must be more than 1m below base of swale if infiltration required[1] Inappropriate for clean coarse sandy soils as it is difficult to establish dense vegetation and prevent erosion even under very low flows[1]. Maybe impractical for storms greater than 1 in 10 year[1]
Utilisation examples	Located at field boundaries, alongside farm tracks/roads or hard standing.
Associated SuDS	The performance of swales can be enhanced by providing vegetated filter strips before runoff enters the swale and by providing check dams/barriers within them[4,6] For information on check dams see "barriers in ditches"
Further Guidance	CIRIA (2004) *Sustainable drainage systems: hydraulic, structural and water quality advice.* CIRIA C609 SAC Environmental (2003) *Guidance on the construction of swales for poultry farms* Northern Ireland Environment Agency

Rural SUDS component	Infiltration trench	
Summary	A narrow trench filled with stone or a commercial drainage material one to two meters deep with no outlet which encourages slow infiltration into the subsoil through the creation of an underground reservoir[1]	
Description	A shallow trench, one to two meters deep, back-filled with stone with no outlet. Runoff is retained within the spaces between the stones and infiltrates into the soil surrounding the trench[1]. A geo textile wrap maybe required to prevent contamination of the stone with soil, in the majority of cases a geotextile sheet will be required if the stone is to be covered with topsoil[1]. Infiltration trenches perform well for the removal of fine sediment and associated pollutants. The use of buffer strips, swales or detention basins is important to prevent coarse sediment entering the trench causing it to clog. Infiltration trenches are similar to filter drains but with no outfall for normal events, therefore filter drains are often preferred[1].	
Cost (£)	**Set up**	***Medium,*** requires significant raw materials, likely to use a tonne of stone per 3m trench[1]
	Running/ Maintenance	***Medium,*** requires care, regular inspection for signs of clogging, may involve replacement of sections of the trench[1].
Performance	**Flow**	***High***[E] trench retains water and encourages infiltration
	Suspended solids	***High***[2,3]***,*** trench stores and filters water, encouraging sedimentation
	Total Phosphorus	***Medium***[2,3]
	Total Nitrogen	***Medium*** [2,3]
	Pesticides	***Medium*** [E] no data identified, removal with sediment, but conditions unlikely to promote pesticide break down.
	Pathogens	***High***[2,3] data for *E-coli* indicates high pathogen removal.
Cost effectiveness	***Medium value,*** the medium costs and the on average medium to high effectiveness, means this system is on average relatively moderately cost effectiveness.	
Additional Benefits	**Biodiversity**	***Low***, apart from reducing impact on nearby water bodies
	Amenity	***Low***
Common factors affecting performance	Soil permeability, storage volume, age, climate, slope of contributing area and water table and bedrock depth[4].	
Reliability/ consistency	If improperly sited or maintained have high failure rate[4]	
Lifespan (years)	***Medium,*** 5-10years[1]	
Design guidelines	Detailed guidance and equations to help design the length and slope of a swale are available from CIRIA (2004)[1]	

<table>
<tr><td></td><td>


© California storm water quality association [4]

Key points:

Design to have diffused inlet along the length of the trench and potential for emergency overflow provision in extreme events[1].
The maximum catchment area to an individual infiltration drain should generally be less than 5 acres[4]
Pre-treatment with buffer strips, swales or detention basins to remove coarse sediment and prevent clogging[4].
Trench stones should by 1.5 to 2.5 inches in diameter[4]
Determine the trench volume by assuming the water quality volume will fill the space between the stones based on the computed porosity of the stone (normally about 35%)[4]
The longitudinal slope should not exceed 2%[5].
The seasonally high groundwater table should be more than 1m below the base of the trench.
Design must comply with the environmental regulator’s policy on infiltration and groundwater protection[5].
Trenches should be able to drain and re-aerate between rainfall events[5].
Potential to include layer of filter fabric just below the surface of the trench to retain sediment and reduce the potential for clogging[4].

</td></tr>
<tr><td>Site suitability/ limitations</td><td>Not suitable for sites with low permeability soil or high water table, significant dissolved pollutants or where groundwater contamination is an issue[1].
Potential for clogging in areas with high sediment load, therefore filter (French) drains preferred in farm situations[1]. High failure rate if soil and subsurface conditions not correct[4]</td></tr>
<tr><td>Utilisation examples</td><td>Located alongside farm track/road, boundary of hard standings, at susceptible areas of field boundaries,</td></tr>
<tr><td>Associated SuDS</td><td>Pre-treatment with sediment trap, buffer strips, swales or detention basins to remove coarse sediment and prevent clogging.</td></tr>
<tr><td>Further Guidance</td><td>Bettess, R. (1996) Infiltration drainage – manual of good practice (Report R156) CIRIA, London

CIRIA (2007) The SUDS manual

CIRIA (2004) Sustainable drainage systems: hydraulic, structural and water quality advice. CIRIA C609</td></tr>
</table>

Rural SUDS component	Filter/French drains	
Summary	A method to move run-off water slowly towards a receiving watercourse. Provides some storage and some treatment[1].	
Description	Filter drains are like infiltration trenches but with an outfall. A shallow excavated trench that has been back-filled with stone to create an underground reservoir from which water may slowly infiltrate into the subsoil or pass slowly to an outfall. As well as providing large voids, which can be filled with water, the gravel provides some physical filtering and microbial breakdown of pollutants. Suitable for small catchments up to 2 to 3 hectares[1].	
Cost (£)	**Set up**	**Medium**[1] – likely to use about a tonne of stone in every three metres of trench.
	Running/ Maintenance	**Medium**[1] Often replacement rather than repair is the usual course of action.
Performance	**Flow**	**High**[E] Attenuation of peak flows
	Suspended soilds	**High**[1,] Filtration and degradation of particles and dissolved run-off
	Total Phosphorus	**Medium**[1,2,3]
	Total Nitrogen	**Low**[1,2,3]
	Pesticides	**Medium**[1)E] Low for hydrophilic, high for hydrophobic
	Pathogens	**Medium**[1,2,3]
Cost effectiveness	**Medium value-** Low-medium costs; Low-medium effectiveness	
Multiple Benefits	**Biodiversity**	**Low** – No direct benefits
	Amenity	**Low** – No direct benefits
Common factors affecting performance	Soil permeability and water table depth affect degree of infiltration Mechanism of water collection – water collected directly from roofs has little sediment and therefore does not lead to clogging, whereas water from e.g. paved areas allows silt and debris to enter leading to blockage [4].	
Reliability/ consistency	Few if any failures reported in scientific literature, but dependent on preventing clogging[4]	
Lifespan (years)	5-10 years[1] (more if water comes directly from roofs) [4]	
Design guidelines	A geotextile sheet should be placed over the stone if it is proposed to backfill with topsoil. For soils with small particulates (e.g. silt), geotextile should be wrapped around the stone. For soils that allow infiltration a perforated pipe should be installed near the surface for the last few metres of the filter drain before the outfall. Where permeability is low, a low-level perforated pipe outlet should be provided over the last few meters of the filter drain. Generally preferable to infiltration trenches[1].	
Site suitability/ limitations	• Could become clogged if receiving water with a high suspended solids content, a significant risk in fieldsome fields. • Should not be part of cultivated field • Suitable for short lengths in high risk areas of field • Longevity may be increased by pre-treating the water with swales or with sediment traps to remove suspended solids.	

	May not be suitable where water is contaminated with dissolved pollutants and ground water contamination is an issue, especially on permeable soils[1].
Utilisation examples	Interception of yard run off water into a wider collection pond
Associated SuDS	Swales (suggested use in conjunction with filter drains)
Further Guidance	Environment Agency - Sustainable Urban Drainage Systems - An Introduction. Publication[5] Design Manual for Roads and Bridges[6] Infiltration Drainage – Manual of Good Practice[7]

Rural SUDS component	**Barriers/traps within ditches & swales**	
Summary	Barrier/traps cause ditch water to pond inducing sedimentation and increased filtration. Sometimes the measure includes material which encourages further removal of pollutant from the water e.g. ochre traps[1].	
Description	Barriers and traps within ditches retain ditch water causing water to slow inducing sedimentation and increased filtration[1]. Under low-flow conditions, water ponds behind the structure and then seeps slowly through the barrier, infiltrates or evaporates. In high flow situations water flows over and or through the structure[2]. Barriers/dams can be made from natural wood, straw bails, concrete, plastic, stone and earth[1,3]. To enhance the water quality benefits barriers can include sediment traps with include filter material which aids pollution removal e.g. ochre traps made of small absorbent pebbles of Iron Hydroxide capable of absorbing dissolved P and trapping fine sediment and the associated particulate P. The ochre can be recycled to land as slow release P fertilizer[1].  Photographs © Newcastle University [1] Swales and ditches which include these barriers are much more effective at mitigating runoff quantity and quality than those without[3].	
Cost (£)	**Set up**	Set-up costs are highly variable depending on the material they are made from and the width of the channel, from ***low*** (simple wood barrier) to ***high*** (Ochre trap)
	Running/ Maintenance	***Low*** for basic barriers, periodic removal of sediment build up, structural inspection and repair. Costs are ***high*** in the case of replacement of material in Ochre Traps[1]
Performance (For basic option, with indication of variation)	**Flow**	***High[E],*** no data is identified. Reduces peak flows through encouraging attenuation and detention[1]
	Suspended solids	***Medium[E],*** no data identified for basic barriers, assumed medium effectiveness due to flow retention encouraging sedimentation
	Total Phosphorus	***Medium[1,E],*** no data identified for basic barriers, high effectiveness for both dissolved and particulate where ochre traps and sediment traps inlcuded[1]
	Total Nitrogen	***Low[1]***, limited data identified indicated no impact on annual nitrogen loads.
	Pesticides	***Low[E],*** no data identified for basic barriers, some loss through sedimentation, but conditions unlikely to promote breakdown.

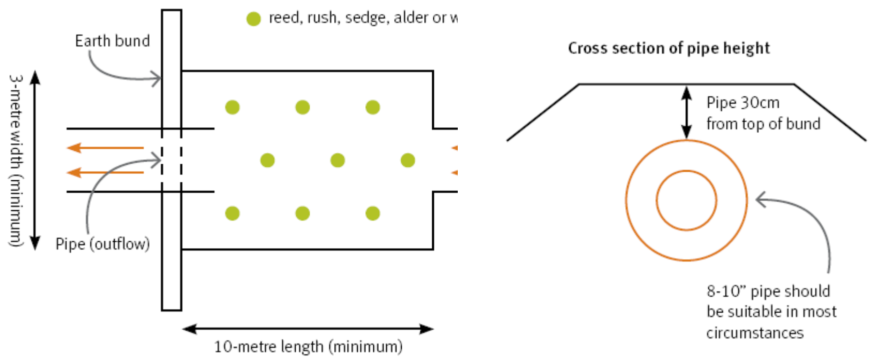
	Pathogens	***Low*[E]*,*** no data identified for basic barriers, some loss through sedimentation, but conditions unlikely to promote die off.
Cost effectiveness	***Medium value,*** low cost and medium/low effectiveness.	
Additional Benefits	**Biodiversity**	***Medium***, some benefit maybe achieved if natural willow barriers are employed.
	Amenity	***Low***
Common factors affecting performance	Size, frequency, maintenance, type/complexity of stricture, degree of retention.	
Reliability/ consistency	If maintained, with regular removal of accumulated sediment, reliable and consistent, although can cause erosion downstream of the dam. Potential to become a source in large events.	
Lifespan	Barriers, indefinite if maintained. Ochre traps require last several years, before needing replacing[1]	
Design guidelines	The design of barriers within ditches can be highly variable. The frequency and design of barriers and check-dams in a swale or ditch will depend on the swale or ditch length and slope, as well as the desired amount of storage/treatment volume[3] Barrers/dams can be made from natural wood, concrete, plastic, stone and earth. Earthen dams are not recommended due to erosion issues[1,3]. Straw bales are prone to failure at times of high flow[2]. A case study constructed by Newcastle University primarily aimed at trapping sediment included a 5-m concrete-lined section in the ditch with a barrier at the lower end of the section. The barrier, constructed from semi-permeable Aquadyne recycled plastic, allowed the average flow to pass through. A line of less permeable geotextile bags situated downstream of the barrier then causes the ditch water to pond, which induces sedimentation conditions. The material collected can be recycled to land, protecting soil resources and reducing the need for P fertilizer[1].  Key design suggestions from the literature include: • Drainage area to each dam should not exceed 2 acres[4] • Maximum height should not exceed 3 feet, and should be a minimum of 6 inches below the top of the ditch to encourage a “weir effect”[4] • For stability the dam should be keyed into the soil approx 6 inches[4] • Where multiple barriers are used maximum spacing should mean tow at the upstream barrier is at the same elevation as the downstream dam[2,4]. • Barriers should not be impermeable[1].	
Site suitability/ Limitations	Literature suggests where multiple dams are used on steep slopes a short spacing is required between barriers (tow of upstream dam should as minimum be the same height as the top of the downstream dam),, sediment removal practices still required, potential to cause erosion downstream.	
Utilisation examples	Within existing or new ditches/swales.	
Associated SuDS	Swales	

Further Guidance	Virginia department of forestry (unknown) BMP specifications http://www.dof.virginia.gov/wq/resources/BMP-Append-A3.pdf

<table>
<tr><td>Rural SUDS component</td><td colspan="2">Wetlands within ditches</td></tr>
<tr><td>Summary</td><td colspan="2">Creation of a small linear wetland feature within a ditch, increasing sedimentation, denitrification and nutrient utilization[1].</td></tr>
<tr><td>Description</td><td colspan="2">Widening and planting of ditches to create a linear wetland feature, increasing sedimentation, denitrification and nutrient utilization[1]. Normally involve drainage control measures to aide the retention of water. Conditions created within the wetland are ideal for the removal of nitrogen via denitrification[2,3].

Jonczyk et al 2008 [1]

(Evans et al 2007[2])
The limited studies available within the literature have shown variable phosphorus and sediment removal rates, in particular where wetlands are established in existing ditches. In several studies the wetlands became a source of these pollutants or removal rates reduced over time.</td></tr>
<tr><td rowspan="2">Cost (£)</td><td>Set up</td><td>High, can require significant equipment and advice to widen ditch and install required barriers and plants to maximize efficiency.</td></tr>
<tr><td>Running/ Maintenance</td><td>Low, research shows that once established plant have high survival rate. regular inspection required.</td></tr>
<tr><td rowspan="6">Performance</td><td>Flow</td><td>High[E], reduction in flow velocity by roughness provided by wetland plants and retention on volume through associated drainage control measures[2]</td></tr>
<tr><td>Suspended solids (SS)</td><td>Medium[2], but some research has shown poor retention of sediment removal due to resuspension particularly where wetlands are constructed in existing ditches.</td></tr>
<tr><td>Total Phosphorus</td><td>Medium[1,2], but some research has shown poor removal ,due to resuspension particularly where wetlands are constructed in an existing ditch Conditions can also cause P to be released from iron complexes.</td></tr>
<tr><td>Total Nitrogen</td><td>Medium[1,2,3], conditions created by in-ditch wetlands are ideal for nitrogen removal via denitrification.</td></tr>
<tr><td>Pesticides</td><td>Medium[E], no data identified, assumed medium due to presence of vegetation and retention.</td></tr>
<tr><td>Pathogens</td><td>Medium[E], no data identified, assumed medium due to retention.</td></tr>
<tr><td>Cost effectiveness</td><td colspan="2">Low value, relatively high cost and low performance. Measure should only be considered where nitrogen contamination is a specific issue and construction of an</td></tr>
</table>

	actual wetland is not viable	
Additional Benefits	**Biodiversity**	***High,*** provision of habitat for invertebrates, plants and birds
	Amenity	***High,*** can improve the visual appearance of a ditch
Common factors affecting performance	Hydraulic retention time, age, seasonality, vegetation, incorporation of drainage, size of event, control structures, length, whether ditch was specifically constructed or existing.	
Reliability/ consistency	Studies show the performance to be highly variable with event and wetland.	
Lifespan	Assumed the same as constructed wetland therefore 50-100yrs if maintained	
Design guidelines	Design should be tailored to the particular site i.e. presence of ditch, space available. Example used in as part of Farm Integrated Runoff Management Nafferton Farm, Northumberland[1] involved the development of a sedge wetland by widening the ditch to 3m and back filling with earth to create shallow flat bed. A series of steps were created to maximize contact of flow with sedge and roots.It is recommended they are constructed in association with drainage control structures i.e barriers within ditches.  Environment Agency (2008)[4]	
Site suitability/ limitations	Appear to be suitable in the majority of areas where sufficient water available to maintain wetland conditions, adjacent water table should not reach surface	
Utilisation examples	Within existing or new ditches/swales.	
Associated SuDS	Swales, barriers within ditches, riparian buffers/grass filter strips (potential for includsion along the side of the ditch)	
Further Guidance	None identified, general constructed wetland guidance maybe of use.	

6.2.3 Ponds

Rural SUDS component	Detention basin/pond	
Summary	Normally dry basins designed to temporally store and slowly release runoff water[1,2].	
Description	Basins/depressions which are usually dry and are designed to temporally store and slowly release runoff water to meet flow and water quality criteria. Water leaves the basin via a restricted outflow control leading to a longer detention time and improved particulate pollution sedimentation. Pollution removal improved by including features such as pre-treatment sediment traps, deeper areas at or near inlets and low flow channels[1,2]. Detention time greater than 24 hrs = extended detention basin. These can also provide flood control by providing additional flood detention storage.	
Cost (£)	**Set up**	***High***[6], construction and provision of outflow control likely to require expert advice and specialist equipment.
	Running/ Maintenance	***Moderate,*** monthly removal of leaves and debris[1,2]. As required, mowing of side slopes and repair of damaged vegetation[1,2]. Annually or every three years, bank clearance, manage wetland plants[1,2]. Three to seven years, remove sediments from sediment trap[1]. Remove sediments from main pool, typically every 25 years[1].
Performance	**Flow**	***High,*** retains water and slowly releases it[2,7]
	Suspended solids (SS)	***High,*** encourages sedimentation and nutrient uptake by plants[1,2,3,4,5,6,8,9,10,11,12]
	Total Phosphorus (TP)	***Medium,*** encourages sedimentation and nutrient uptake by plants[1,2,3,4,5,6, 9,10,11]
	Total Nitrogen	***Medium,*** encourages sedimentation and nutrient uptake by plants[1,2,3,5,6, 9,12]
	Pesticides	***Medium***[E,11]
	Pathogens	***Medium***[E,12]
Cost effectiveness	***Medium value,*** High initial costs, but low maintenance costs, long life time and reasonable effectiveness	
Additional Benefits	**Biodiversity**	***High,*** increases habitat diversity, temporary water with large drying margins. Must be designed well to achieve full benefit[2].
	Amenity	***Medium,*** normally dry therefore lower amenity value than retention ponds
Common factors affecting performance	Detention time, vegetation, depth to water table, soil moisture content, soil permeability	
Reliability/ consistency		
Lifespan (years)	Indefinite[2]	
Design guidelines	Key factors, for extended detention basin, taken from CIRIA (2004)[1] unless otherwise stated: • Same as retention ponds, although permanent pool much smaller or non-existent. • Irregular shape with bars • Length: width 1.5:1 to 4:1[1,13] • 0.3-0.5m/s inlet velocity • Sediment trap should be approximately 20% of the pool volume	

	• Potential to include small ponds and inlet and outlet to prevent re-suspension in heavy storms[1,13]. • Side slopes 1:3 maximum, any steeper and they will require stabilisation[1,13.] • No more than 50% of the water quality volume should drain within 24 hours, complete drawdown should occur within 72hours[13].   Establishing a detention pond. Photographs courtesy of Andy Vinten
Site suitability/ Limitations	Suitable for most sites where space is available, can be used with almost all soils and geology, with minor design adjustment for highly permeable sand soils i.e. inclusion of impermeable liner. Base should not intercept water table, and should become dry between storms. May not be suitable where water contaminated with dissolved pollutants and groundwater contamination maybe an issue, especially in permeable soils[2].
Utilisation examples	Bottom of the slope in fields particularly those draining to a single corner. Storage of run-off collected through other RSuDS e.g. from tracks and hardstanding
Associated SuDS	Sediment trap before inlet [1,2] Permanent wetland at outlet increases treatment and biodiversity [2] Collection or diversion via other RSuDS e.g. swales, cross drains, berms etc.
Further Guidance	CIRIA (2004) *Sustainable drainage systems: hydraulic, structural and water quality advice.* CIRIA C609

<table>
<tr><td>Rural SUDS component</td><td colspan="2">Infiltration basin</td></tr>
<tr><td>Summary</td><td colspan="2">A depression designed to store runoff and infiltrate it into the ground[1]</td></tr>
<tr><td>Description</td><td colspan="2">Open depressions designed to store runoff and infiltrate it into the ground[1]. Infiltration basins remove pollutants from the runoff using the natural filtering ability of the soil. They store water until it gradually infiltrates through the soil. They have a high pollutant removal and also encourage groundwater recharge[1].

Basins can be developed by excavating a depression into the ground or by building an embankment at the bottom of a slope to impound stored runoff water[1].


Photograph © Newcastle University[2]


A sediment retention bund which effectively forms an infiltration pond in a susceptible field. Photograph courtesy of Andy Vinten.</td></tr>
<tr><td rowspan="2">Cost (£)</td><td>Set up</td><td>Low, often involves the construction of a simple levee or berm at the bottom/in the corner of a sloping field. Main cost is the value of land[3]</td></tr>
<tr><td>Running/ Maintenance</td><td>Low[3], monthly inspections, mowing as required[1], occasional sediment removal from any pre-treatment device[1], annually/as required repair damaged vegetation, scarify and spike[1]
Sediment removal as required (typically every five years)[1]</td></tr>
<tr><td rowspan="2">Performance</td><td>Peak Flow</td><td>High, reduce volume of water running directly to watercourse and encourages groundwater recharge[1]</td></tr>
<tr><td>Suspended solids</td><td>High[1,4,5,6]</td></tr>
</table>

	Total Phosphorus	***Medium*** [1,4,5,6]
	Total Nitrogen	***Medium*** [1,4,5,6]
	Pesticides	***High*[E]*,*** no data identified assumed high due to high suspended sediment retention
	Pathogens	***High*[E]*,*** no data identified assumed high due to high suspended sediment retention and retention time.
Cost effectiveness	***High value,*** low cost and relatively high effectiveness	
Additional Benefits	**Biodiversity**	***High,*** Farmland waders and other birds which like damp areas subject to intermittent flooding[3]
	Amenity	***Low,*** Not normally, but can be landscaped or combined with bioretention methods to provide amenity and aesthetic value[1]
Common factors affecting performance	Low infiltration rate of soils, high water table leading to standing water, sedimentation, difficulty sustaining grass growth in bottom (standing water issue)[1,3]	
Reliability/ consistency	Some studies have shown higher failure rate than other management techniques due to sediment accumulation. Use in conjunction with a sediment trap is likely to improve consistency.	
Lifespan (years)	Up to 30 years if correctly designed and maintained[1]. 20 years, longevity increased if pre-treatment included e.g. swales of sump pits[3]	

Design guidelines

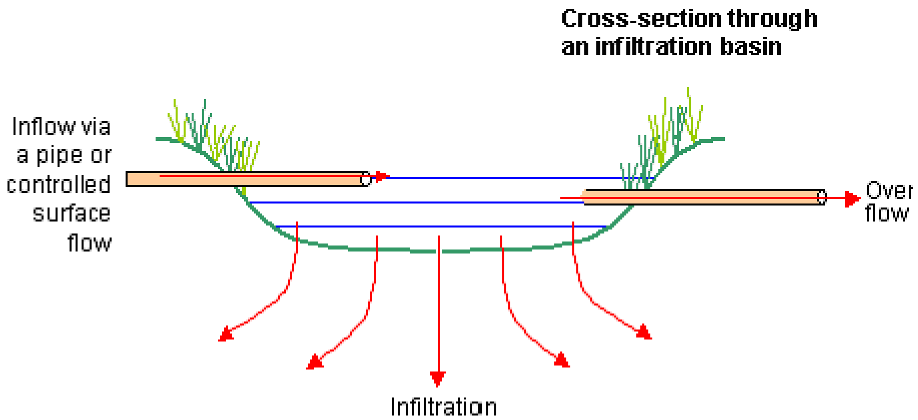


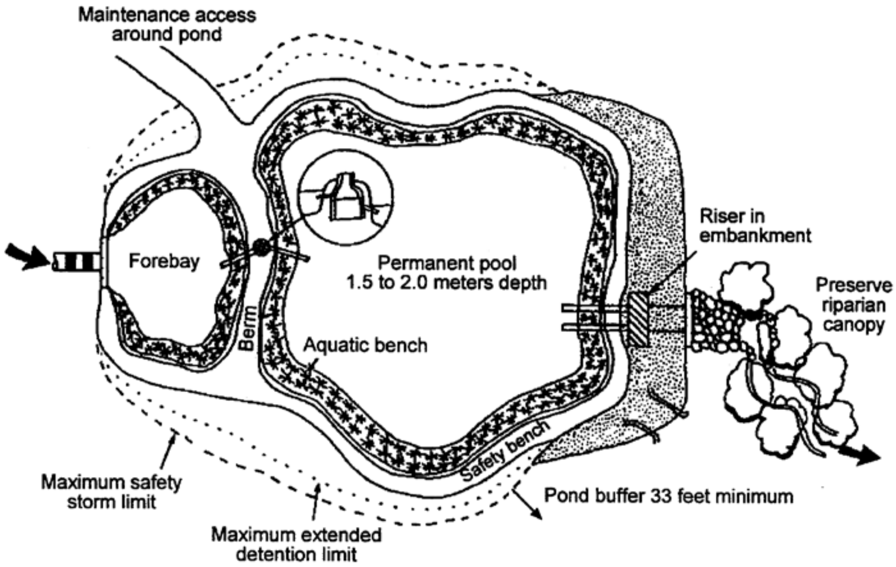
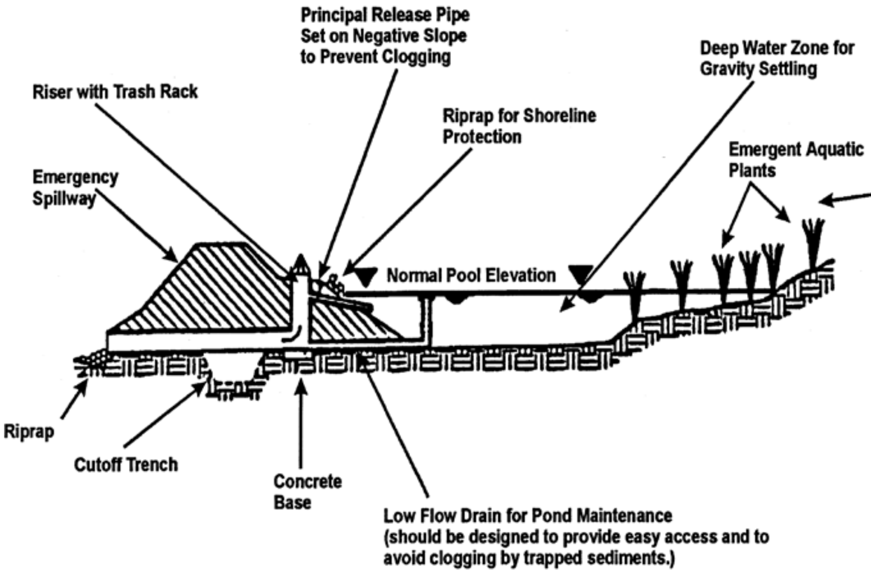
Diagram © CIRIA (2009)

Key factors taken from CIRIA (2004)[1] unless otherwise stated:

- Maximum storage depth should be limited to 0.8m to limit effects of water pressure on vegetation in the basin
- Design to half empty within 24 hours again to avoid stress on vegetation.
- Pre-treatment to remove sediment important element – sediment forbay or stilling basin and outlet via grassed filter strip to reduce clogging (stilling basin volume 25% of water quality treatment volume design criteria are the same as ponds)
- Erosion protection at inlet and overflow weir and overflow arrangement (e.g. emergency spillway) to deal with events that exceed design
- Base level and even and at least 1m above water table
- Safety reason sides should be no greater than 1:3.
- Planting to withstand wet and dry conditions, deep rooted vegetation will improve infiltration
- Water quality volume determined by local requirements or sized so that 85% of the annual runoff volume is captured[7]
- Establishing vegetation on the basin floor may reduce the rate of clogging.

Site suitability/ Limitations	Specific soil requirements, permeable soils (low clay content) For lightly contaminated yard run-off only use in areas where groundwater contamination is not an issue[1,3]. Clogging risk in areas with high sediment load[4], difficult to restore function once clogged[7]. Risk of permanent standing water in low permeable soils or if water table too high[1].
Utilisation examples	Bottom of the slope in fields particularly those draining to a single corner. Drainage from clean hard standing and tracks
Associated SuDS	Sediment trap, Grassed filter strip, swale, pre-treatment to remove excess sediment and prolong life time of basin.
Further Guidance	CIRIA (2004) *Sustainable drainage systems: hydraulic, structural and water quality advice.* CIRIA C609 CIRIA report 156

Rural SUDS component	Retention ponds	
Summary	Wet ponds, designed to permanently retain some water at all times and provide temporary storage above it, through an allowance for large variations in level during storms[1,2].	
Description	Basins with a permanent pool of water (or at least throughout the wet season) with temporary storage provided above this level. They primarily differ from constructed wetlands through having a greater average depth of water[1,2].   Photographs © Fabrice Gouriveau Pollution removal occurs through the settling out of solids and biological activity in the ponds which removes nutrients[1,2].	
Cost (£)	**Set up**	***High,*** to maximize effectiveness. Costs variable, depending on size and need for liner[2].
	Running/ Maintenance	***Low***[2] annual inspections, also typically monthly mow side slolpes[1], Annually or every three years clear banks and manage wetland plants.[1], Three to seven years remove sediment from sediment trap[1], Repair damaged vegetation as required[1], Remove sediment in main pond every 25 year or greater when required[1].
Performance	**Peak Flow**	***High***[E]***,*** reduce volume of water running directly to watercourse and encourages groundwater recharge[1,17]
	Suspended solids	***High***[1,3,4,5,6,7,8,9,10,11,12,13,14,15,16] Removal of sediment and associated pollutants inc. P, FIO's, pesticides[15]
	Total Phosphorus	***Medium***[1,3,4,6,7,8,9,10,11,12,14,15,16] Removal of sediment and associated pollutants inc. P, FIO'S, pesticides[2]
	Total Nitrogen	***Medium***[1,3,4,6,7,8,11,12,14,15,16]
	Pesticides	***High***, no data identified, assumed high from high sediment removal
	Pathogens	***High***[16]
Cost effectiveness	***Medium value,*** high cost with a medium/high effectiveness.	

Additional Benefits	**Biodiversity**	Rich habitats for aquatic invertebrates, aquatic plants and amphibians, also used by mammals, birds and fish[18,19,22]. If considered in early design[1].
	Amenity	If considered in early design, well managed and maintained ponds can be valuable community asset[19]
Common factors affecting performance	Volume of the permanent pool relative to the amount of runoff from typical event and the quality of the base flow which sustains the permanent pool. Residence time, aquatic benches, well established vegetation, evaporation levels and season.	
Reliability/ consistency		
Lifespan (years)	Indefinite if maintained i.e. sediment removal[2], Scottish study based on sedimentation rates calculated the life span as 31-37 years if sediment not removed, effectiveness would also decrease as storage volume reduces[20]	
Design guidelines	 (Schueler, 1987)[21]  ©Maryland Department of the Environment, Key factors taken from CIRIA (2004)[1] unless otherwise stated: • Pond shape irregular with islands and bars[1,19] • Permanent pool maximum 1.2 -1.8m depth • Length: width 1.5:1 to 4:1 • Inlet velocity 0.3 -0.5 m/s to prevent short circuiting[18]. • Overflow for extreme events essential, preferably arranged so only the first flush passes through the pond[2]	

	• Retention of at least 20 days recommended, for purposes such as P removal 40 up to 100 days required[2] • Side slope 1:3 maximum[1] • Volume of permanent pool =Vt (exceptionally 4Vt) Vt = water quality volume of runoff from catchment[1] • Sediment trap = 20% of permanent pool volume[1] • Minimum catchment area to sustain pond required, available guidance varies from as low as 3ha to 10 ha [1], will depend on runoff rates, soil type and local weather conditions. • If building an embankment impounding greater than 25000m^3 subject to the reservoirs act 1975[1]. • Erosion protection sides and base of pond provided at inlets and at water courses below the outfall. Overflows should be designed to carry flows in excess of design water levels (from a 1% probability storm) to the downstream conveyance system, watercourse or sewer, freeboard above maximum level should be at least 0.3m [1].  Retention ponds intercepting field drains to allow sediment settlement before overflow to ditch. Photograph courtesy of Jamie Letts (Environment Agency).
Site suitability/ Limitations	Soil below pond needs to be sufficiently impermeable and sufficient catchment required to maintain baseline water level, ideally they should not intersect the water table (some evidence of impaired performance)[1]. Liner required where water contaminated dissolved pollutants and groundwater contamination is an issue[2] and also to ensure retention of water for biodiversity and amenity value where soils are permeable.
Utilisation examples	At the bottom of the slope particularly in fields draining to a single corner. A collection point for field drains to reduce sediments Taking drainage from farm yard area before entering surface water
Associated SuDS	Additional sediment trap upstream and outlet sumps are desirable increase lifespan and suspended sediment removal[1,2].
Further Guidance	CIRIA Book 14 Design of flood storage reservoirs. CIRIA (2004) *Sustainable drainage systems: hydraulic, structural and water quality advice.* CIRIA C609

6.2.4 Use of woodland

Rural SUDS component	**Woodland shelter belts**	
Summary	Planting mixed woodland to produce a belt which primarily reduce wind speeds, but also encourages infiltration and prevents soils erosion.	
Description	Involve the planting of a mixed woodland as a belt, as they are normally developed primarily to intercept wind they tend to be developed perpendicular to the dominant wind direction, for drainage purpose they should be built perpendicular to the slope of the land. Trees intercept and evaporate a significant proportion of rainfall, root depth increases and soil structure improves, infiltration rates increase and overland flow decreases, surface runoff from upslope can be captured and infiltrated[1]. Water infiltration rates up to 60 times higher in areas planted with young trees than in adjacent grazed pastures, have been recorded[2].	
Cost (£)	**Set up**	***Medium,*** variable, early set-up can be high[3].
	Running/ Maintenance	***Low,*** Potentially require stock proof fencing, keep trees 1.5m from the fence[2],[3], Management requirements change as the woodland matures. On-going woodland management required[3]. Keep grass and weeds down and fertilise for a few seasons. If shelter becomes bare at the base as it gets older, try under planting[2].
Performance	**Flow**	***Medium[1,4]*** Slows velocity through roughness and encourages infiltration through retention, increased evapo-transpiration and improved soil structure
	Suspended solids (SS)	***High[8]*** Slows velocity encouraging sedimentation and traps sediment when undergrowth included.
	Total Phosphorus (TP)	***Medium[5,7]*, **shown to have medium removal of dissolved phosphorus, although can also act as a source. Where undergrowth included likely to retain sediment and associated particulate P
	Total Nitrogen	***Medium[5,6,7]*** although studies show *high* removal of nitrates in groundwater, shelter belts can be sources of ammonia due to the break down of organic matter.
	Pesticides	***High[E]*** physical barrier enhancing sediment and associated pesticide trapping[1] and reduction in wind blown pesticides..
	Pathogens	***Medium*** [8]
Cost effectiveness	***Medium value,*** medium set up costs with relatively average water quality performance.	
Additional Benefits	**Biodiversity**	Increasing habitat diversity, wildlife corridors, habitat and food source to water bodies – can have adverse impact through shading of streams[3].
	Amenity	Landscape benefits.
Common factors affecting performance	Location and also see factors affecting riparian buffers[3].	
Reliability/ consistency	.	
Lifespan (years)	Indefinite[3]	

Design guidelines	Guidance on planting schemes and management options including site preparation are available from the Forestry Commission website (see below)[3,9]. The basic principles involve creating a mixed woodland shelterbelt that reduces windflow to around 50%. Existing design guidance, based on wind reduction rather than RSuDS application recommends the following: Space double rows about 1.2 metres apart and plant the trees about 2 metres apart in the rows. For multiple rows, space the rows about 1.5 metres apart and the trees 2.5 to 3 metres apart in the rows. Stagger the trees in each row[10]. To maximize amenity value randomise the spacing of the trees in the rows and between the rows to achieve a more natural appearance[10]. Limit use of N fixing species, particularly in riparian and NVZ areas[3]. Planting density should allow under growth development even at maturity[3] Choose deciduous native trees. For damp ground, use willow and alder[10].
Site suitability/ Limitations	Requires sufficient soil depth to allow the growth of trees. Long term requirement, dense root growth may affect existing field drains. Increased evaporation may affect local water balance[1]. Potential shading of crops and stream systems[3]
Utilisation examples	To break up long slopes, or across exposed slopes. Where grass buffer strips alone are unlikely to reduce run-off e.g. where natural slopes tend to channel run-off.
Associated SuDS	Riparian buffer strips
Further Guidance	Forestry Commission website http://www.forestry.gov.uk/pdf/FCGL002.pdf/$FILE/FCGL002.pdf. CIRIA (2004) *Sustainable drainage systems: hydraulic, structural and water quality advice.* CIRIA C609

6.2.5 Buffer strip/headland options

<table>
<tr><td>Rural SUDS component</td><td colspan="2">Hedgerow planting/management and construction of dry stone dykes</td></tr>
<tr><td>Summary</td><td colspan="2">Plant hedges or build dry stone dykes and maintain them across slopes in erosion vulnerable areas[1].</td></tr>
<tr><td>Description</td><td colspan="2">The planting and management of traditional hedges or the building and maintenance of dry stone dykes across erosion prone slopes, to intercept over-land flow or erosion and reduce the concentration of animals or machinery operations in these vulnerable areas[1].


© Natural England/Robert Goodison

Newly planted hedge or existing hedges managed using traditional hedgerow management practices e.g. hedge laying, with the objective of developing a more substantial barrier to erosion and run-off, improving infiltration and sedimentation[1]. Hedges retain eroded particles carrying pesticides and phosphorus; oxygen depleted conditions may occur in the soil close to hedges and support de-nitrification; and trees in hedges may selectively absorb some dissolved elements.[2]

Can be designed to ensure optimum field boundary control e.g. along ditch or river banks and to control the placement of access points [1].

Depending on site, alternatives such as 2m wide tussock grass margin/filter strips may be suitable[1].

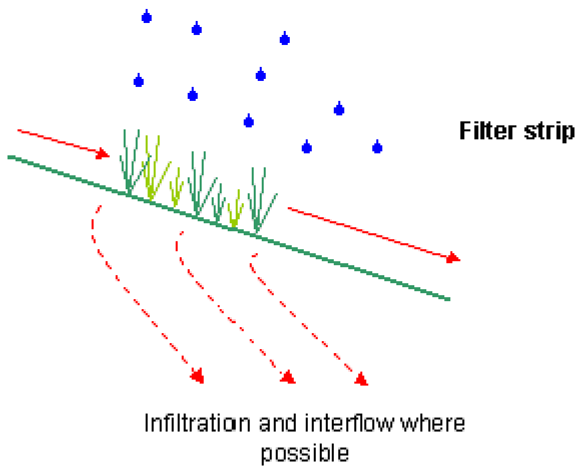
Influence on water quality can be increased if built/planted on top of a berm/bund.

Hedges/dykes will never exist in isolation, part of their performance relates to the buffer area which exists on either side which remains uncultivated, this should extend approximately 2m from the centre line of the hedge.</td></tr>
<tr><td rowspan="2">Cost (£)</td><td>Set up</td><td>Medium, work can be undertaken by farmer with minimal training and with out need for specialist equipment, raw material required particularly for dykes.</td></tr>
<tr><td>Running/ Maintenance</td><td>Low, Regular maintenance required[1].LMC and GAEC outlines details on how hedges should be managed[1].</td></tr>
</table>

Performance	**Flow**	***Medium*** [E] decrease flow velocity and encourage infiltration
	Suspended solids	***Medium*** [E, 2]
	Total Phosphorus	***Medium*** [E]
	Total Nitrogen	***Low*** [E]
	Pesticides	***Medium*** [E]
	Pathogens	***Medium*** [E]
Cost effectiveness	***Medium value,*** medium setup and effectiveness.	
Additional Benefits	**Biodiversity**	Habitat provision, wildlife corridors[1] The two most important factors are size (height/width/volume) and structural complexity. They provide physical shelter and roost sites. Hedges are an important source of winter food supplies, especially berries and other fruits[3,4].
	Amenity	Often seen as defining character of the English landscape[5]
Common factors affecting performance	Slope, density (vegetation or stones), thickness/width, continuity	
Reliability/ consistency		
Lifespan (years)	Rejuvenation of hedges, hedge laying, if carried out regularly (approx. every 20-30 years) can extend the life span of most hedgerow species almost *indefinitely*[4]. Regular maintenance of stone dykes will also allow them to last indefinitely.	
Design guidelines	*Hedges* To maximize biodiversity benefits choose a mix of native hedging species e.g. hawthorn, blackthorn. Planting must not take place into frozen or waterlogged soil so plant the hedge in the autumn when the soil is warm after the summer and damp from autumn rain. It is often recommended plant a staggered double row of plants, approximately 5 per metre. They should be spaced 12-18" (30-45cm) apart and the second row about 18" (45cm) from the first. X X X X X Hedgerow maintenance should be carried out between September and February An uncultivated buffer should extend to 2m from the centre line of the hedge. Extending this buffer in areas of high run-off risk is likely to increase run-off interception. *Dry stone dykes* In general they are built of two "skins" of stone, tied together by stone laid length ways into the wall, with a batter, which tapers the dyke evenly on both sides from ground level to the top[10]. Guidance by SNH includes the following key points[6]: • To give the greatest strength to the dyke stones should be laid with the longest dimension into the dyke, rather than along the wall. • So there are no vertical breaks in the dyke, each gap between stones should be securely covered by a stone in the next course. • To increase longevity, stones should not slope into the dyke to prevent water falling on the face of the dyke running into the middle. • The face should be even so that no stones are protruding from the dyke except the through stones. • Even when working on a slope stones should be laid horizontally along the line of the dyke • Wedges (smaller stones to secure larger stones) should only be placed on the inside and not on the face of the dyke • Coping stones should always be tight.	

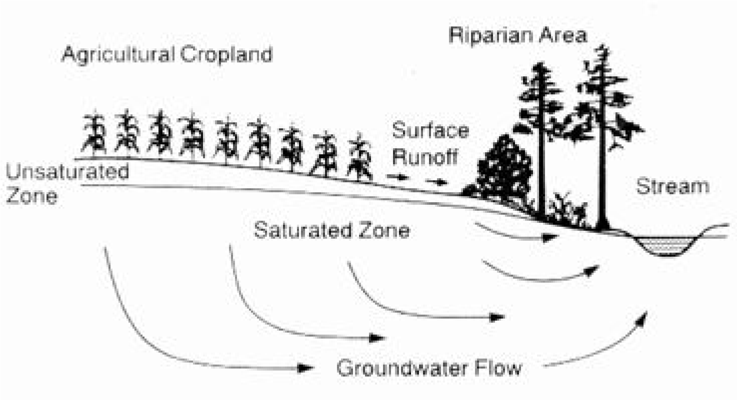
Site suitability/ Limitations	In areas where it is inappropriate to build hedges it should be possible to build stone dykes. It may not be feasible to built stone dykes where stone in not available on site.
Utilisation examples	Field boundaries or to split fields with high risk of run off.
Associated SuDS	Grass filter strips, soil berms/contour bunds, ditches
Further Guidance	Hedges http://www.hedgelink.org.uk/ http://www.defra.gov.uk/farm/environment/landscape/hedgerows.htm Dry stone dykes SNH Advisory note Number 25 Drystane dykes.http://www.snh.org.uk/publications/on-line/advisorynotes/25/25.htm

Rural SUDS component	Dry grass buffer/filter strip	
Summary	Broad, gently sloping area of grass or other dense vegetation[1] that can be placed on slopes around the farm to intercept run-off around vulnerable areas.	
Description	Wide and low-angle slopes of grass or other dense vegetation. They are designed so runoff will occur as sheet flow across the filter strip at a velocity which allows the vegetation to filter out sediment and associated pollutants and providing some infiltration into underlying soils [1,2]. Often used as pre-treatment before other SUDS techniques to reduce the risk of silting[1,2]. Because they use sheet flow and not channelised flow they are more effective than swales at removing suspended solids from runoff[2]. They differ from buffer strips as in the majority buffer strips are left undisturbed[2].	
Cost (£)	**Set up**	**Low,** Seed mix approx. £50/ha sowing and selective herbicide use[3], good design will require clearing and grading, construction of a spreader and potentially a toe berm.
	Running/ Maintenance	**Low**[3], Monthly inspections, litter removal and mowing (maintain 4-6'' of dense grass cover) , scarifying and spiking, remove silt and replace damaged vegetation as required [1,2].
Performance	**Flow**	***Medium*** **[7,8,13,14]** Not designed to attenuate flow, although some flow attenuation through design requirements and where toe berm employed[1].
	Suspended solids	***Medium*** [1,4,6-8,11,13,14-19] Filtration, CIRIA design values 50-85%
	Total Phosphorus	***Medium*** [1,6,11,15-19,21,23-25] CIRIA design values 10-20%
	Total Nitrogen	***Low*** [1,6,11, 15-19,21-25] CIRIA design values 10-20%
	Pesticides	***Medium*** [4-7,19,20,22,26] Remove pesticides dissolved in runoff water to the extent that the water infiltrates into the underlying soil and removed those attached to sediment through filtration and encouraged sedimentation.
	Pathogens	***Medium***[9,10] studies have shown that grassland buffers are an effective method for reducing animal agricultural inputs of waterborne E. coli into surface waters[10]
Cost effectiveness	***High value***, effectiveness relatively high considering the cost of this measure.	
Additional Benefits	**Biodiversity**	Restore semi natural habitat[3].
	Amenity	
Common factors affecting performance	Soil and vegetation type, flow rate[1] Effectiveness depends largely on the quantity of water treated, the slope and length of the filter strip, the type of vegetation, and the soil infiltration rate[2].	
Reliability/ consistency	Pollutant removal is highly variable[16]	
Lifespan (years)	Very long if maintained[3]	

Design guidelines	Detailed guidance and equations to help design the length and slope of a filter strip is available from CIRIA (2004)[1]  Diagram © CIRIA (2009) Key factors taken from CIRIA (2004)[1] unless otherwise stated: • Designed for sheet flow • Mannings equation for overland sheet flow can be used to calculate the flow across the filter strip. Sheet flow should be maintained with water depths less than the vegetation height, typically less than 50mm[1]. • Minimum residence time of 5 minutes[16] • Flow velocities need to be kept low to promote pollutant removal and a flow spreader, such as a gravel diaphragm, should be used to encourage sheet flow[3]. In the UK a max flow velocity of 0.3m/s is recommended to promote sedimentation[27]. • Guidance in USA suggests a slope for the filter strip of between 2-6% and it must be even and consistent with no severe inundations[1]. • Filter strips generally 5-15m wide to be effective, the lower the slope and denser the vegetation the smaller the width required[1,3]. • Grass/vegetation should be able to withstand wet and dry and quite high flow velocities[1,2]. • field to buffer area ratios (BAR) greater than 30:1, the maximum design criteria specified for grass filter strips by the Natural Resources Conservation Service[28]
Site suitability/ Limitations	All soil conditions, at least 1m above the water table if infiltration is likely to occur[1]. Should not be used to treat runoff that has been concentrated designed to treat sheet flow[1,3]. Channelisation and premature failure may result from poor design, imprecise construction, or lack of maintenance. Proper design requires a great deal of finesse, and slight problems in the construction, such as improper grading, can render the practice less effective in terms of pollutant removal[2].
Utilisation examples	Filter strips are ideal components of the outer zone of a stream buffer, or as pre-treatment to another storm water treatment practice[2] Can be used to treat roof runoff that is discharged over a level spreader.
Associated SuDS	Often situated upstream of other SuDS which undertake water quality treatment e.g. swales[1]. Soil berms
Further Guidance	CIRIA (2004) *Sustainable drainage systems: hydraulic, structural and water quality advice.* CIRIA C609

Rural SUDS component	**Riparian buffer strips (dry)**	
Summary	Medium width, dry, bands of natural or naturalized vegetation situated alongside waterbodies[1,2].	
Description	1-50 m wide bands, normally 5-15 m wide, of natural or naturalized vegetation situated alongside water bodies. They ensure activities such as machinery operations and livestock are kept away from water bodies reducing the risk of direct pollution[1,2]. They also encourage sedimentation by slowing flow velocities and trapping suspended solids further reducing water pollution[1]. Work in situations where overland flow, sheet flow dominates[1].  	
Cost (£)	**Set up**	***Low***[9] – **medium** fencing will increase cost[3,4]
	Running/ Maintenance	***Low*** Coppicing, cutting and selective herbicide use, maintenance of fencing[3,4]
Performance	**Flow**	***Medium***[6, 7, E] , roughness will decrease water velocities.
	Suspended solids	***High,*** *e*ncourage sedimentation and trap particles [3,5-7,10,13-19,22, 33-35]
	Total Phosphorus	***High*** *e*ncourage sedimentation and trap particles and plant uptake of dissolved nutrients [3,5,6,10-18,20,21,24,35,36 E]. Potential to become a source of dissolved phosphorus if nutrients build up.
	Total Nitrogen	***Medium*** [3,5,6,10,14,16-18,25-32]
	Pesticides	***High*** [5-7]

	Pathogens	***High*** [8.9,19,23]
Cost effectiveness	***High value,*** relatively low cost to implement, apart from loss of land (not considered), and high effectiveness	
Additional Benefits	**Biodiversity**	Restore semi natural habitats and provide shading of rivers reducing plant growth[1].
	Amenity	Landscape benefits
Common factors affecting performance	Width, season, vegetation age and density, vegetation complexity (i.e. include grass/ground vegetations and trees), slope, contributing area, flow type (works better where sheet flow dominates), soil type (potential for groundwater flow). P reduction dependent on vegetation and binding capacity of the soil[6].	
Reliability/ consistency	In time may begin to leach nutrients	
Lifespan	Very long if maintained[2]	
Design guidelines	No definitive width. General Binding Rules in Scotland specify a minimum of 2m field margin being left uncultivated. A buffer strip of any width will act as a hydraulic barrier, reducing flow rates and promoting deposition, but evidence from the literature indicates that buffers greater than 5m are likely to provide greater long-term protection from sediments, depending on slope, soil type and vegetation management. It should be noted that the majority of this evidence is based on plot studies often involving single erosion events and not long-term realistic field trials. In general the wider the strip and denser the vegetation the higher the efficiency[2]. A commonly accepted authority[38]recommends the following: • 30m sufficient to trap sediment under mos circumstances, wider for steeper slopes, minimum of 9m. • Extend along all streams, including intermittent and ephemeral channels • Nitrate most cases 30m provide good control, many situations 15m sufficient Care required to try and ensure flow enters the buffer as sheet flow e.g. furrow left at edge of buffer can act as a ditch concentrating flow and exacerbating erosion[39]	
Site suitability/ Limitations	Require sheet flow, where topography concentrates overland flow into hollows, they are unlikely to be very effective. They are not effective at removing pollutants from field drainage tiles or in freely drained soils where pollutants are likely to pass underneath the active area of the buffer and enter the stream bed untreated. System can break down in high run-off events washing out all the stored sediment from earlier, lower flow events[1].	
Utilisation examples	Bordering water bodies, in particular those at the bottom of slopes.	
Associated SuDS	Grass filter strip, ditch/swale, berm	
Further Guidance	Defra project Strategic placement and design of buffering features for sediment and Pin the landscape - PE0205 http://randd.defra.gov.uk/Document.aspx?Document=PE0205_6742_ABS.pdf Wenger, S. (1999) *A review of the scientific literature on riparian buffer width, extent and vegetation* Office of Public Service & Outreach ,Institute of Ecology, University of Georgia	

Rural SUDS component	**Riparian buffer strip (wet)**	
Summary	A broad, strip of natural or naturalized wetland vegetation or wet woodland alongside a water body[1].	
Description	1-50m wide strips of natural or naturalized wetland vegetation or wet woodland situated alongside water bodies.  Evans et al 1996[2] Most useful where field drain systems can be disrupted across the buffer and allowed to discharge onto the buffer creating continually wet conditions to encourage denitrification[1]. Denitrification occurs most in buffer strips containing stands of young stages of woodland succession because of high stem density. Coppicing and grass cutting (or restricted grazing) produce most efficient strips[1]. Reduce dissolved P through plant uptake and soil adsorption or binding in aerobic zones. However majority of P is in particulate form therefore P reduction effectiveness limited. Wet woodland strips not very effective for P removal, this is presumable caused by the development of anaerobic conditions, therefore grass strips required which have higher retention except in sandy soils because P reduction is depends binding capacity of the soil)[1]. Combined N and P reduction can be achieved by having a grass strip between the woodland and the stream.[1] Location critical to ensure potential flushing effect does not exacerbate potential water quality issues[1]. Careful cultivation required at the edge of the buffer to prevent plough furrow concentrating flow[1].	
Cost (£)	**Set up**	***High***[E]***,*** to ensure necessary conditions are maintained require site investigation and careful design, machinery required.
	Running/ Maintenance	***Low*** May require cutting[1]
Performance	**Flow**	***Medium*** [E] some attenuation of flow
	Suspended solids	***Medium*** [1] some attenuation of flow encouraging sedimentation
	Total Phosphorus	***Medium*** [1] some attenuation of flow encouraging sedimentation
	Total Nitrogen	***High*** [1,2,3] ideal conditions for denitrification.
	Pesticides	***Low*** [E] minimal breakdown and uptake likely before reaches water body
	Pathogens	***Low*** [E] minimal die off likely before reaches water bodywater body

Cost effectiveness	***Low value*,** relatively expensive to construct and limited effective for the majority of parameters considered without inclusion of additional SuDS techniques.	
Additional Benefits	**Biodiversity**	Wet woodland and wetland important habitats within biodiversity action plans
	Amenity	Landscape value. Can be combined with short brotational coppice for biofuels
Common factors affecting performance	Width, age and density of vegetation, vegetation type, oxygen status[1]	
Reliability/ consistency		
Lifespan (years)	Very long if maintained	
Design guidelines	Can be designed to encourage vertical infiltration of soluble nutrients is dependent on vegetation, slope and soil type[1] The design and construction of wet riparian buffers is highly site dependent and no general design guidelines are available.	
Site suitability/ Limitations	Best in areas with existing field drainage that can be interrupted, freely drained soils, areas where groundwater recharge is not a major transport process[1]. Some farmers are unhappy with cutting the field drains. System is ineffective in freely drained soils or in areas where ground water recharge is a major water transport process. They may require a significant land take.	
Utilisation examples	Along the edge of water bodies.	
Associated SuDS	Grass filter strip, dry riparian buffer strips, ditch and /or berm.	
Further Guidance	Wenger, S. (1999) *A review of the scientific literature on riparian buffer width, extent and vegetation* Office of Public Service & Outreach ,Institute of Ecology, University of Georgia	

Rural SUDS component	**Berms and water diversions**	
Summary	Low ridges or banks to redirect runoff [1].	
Description	Low ridges set at a low angle to contour, to divert runoff or erosion materials away from water bodies preferably to additional rural SuDS e.g. grassed waterway or swale[1]. Around retaining pond or sediment basin or at intervals across a filed slope to break it up and prevent runoff[1]. The berms can be vegetated or unvegetated.	
Cost (£)	**Set up**	***Low*** construction materials are relatively low in cost, costs are lower in areas of gentler slopes and low rainfall
	Running/ Maintenance	***Low***. berms should be inspected regularly, as well as after each rainfall event, to ensure that they are intact and the area behind the berm is not filled with silt. Accumulated sediments should be removed from behind the berm when the sediments reach approximately one third the height of the berm. Any areas that have been washed away should be replaced.
Performance	**Flow**	***Medium***[E] Slow down runoff and prevent it from entering waterbodies directly[1].
	Suspended solids	***Low***[E] Encourage some sedimentation and infiltration, however treatment in majority related to associated SuDS[1].
	Total Phosphorus	***Low***[E] Encourage some sedimentation and infiltration, however treatment in majority related to associated SuDS[1]
	Total Nitrogen	***Low***[E] Encourage some sedimentation and infiltration, however treatment in majority related to associated SuDS[1]
	Pesticides	***Low***[E] Encourage some sedimentation and infiltration, however treatment in majority related to associated SuDS[1]
	Pathogens	***Low***[E] Encourage some sedimentation and infiltration, however treatment in majority related to associated SuDS[1]
Cost effectiveness	***Low Value***, although the cost of this measure is low the effectiveness is also low unless used with other retention measures.	
Additional Benefits	**Biodiversity**	If grassed and permanent may have benefit to plants, invertebrates and birds[1].
	Amenity	None
Common factors affecting performance	Slope, material, soil of site, rainfall amount, local hydrologic, hydraulic, topographic, and sediment characteristics.	
Reliability/ consistency		
Lifespan (years)	Indefinite as long as maintained	
Design guidelines	Constructed at a low angle to contour at a sufficient gradient to transfer water but low enough to prevent erosion of the berm[1]. Can simply involve deep ploughing with a small vegetated strip maintained adjacent to a riparian edge to create a raised berm, or more engineered such as strengthened soil structures[1]. In the case of the later berms are usually trapezoidal in cross section, with the base generally twice the height of the berm. The height and width of the berm will vary depending upon the precipitation and the rainfall erosion index of the site[3]. Is often inadequate in areas of steep slopes and erosive rainfall because the resulting berm channels are too steeply graded and too widely spaced, and insufficient attention is given to their outlets[2].	

	The Universal Soil Loss Equation provides should be used to determine the spacing required to achieve a specified erosion target for given conditions of rainfall, soils and slopes. Where the required spacings are not feasible because they are too close, spacings should be based on ensuring that flow velocity does not exceed 80% of the maximum non-eroding velocity, and additional supporting erosion-control measures should be provided[2]. Channels should be graded at 0.4% and the grade should never exceed 2%[2]. The choice of type of outlet should be determined by the erodibility of the soil, the steepness of the slope, vegetation cover and whether the outlet slope is on undisturbed or made-up ground[2]. Berms are intended to be used only in gently sloping areas (less than 10 percent)[2] Vegetation within the berm should be encouraged to ensure adequate infiltration and filtration of flow.
Site suitability Limitations	Berms are not suitable in areas of concentrated runoff unless the drainage is small and the flow rate is relatively low[3]. However, used in conjunction with ponds or other retention measures these can be very useful.
Utilisation examples	Used to collect and direct runoff from a slope to other RSuDS
Associated SuDS	Often situated upstream of other SuDS which undertake water quality treatment e.g. swales[1].
Further Guidance	

6.2.6 Wetlands

Rural SUDS component		Constructed Wetlands/ Wetland Restoration
Summary		Constructed wetlands (CWs) are engineered systems designed to utilize natural processes for water quality improvements. They perform this function by removing contaminants via a combination of physical (filtration, sedimentation), biological (microbial processes, plant uptake) and chemical (precipitation, adsorption mechanisms.[1,2] Wetland restoration is the restoration of areas of land to their previous permanently or semi-permanently flooded state to provide temporary storage and break down pollutants through mechanisms described above[1,2]. Restored wetlands are likely to function as surface flow wetlands (see below).
Description		• Removes particulate and soluble pollutants • Mitigates high flows • CWs treat lightly contaminated surface water run-off containing a range of pollutants including BOD, suspended solids and faecal coliforms/pathogens • Natural (or restored natural) wetlands should not be used to treat contaminated farm run-off, use CWs (above) for this. • Can retain/transform N and particulate P • Can retain/transform dissolved (by physical sorption onto soil and roots plant uptake (summer), microbial uptake (aerobic conditions during plant photosynthesis) • Can break down hydrocarbon mixtures[1,2] *Types of Constructed wetland:* Surface Flow - permanent depth of water flow across bed surface. Often large dimensions, resemble natural marshes and swamps with diverse ecology[3]. Subsurface flow – Root Zone methods widely used throughout Europe. An excavated basin is filled with porous media (gravel, sand , soil or mixtures thereof) and planted with aquatic macrophyte, frequently *Phragmites australis* or *Typha latifolia* L (reed beds). Waste water flows horizontally (Horizontal flow CW) or vertically (Vertical flow CW) through selected bed medium and root zone[4]. Wetlands have a high habitat value and can be established or re-established as riparian features by intercepting field drains or the water table and may be useful in Nitrate Vulnerable Zones[2].
Cost	**Set up**	***High***[2] **–** A typical small wetland may be built for less than £5000 but if a lining is required the costs will increase.
	Running/ Maintenance	• Weekly visual check of influent and effluent pipework and removal of blockages as required. • Occasional cleaning out of any sediment trap • Level control[2,5]
Performance	**Flow**	***High***[5,6] - Should be designed with significant storage capacity
	Suspended soilds	***High*** - Removes particulates by filtration and sedimentation
	Total Phosphorus	**Medium** - Particulate P retained as above, dissolved P can adsorb but limited depending on media and can become source for dissolved P over time.

	Total Nitrogen	***Medium*** – moderate denitrification potential
	Pesticides	***Medium***^{E} – retention time for degradation and sedimentation of particle-associated pesticides
	Pathogens	Retained through filtration, sedimentation and die-off occurs over time, depending on retention time.
Cost effectiveness	**Medium value**, High set up costs but effective performance	
Multiple Benefits	**Biodiversity**	Provides habitat for birds, wildlife and aquatic flora and fauna[7]
	Amenity	Where access available provides bird and wildlife watching, walks, picnic opportunities
Common factors affecting performance	• Hydraulic retention time (determined by size; flow rate) • Age • Seasonality • Vegetation choice	
Reliability/ consistency	Reliable and efficient Capable of coping with accidental spillages[5] Function well in cold climates[8]	
Lifespan	50-100yrs[5] if maintained	
Design guidelines	Design should be tailored to nature and anticipated volumes of influent flow. There is significant literature available for design guidance[4] and it is recommended to contact SEPA/ consult the SEPA/EHS design manual[9] for constructed farm wetlands and the Constructed Wetlands Association[10] for assistance. Basic design equations are given below.	

Parameter	Subsurface flow HFRB	VFRB
Flow	Continuous	Intermittent; batch
Bed design equation [1,4,11,12]	$A_1=5.25P^{0.35} + 0.9P$	$A_h=Q_d\,(\log C_e - C_i)/K_{BOD}$

A_2 = area of a second beds estimated at 50% that of A_1.

Prevailing condition	Anaerobic	Aerobic

Porous substrates such as pea gravel would be recommended to minimize clogging and increase the life span of the bed, but specialized media may be recommended for binding phosphate.[9]

	 A farm wetland (photograph courtesy of Miklas Sholtz, University of Edinburgh)
Site suitability/ limitations	• Suitable for lightly contaminated run-off not manures and slurries • Soils with clay contents in excess of 20% are unlikely to require liners and some lighter soils can be made sufficiently impermeable by suitable treatment. • Adjacent water table must not reach surface • Land requirement • Cost if liner needed • Generally lower removal efficiencies when cool or in high flow. • Risk of inundation during extreme rain events or structural failure. • Operation efficiencies are improved when influent flows are regulated through use of initial collecting point, although this adds to the costs. • Effluent can still contain FIO concentrations greater than the receiving water. SEPA should be consulted prior to construction of wetland systems to treat contaminated water. • Anaerobic conditions P release to the water column can occur • Efficiency of systems can decline with age due to pore clogging from suspended solids and P saturation of adsorption sites on media [2,5]
Utilisation examples	Interception of field drains Lightly contaminated farm runoff[13] (CWs,not restored natural wetlands) Agricultural run-off; Ireland (CWs,not restored natural wetlands) [14,15]
Associated SuDS	Sediment trap prior to inflow will reduce maintenance by limiting sediment clogging. Combinations of different CWs can provide additional pollutant removal e.g. ammonium ions can be transformed by nitrification to nitrate in an aerobic wetland e.g. Vertical flow CW and then by denitrification to nitrogen gas or NOX in an anaerobic bed e.g. horizontal flow CW. Diversion of uncontaminated water to swales and ditches is recommended[5]
Further Guidance	Constructed Wetlands Association[10] SEPA/EHS design manual for constructed farm wetlands[9] http://www.sepa.org.uk/land/land_publications.aspx[6)]

6.2.7 Farm buildings

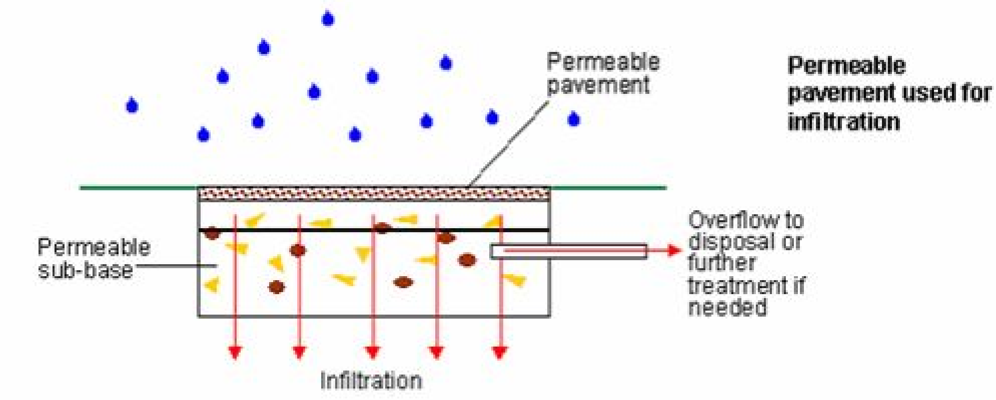
Rural SUDS component	**Rainwater harvesting and diversion**	
Summary	Rainwater is collected from roofs and impervious hard standing areas and diverted from surface waters[1]. It can be stored and used around properties and farms or to be diverted to soak-awaysoak-away	
Description	Water is usually held in offline storage tanks. Storage capacity provides for storm events and reuse activities. Water runs from the roof via a course filter into the storage tank. It is then either pumped to a header tank or direct to where it is needed. Alternatively, it may be just diverted to a soak-away with or without interim storage[1].  A simple rainwater collection system which overflows to a soak-away. Photo courtesy of Lisa Avery.	
Cost	**Set up**	***Medium-High***[E] depending on storage requirement (large underground storage will require engineering and expert advice). Pipework to divert rainwater to another RSUD component will be low cost.
	Running/ Maintenance	***Medium***[1] • Inspect and clean tank, inlets, outlets, filters and gutters – annual • Replace filters – every 3 months • Electricity for pumps and repair of pumps as required • Check overflow for erosion and repair as required
Performance	**Flow**	***High***[E] - Rainwater collection and storage capacity
	Suspended soilds	**N/A** (Pre-treatment/additional treatment required for water quality attenuation[1]).
	Total Phosphorus	**N/A**
	Total Nitrogen	**N/A**
	Pesticides	**N/A**
	Pathogens	**N/A**
Cost effectiveness	**Medium value**– medium cost; high flow/peak flow attenuation which is the only application as links to other RSUDS or reuse	
Multiple Benefits	**Biodiversity**	**Low** – no obvious benefits
	Amenity	**High** – provision of relatively clean water for irrigation or domestic (not potable) use of for further treatment to supplement private

		potable supplies.
Common factors affecting performance	Sediment/debris build up on roofs or hard surfaces and subsequently in tank/filters[1]	
Reliability/ consistency		
Lifespan	Indefinite if maintained	
Design guidelines	Components required are[1]: Collection pipe work • Collection tank • Treatment or disinfection devices (Some end uses (e.g. potable and some household uses may require treatment or disinfection. • Pump • Cistern • Distribution pipe work • Controls (mechanical float switches or electronic controls) For household water use, storage should be sized based on 5% of the annual rainfall or of the household demand, whichever is the lower. For larger systems a more rigorous analysis including seasonal rainfall patterns is required.	
Site suitability/ limitations	Ideally close to the source of rainfall collection and close to any reuse applications Storage underground moderates water temperature for longer term storage which reduces bacterial growth Sites from which run-off is collected should be relatively clean and free of debris[1]).	
Utilisation examples	Dairy Farm water provision (R. Harrison and sons[2]). Eden Project[3] – used for plant irrigation, biome humidification and toilet flushing	
Associated SuDS	Extra storage can be provided by diverting rainwater directly to other RSUDS such as ponds designed with extra capacity or storage under pervious pavements[1]	
Further Guidance	Harvesting Rainwater for Domestic uses – an information guide[4] (Environment Agency) Rainwater and Grey water use in buildings: best practice guidance [5]	

Rural SUDS component	**Green Roofs**		
Summary	A multi-layered system covering the roof of a building with vegetation cover or landscaping over a drainage layer. They are designed to intercept and retain precipitation, reducing run-off volume and attenuating peak flows[1].		
Description	Green roofs have tended to be applied in urban environments to promote urban greening and biodiversity. In the farm environment, they can fulfil similar functions in terms of attenuation of peak flows; particulate retention and habitat. In a green roof system, much of the precipitation is captured in the media or vegetation and will eventually evaporate from the soil surface or will be released back into the atmosphere by transpiration. Although green roof systems retain stormwater, runoff still occurs once the media becomes saturated. However, runoff is delayed because of the time taken for the media to become saturated[2].This time-lag can reduce peak flows to surface waters. Three main types: Extensive – entire roof covered; low growing, low maintenance plants e.g. mosses, succulents, herbs, grasses. Lightweight. Intensive – landscaped (e.g. trees, planters), high amenity, accessible Simple intensive – ground covering vegetation e.g. lawns[1]. The roof is protected by a waterproof membrane.		
Cost	**Set up**	***High***[1] Dependent on existing structure and type of green roof	
	Running/ Maintenance	**Extensive**	***Low***[4]
		Intensive	***Medium***[3] - significant on-going maintenance especially first 2 years.
		Simple intensive	***Medium***[3] - regular maintenance (cutting, irrigation, feeding) especially first 2 years.
		Irrigation during establishment Inspection for bare patches and replacement of plants Litter removal depending on setting and use[1]	
Performance	**Flow**	**High**[2,5,6] Attenuation of peak flows (rainfall retention upto100 % annually)	
	Suspended soilds	**N/A**	
	Total Phosphorus	**N/A**	
	Total Nitrogen	**N/A**	
	Pesticides	**N/A**	
	Pathogens	**N/A** and likely input from bird faeces. Can reduce water quality[7]	
Cost effectiveness	**Medium value**, Generally costs are high compared to conventional roofs but flow attenuation good Extensive – more cost effective[4].		
Multiple Benefits	**Biodiversity**	**High** – provides habitat, often undisturbed, for micro-organisms, insects and birds[2]. (Intensive>extensive>simple intensive)	
	Amenity	**High** – aesthetically pleasing, intensive may provide amenity space	
Common factors affecting	• Roof pitch • Depth of media		

performance	• Type of vegetation[5,6]
Reliability/ consistency	
Lifespan	Evidence suggests 25-40 years[3]
Design guidelines	Design for interception storage Minimum roof pitch of 1 in 8-; maximum 1 in 3 Structural roof strength must provide for full additional load of saturated system. Hydraulic elements should follow BSEN 12056-3[8]. Multiple outlets reduce risk from blockages Lightweight soil medium and appropriate vegetation. Further design details are provided by CIRIA [1].   Green roof at a rural property. Photograph courtesy of Simon Langan.
Site suitability/ limitations	New build or suitable existing structure for retrofit. Extensive systems are suited to a wide variety of locations. May not be suitable for wide span farm buildings Dust from livestock buildings can settle on roofs and be a source of ammonia pollution following rain
Utilisation examples	Domestic roofs
Associated SuDS	Runoff can be diverted to additional RSUDS components.
Further Guidance	The SUDS Manual (CIRIA[1]) BSI 6229. Code of practice for flat roofs with continuously supported coverings[9] Guideline for the planning, execution and upkeep of green roof sites[10]

Rural SUDS component	Pervious surfaces	
Summary	Pavement or hard standing constructions or other pervious surfaces that allow rainwater or run-off to infiltrate through the surface to an underlying temporary storage area[1].	
Description	Porous surfaces allow infiltration across the entire surface e.g. grass and gravel, porous concrete/asphalt, woodchips, recycled plastic car parking. Permeable surfaces are made from impervious material but contain voids through the surface to allow infiltration, e.g. concrete block paving. Porous and permeable surfaces are more widely used in urban drainage to collect rainwater[1]. In a field situation, lightly contaminated run-off may be collected which could then be directed to additional RSuDS components. This might be suitable for outdoor machinery and equipment storage. Livestock tracks and poached gateways are an important source of polluted run-off. Reducing poaching from livestock and tractors movement is therefore particularly desirable. Hardstanding or other permeable surfaces which prevent poaching and encourage infiltration is therefore desirable. Where clean run-off is collected, it may be diverted to soak-away. Lightly contaminated run-off can be directed to other appropriate RSuDS and heavily contaminated run-off to appropriate storage or treatment. Woodchips may also be used to enhance infiltration in vulnerable areas e.g. tracks and gateways.	
Cost	**Set up**	***Low-High*** - Pervious surfaces – range depending on specification. Porous paving \$2-3 per square foot[2,3] Woodchip £40-£50 per tonne[4] Recycled plastic paving - under £200 for $10m^2$[5]
	Running/ Maintenance	***Low***[1] - Pervious paving – monthly inspections for clogging and water ponding. Sweeping twice a year. **Low**[E] Woodchip replaced annually as needed
Performance	**Flow**	***High***[1,6,7] - attenuation of peak flows- temporarily store run-off.
	Suspended soilds	***Medium***[1,8] - pollutants physically adsorbed, retained or filtered
	Total Phosphorus	***Medium***[1] - pollutants physically adsorbed or filtered, some microbial degradation where there is retention prior to infiltration
	Total Nitrogen	**Low**[1,8] Higher where underdrain present
	Pesticides	***Medium***[E] - pollutants physically adsorbed or filtered, some microbial degradation where there is retention prior to infiltration
	Pathogens	***Medium***[E] - pollutants physically adsorbed or filtered, some microbial degradation capacity there is retention prior to infiltration
Cost effectiveness	**Medium value -** Medium costs, low-high effectiveness	
Multiple Benefits	**Biodiversity**	***Low*** – No clear benefits
	Amenity	***Low*** – No clear benefits
Common factors affecting performance	Soil permeability and water table depth affect degree of infiltration	

Reliability/ consistency	
Lifespan	Unknown but >6 years[9] Dependent on size of air voids (more oxidation; + less durability) Shorter than impermeable paving
Design guidelines	Structural design methods for pervious paving are the same as for conventional paving, but allowing for the different properties of materials and presence of water. There is usually a granite sub-base, geotextile layer, gravel bedding layer topped with concrete blocks[1]. Hydraulic design must provide storage based on the relationship between rainfall and outflow during storm events[1]. Further design info is available from CIRIA[10]. Where storage is required, the base and sides of the paving will be provided with an impermeable membrane[1]. Systems with underdrains allow infiltration into that rather than the soil which can assist denitrification[8].  © CIRIA 2009
Site suitability/ limitations	Site slope[1] May need to protect weak sub grades or prevent infiltration[1] Where there is concern about possible migration of pollutants into groundwater, permeable paving systems should be constructed with an impermeable membrane and treated storm water discharged into a suitable drainage system.[8] Siting should take account of the proximity of existing features, such as private water supplies, land drains and open channels.
Utilisation examples	Increasingly used in urban environment – 1087 permeable paving systems in Scotland in 2002[11] Cattle tracks
Associated SuDS	Rainwater passing through a pervious surface could be directed to a soak-away; lightly contaminated run-off could be directed to infiltration drains or other flow-attentuating RSuDs.
Further Guidance	C582 CIRIA[10]

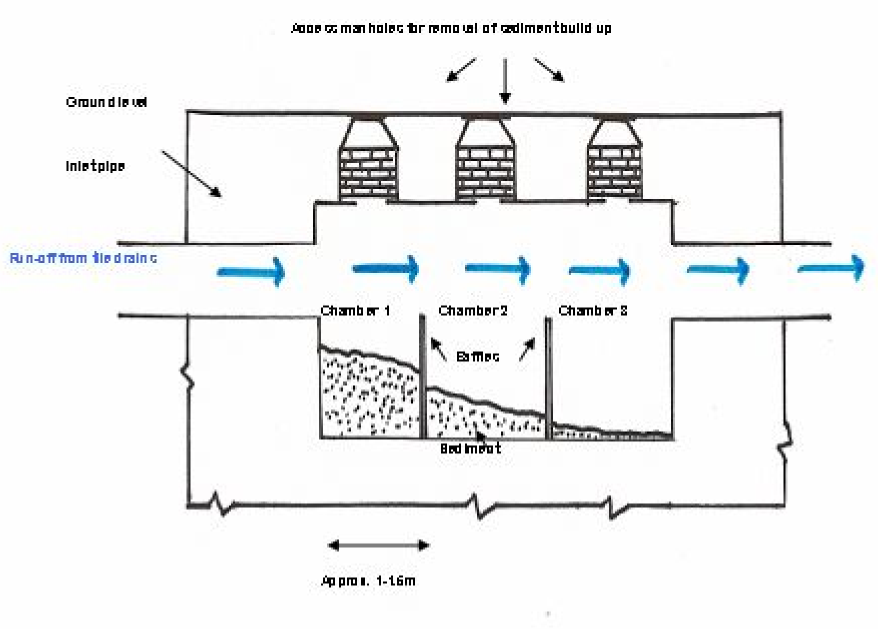
<table>
<tr><td>Rural SUDS component</td><td colspan="2">Cross drains</td></tr>
<tr><td>Summary</td><td colspan="2">A cross drain is a system to convey water across a path or route. A cut-off drain is a more durable form of cross-drain(1) and can also be used to collect run-off from a vulnerable area. For example, tracks, which provide a significant transport pathway for water and sediment.</td></tr>
<tr><td>Description</td><td colspan="2">Board and log cut-offs are simple means of diverting a limited volume of water from a path or track. Typically they comprise an embedded bar of stone or wood crossing the route(1). Cut off drainage ditches can prevent run-off from a vulnerable area e.g. cattle crossing areas vulnerable to poaching or to cut-off field run-off.</td></tr>
<tr><td rowspan="2">Cost</td><td>Set up</td><td>Low[E]</td></tr>
<tr><td>Running/ Maintenance</td><td>Low[E] - should be inspected, cleaned out, or reshaped to original capacity after each storm.</td></tr>
<tr><td rowspan="6">Performance</td><td>Flow</td><td>High[E] - diversion of flow from trackways and field areas</td></tr>
<tr><td>Suspended soilds</td><td>N/A – diversion only</td></tr>
<tr><td>Total Phosphorus</td><td>N/A – diversion only</td></tr>
<tr><td>Total Nitrogen</td><td>N/A – diversion only</td></tr>
<tr><td>Pesticides</td><td>N/A – diversion only</td></tr>
<tr><td>Pathogens</td><td>N/A – diversion only</td></tr>
<tr><td>Cost effectiveness</td><td colspan="2">High value - Low cost, high effectiveness for flow attenuation</td></tr>
<tr><td rowspan="2">Multiple Benefits</td><td>Biodiversity</td><td>Low – no obvious benefits</td></tr>
<tr><td>Amenity</td><td>Low - Stability of tracks for farm traffic and machinery</td></tr>
<tr><td>Common factors affecting performance</td><td colspan="2">Spacing
Storm intensity (peak runoff)
Traffic volume, type, and weight
Strength of cross drain surfacing material Drain geometry
Soil and surfacing type/erodability
Grade and location on slope
Fill height
Frequency of maintenance (affects ponding and drain function)
Capacity quickly reduced as sediment and debris in storm runoff settle in these(2).</td></tr>
<tr><td>Reliability/ consistency</td><td colspan="2"></td></tr>
<tr><td>Lifespan</td><td colspan="2">Indefinite</td></tr>
</table>

Design guidelines	The size of the cross drain will depend on local conditions. Small drains are typically 0,1 x 0.1m, constructed of concrete, wood or clay pipe. For heavy rainfall, 0.2 x0.2 drains can be constructed from stone or wood. The bar must be high enough to divert the flow but not so high as to be an obstruction or danger to path users or animals. The bar must not be more than 5 cm from the surface of the path on the lower side and the downslope should be flush with the bar, requiring some in-fill with soil. The bar should be placed at 20-45 º to the path and the channel gradient should be at least 5%. The bar should extend beyond the sides of the path[1]. Locate at intervals close enough to prevent volume concentration that causes surface erosion or unstable slopes. Locate away from streams. Surface and ditch water should be diverted and dispersed before it enters streams using other RSUDS e.g. swales, ponds, etc Where overtopping of the road could occur, a dip or grade roll should be designed to ensure that the overtopping flow crosses the road at a point that minimizes erosion and so that flow is not diverted along the road or away from its natural flow path. Locate above breaks in vertical profile from shallow to steep grades to prevent the shallow grade surface drainage from gaining velocity and erosive power on the steep grade. Consider lining to reduce erodibility Cross drains should be armoured where soils are highly erodible. Permanent erosion control measures (armouring, flow spreaders, vegetation) should be used at all outlets in areas of easily eroded soil[2].  A cut off drain. Photograph courtesy of Andy Vinten
Site suitability/ limitations	Unsuitable for areas experiencing very high flow rates
Utilisation examples	Cross drains can be used to direct water to a SuDS Frequently used for footpaths in rural areas[1].
Associated SuDS	Flow from cross drains should be directed into ponds, wetlands or other RSUDS which provide flow attenuation and where required, sediment retention[2].
Further Guidance	Guidance on design - Copstead et al (1998) [2]

6.2.8 Other

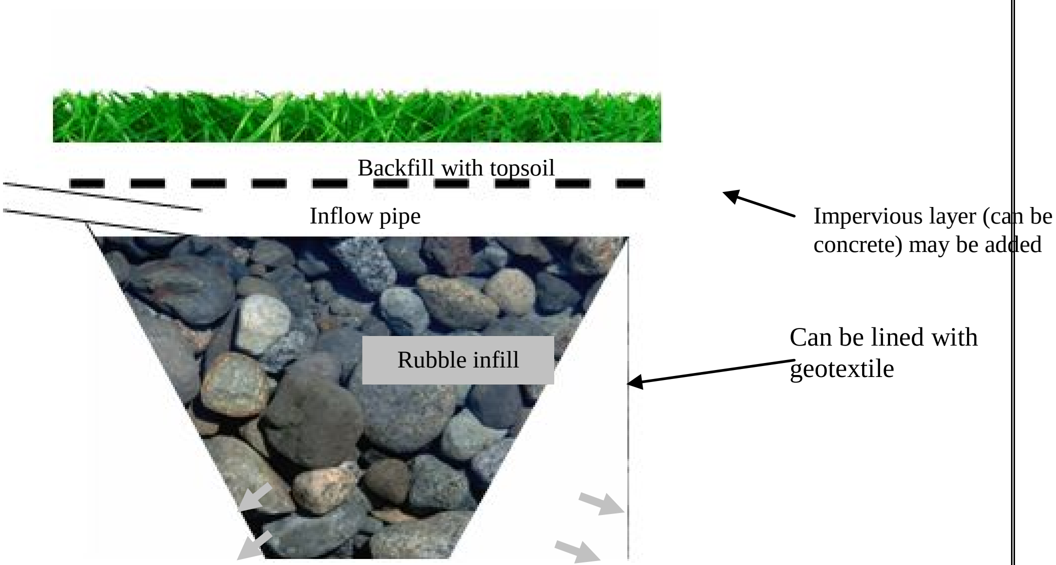
Rural SUDS component	**Biobeds**	
Summary	Biobeds are intended to collect, retain and degrade pesticide residues arising from agricultural pesticide handling activities e.g. handling/diluting pesticides and washing of equipment and have the potential to reduce pollution of surface waters[1,4].	
Description	A typical biobed comprises a lined pit containing mixtures of straw, soil and peat-free compost which is turfed over. It encourages the retention and bacterial breakdown of pollutants such as pesticides[1,4]. Treats particulate and dissolved pollutants, particularly pesticides. Lined biobeds require a waste management license but an exemption can be granted for disposal of agricultural waste consisting of dilute pesticide washings into the lined biobed[2]. There are a number of key provisions within the exemption to ensure the biobed is correctly built, maintained and operated[3].	
Cost	**Set up**	***Medium***[1,5,6] **–** estimated at between £3,500 and £7,000; depends on site characteristics - more if pumps are required rather than gravity.
	Running/ Maintenance	***Low***[5,6,7] - require regular checking and maintenance. Biobed mixture (straw, soil, compost) should be replaced at least every 5-8 years.
Performance	**Flow**	**N/A**
	Suspended soilds	**N/A**
	Total Phosphorus	**N/A**
	Total Nitrogen	**N/A**
	Pesticides	Generally **high**[4,7,8] but dependent on specific pesticide
	Pathogens	**N/A**
Cost effectiveness	**Medium value -** medium cost; high pesticide attenuation	
Multiple Benefits	**Biodiversity**	None
	Amenity	None
Common factors affecting performance	• Biomixture composition[4]. • Biobed water Management – over-saturation[4]. • Can be less effective if oversaturated e.g. in high rainfall. [4,9].	
Reliability/ consistency	Studies of efficiency in warmer countries required[4].	
	Indefinite if maintained	

Design guidelines	The surface area dimension depends on the water loading, which is controlled by the nature and frequency of pesticide handling activities on the farm. A depth of 1 - 1.5 m has been suggested. A biobed can either be a direct (or "drive-over") system, where liquids fall directly onto the biobed, or an indirect system, where all liquids are intercepted in a buffer tank, and then directed to the biobed (via gravity or a pumped system) [1]. Bunded handling area size is dictated by size of sprayer. (guidance available) [2] Mix: topsoil:straw:compost missed in the ratio 1:2:1 Leave to stand 30-90 days before adding to biobed. Design requirements include[2,4]: • Provision of secure storage of dilute pesticide washings (indirect systems) before treatment in the biobed • Every part of area where activity occurs is surfaced with impermeable pavement and has sealed drainage system so all liquids drain onto biobed. • Biobed is located in a secure place • Lining of biobed is impermeable • Biobed is suitable for treating the waste • Biobed is covered with turf • Biobed material is securely stored before spreading to land Locate minimum 10 m from surface water, 50 m from springs, wells, boreholes., away from major access routes. Risk assessment to consider environmental impact if biobed failed must be recorded. If within 250m of an environmentally sensitive area or protected habitat, and environment impact assessment will be required. Further guidance is available from the Environment Agency[2].
Site suitability/ limitations	• Site characteristics will determine the need for pumps over the use of gravity which may place limits on cost-effectiveness. • Lined biobeds can become water logged during periods of heavy rain resulting in a reduced rate of biodegradation • Not suitable for concentrated pesticides • The first tank washings should be sprayed on the target fields. • No more than 15000 L pesticide waste total volume must be treated by a single biobed in 1 year[1,2,4,910]
Utilisation examples	Use in Sweden, UK, Europe, US. Case studies are cited by [4].
Associated SuDS	None – water should be collected specifically for drainage to biobeds and must be sealed from other drainage systems.[2,3,4].
Further Guidance	SEPA BMP[1] Environment Agency[2] del Pilar Castillo et al (2008)[4] Biobeds Manual[5] http://www.biobeds.info/content/default.asp[10]

Rural SUDS component	Sedimentation boxes	
Summary	Sedimentation boxes, also known as baffle boxes, are tanks with a permeable base, connected to tile drains[1].	
Description	Sediment boxes intercept run-off water from tile drains and gravitational settling of suspended solids and associated contaminants occurs. The standard design (USA) has 3 chambers separated by 2 baffles which slow the water and sediment out the solids  Modified from[2] Water infiltrates into the soil at the bottom of the boxes. The function is similar to that of small infiltration basins but not grassed.	
Cost	**Set up**	***Low-medium***[1]. Construction of boxes: costs strongly dictated by the design requirements for capacity[1].
	Running/ Maintenance	***Low***[E] - sediment material must be emptied from tank periodically otherwise the box depth effectively lessens and the trapping efficiency is reduced. Sediment is often removed through manhole access doors at the surface. Coarse sediments may, at times, block the feed pipe, but storm flushing is usually sufficient to clear blockages.
Performance	**Flow**	**Medium**[1] - minimal attenuation of peak flows.
	Suspended soilds	***High***[E]
	Total Phosphorus	**High**[E] Reduces nutrient losses from overland flow[1]
	Total Nitrogen	***Low***[E]
	Pesticides	**Medium**[E]
	Pathogens	**Medium**[E]

Cost effectiveness	**High value**- Low cost, generally medium-high effectiveness	
Multiple Benefits	**Biodiversity**	***Low*** – No clear benefits
	Amenity	***Low*** – No clear benefits
Common factors affecting performance	• The speed of water transport through the box, infiltration capacity of the soil and sediment loading rate affect retention efficiencies. • The number of chambers and baffles is less important, especially if a greater number of chambers results in smaller chambers.	
Reliability/ consistency	Sedimentation boxes are effective at removal of coarse particles but not for fine particles [(2)]. Fine sediment removal is better when the run-off water entering the boxes has a greater load of fine sediment [(2)].	
Lifespan	Considerable if well maintained. May be dictated by feed pipe work.	
Design guidelines	The box is divided into three compartments by two barriers, also known as baffles, as shown above. The barriers slow down the flow of water and allow the sediment to settle in the box. The design concept of a sediment box is similar to the design of a traditional three chamber water quality inlet also known as oil/grit separator[(2)].	
Site suitability/ limitations	Not suitable for soils with poor infiltration e.g. clay Collection of sediment may constitute a point source for P run-off in the future (pollution swapping). Suited to hilly areas with high rainfall	
Utilisation examples	Removal of sediment from subsurface tile drains prior to entry to water course	
Associated SuDS		
Further Guidance	Pandit et al (1996) provides more detailed design diagram[(2)]	

Rural SUDS component	**Soak-away**	
Summary	An infiltration drain. Often square or circular excavations (may also be trenches, see infiltration trenches) filled with rubble, lined with brickwork, pre-cast concrete rings or similar where rainwater and run-off is collected and infiltrates directly into the ground[1,2].	
Description	Soak-aways are the most commonly used infiltration device in the UK. They are a traditional way to dispose of stormwater from buildings and paved areas remote from a public sewer or watercourses. In recent years, soak-aways have been used within urban, fully-sewered areas to limit the impact on discharge of new upstream building works and to avoid costs of sewer upgrading outside a development. They are seen increasingly as a more widely applicable option alongside other means of stormwater control and disposal[1,2]. Soak-away's store the immediate stormwater run-off and allow for its efficient infiltration into the adjacent soil. They must discharge their stored water sufficiently quickly to provide the necessary capacity to receive runoff from a subsequent storm. They can be constructed in many different forms and from a range of materials[2].	
Cost	**Set up**	***Medium/Low*** [1] depends on size
	Running/ Maintenance	***Low***[1] - removal of sediments/debris from pre-treatment device Clean gutters or filters on downpipes Remove any roots causing blockages Monitor performance
Performance	**Flow**	***High***[1,3,4,5] Attenuation of peak flows
	Suspended soilds	***Medium***[3]
	Total Phosphorus	***Medium***[E]
	Total Nitrogen	***Low***[E]
	Pesticides	***Medium***[3]
	Pathogens	***Medium***[E]
Cost effectiveness	***Medium* value -** Low-medium cost; Medium effectiveness	
Multiple Benefits	**Biodiversity**	***Low*** – No clear benefits
	Amenity	***Low*** – No clear benefits
Common factors affecting performance	• Time taken for discharge depends upon the soak-away shape and size • Surrounding oil infiltration capacity	
Reliability/ consistency		
Lifespan	Many appear to function well over long periods but lifespan reduced by clogging[6]	

<table>
<tr><td>Design guidelines</td><td>
For areas of 100m^2 or less, soak-away are traditionally built as square or circular pits either filled with rubble or lined with dry jointed brickwork or precast perforated concrete ring units surrounded by suitable granular backfill. They may also take the form of trenches that follow convenient contours. This provides larger internal surface area for infiltration[2].
Design is based on the following equations:
I-O=S where I is inflow from the impermeable area drained to the soak-away; O is the outflow infiltrating into the soil during rainfall and S is the required storage to balance temporary inflow and outflow.
Inflow is calculated using the equation I = A X R where A is the impermeable area drained to the soak-away and R is the total rainfall in a design storm (i.e. a 10 year return period is used). Guidance on calculation of R is available from BRE[2].
Outflow – α_{s50} x f x D where α_{s50} is the internal surface area of the soak-away to 50% effective depth; f is the soil infiltration rate determined in a trial pit at the soak-away site and D is the storm duration.
Storage volume , S, must be equal to or greater than the inflow minus outflow volumes.
Soak-away should be designed with inspection access to the point of discharge to the soak-away to allow clearing of debris.
Granular material should be separated from soil using geotextile. A pre-treatment device such as a sediment trap is likely to be appropriate for areas with high suspended sediment loads[1,2].


Further design guidance available from CIRIA[1,7]
</td></tr>
<tr><td>Site suitability/ limitations</td><td>

Not suitable for contaminated sites, sewage treatment or those above vulnerable groundwater[1]
Not suitable for unstable ground
Not suitable for areas with high water table
Not suitable within 5m of a building or road[1]

</td></tr>
<tr><td>Utilisation examples</td><td></td></tr>
<tr><td>Associated SuDS</td><td>Sediment trap, rainwater harvesting</td></tr>
</table>

Further Guidance	Guidance from BRE[2] Infiltration Drainage Manual of Good Practice - CIRIA[7]

Rural SUDS component	Grip (gully) blocking	
Summary	Blocking off of grips (drainage ditches) in peatlands.	
Description	Grips are drainage ditches which have been used in managed peatlands to lower the water table to improve the land for grazing. In the last decade there has been recognition of increasing water colouration from runoff draining peatlands in an effort to control this grips have been blocked to raise the water table again. It was suggested that lowered water tables may aid the solubility of dissolved organic carbon (plus small quantities of N and P) by various mechanisms relating to enzyme activity and greater rate of peat decomposition under more aerobic conditions occurring due to grips. Blocking grips may help reduce runoff through increased water retention, although the main aim is to minimize dissolved organic nutrient concentrations (C, N and P) although these are not strictly pollutants in this context. However, excess colouration and organic C particle erosion can harm ecology by limiting light penetration into waters and is a major cost to water companies(1).	
Cost	**Set up**	***Medium***[E] - Small for individual grips but the extensive nature of the grip system and its density on an area of land make the overall costs large.
	Running/ Maintenance	***Low***[E] – no maintenance, since grips tend to sediment up and block themselves once the initial action of providing a dam to stop the flow has been done.
Performance	**Flow**	***Low***[E (3)] limited capacity - once a blocked grip is full of water the flow attenuation is lost. However blocked grips have shown reduced overall discharge[(3)]
	Suspended solids	***High***[E] - good capacity to aid sediment capture (similar to a detainment pond, but with poorer infiltration)
	Total Phosphorus	Not an issue in nutrient poor upland systems e.g. peat upland where these measures are applied.
	Total Nitrogen	Not an issue in nutrient poor upland systems e.g. peat upland where these measures are applied.
	Pesticides	Not an issue in nutrient poor upland systems e.g. peat upland where these measures are applied.
	Pathogens	***Medium***[E] - may be beneficial for the reduction of pathogens in drinking water supply catchments.
Cost effectiveness	***Medium value***[E] - The costs are moderate, given the large area required to be grip blocked to expect any benefits in a catchment, but there is more research required to establish the magnitude and timescales of any benefits before cost-effectiveness can be implied. Most cost effective method is peat dams(3)	
Multiple Benefits	**Biodiversity**	***High*** – Moorland with blocked grips has greater range of wetland bird and plant species
	Amenity	***Low*** – Grip blocking may contribute to lessening erosion in popular recreation areas of Pennine UK and is expected to aid problems of treatment of potable water supplies
Common factors affecting performance	• Slope angle(3) • Rainfall amount and distribution(3) • Ditch dimensions to be grip blocked(3). • Soil shrinkage/erosion around plastic piling allow water to find a preferential path around the grip, reducing the effectiveness of blocking(3).	
Reliability/ consistency	Site limitations dictate that a case-by case assessment of whether grip blocking will be effective should be undertaken(3).	
Lifespan	Potentially indefinite	

Design guidelines	Grips can be blocked by several methods[1,2]:The most widely used is to scoop an adjacent bit of vegetation and peat, and to place this in the grip channel, this is repeated at regular intervals along the length of the channel. Other methods include any sheet piling material (corrugated plastic, wood), or bales of heather or rushes that can be placed across the grip to impede water movement. These methods have the common aim that sedimentation is promoted behind the blockage, and over time the channel fills in and the blanket bog habitat is re-established. The Moors for the Future Partnership Report no 4[3] provides guidance on dam spacing along a grip for water retention.  Photo copyright Natural England/Sara Barrett
Site suitability/ limitations	Limited to upland areas with existing grips Naturally infilling drains have been shown to occur on gentle slopes under 4°, whilst those over 4° rarely infilled. Drains on slopes less than 2° rarely eroded and erosion became more rapid on slopes above 4°. Therefore targeting drains on slopes over 4° seems appropriate[1].
Utilisation examples	Grip blocking has undergone extensive research recently promoted by the water companies, particularly in northern England, who own catchments supplying their water and who have seen recent economic costs associated with treating more coloured waters. This represents a move away from traditional 'end of pipe' solutions for industry into catchment management. • Peatscapes Project (Northumbrian Water, Environmental Agency, Natural England, Durham University) • Geltale and Glendue Fells (Halton Lea Fell SSSI) Restoration Project (Natural England)[1] • Tees Water Colour Project (Northumbrian water) - (9 km then 69 km of grips were blocked 2007-08 as part of a research project) [1]. • Sustainable Catchment Management Project (SCAMP; United Utilities, NW England) - grip blocking, reductions in grazing pressure, buffer zones. • Swale River Restoration Project - 150 ha of moorland has been grip blocked (http://www.riverswale.org.uk/project09.html)

	• Berwyn and South Clwyd mountains, Wales (http://www.blanketbogswales.org/photo-gallery/grip-blocking_132.html)
Associated SuDS	
Further Guidance	Understanding Gully Blocking in Deep Peat. Moors for the Future Report No 4[3]

6.3 Qualitative summary and comparison

The systems reviewed provide a good cross section of performance and cost, and a drainage system consisting of a number of component parts should provide high water quality performance (table 6.1.) RSuDS measures vary in nutrient capture which reflects the difficulty in achieving greater than 75% nutrient removal efficiency particularly for nitrogen. It is worth noting that there is often a trade off between P or sediment removal and N removal, as different conditions are often required for removal of each. This highlights that using a combination or treatment train of RSuDS will be more effective than individual measures. The performance will also be dependant on ensuring that basic field management is operating to best practice. This will reduce run-off and flow at source and make the RSuD more effective.

Table 6.1 Qualitative summary of RSuDS options (E= performance based on expert opinion)

Rural SuDS Component (results for basic version of system)	Multiple Benefits				Performance						Costs				
	Flow	Water Quality	Biodiversity	Amenity	Flow	Suspended solids	Total Phosphorus	Total Nitrogen	Pathogens	Pesticides	Set up	Running	Cost effectiveness	Lifespan	Site suitability/ limitations
In-ditch options															
Swales										E					
Infiltration trench					E					E					
Filter/French drains					E										
Barriers & traps (basic)					E	E	E	E	E	E					
Wetland					E				E	E					
Ponds[3]															
Detention															
Infiltraion									E	E					
Retention									E						
Woodland/Forestry															
Woodland shelter belts															
Buffer strip/headland technology															
New hedges/dry stone dyke					E	E	E	E	E	E					
Dry grass filter strips					E										
Buffer strip (dry)					E										
Buffer strip (wet)[1]					E				E	E					
Contour bund					E	E	E	E	E	E					
Filter Berm					E	E	E	E	E	E					
Wetland															
Artificial/restored wetland										E					
Biobeds															
Farm buildings															
Rainwater harvesting					E										
Cross-drains					E										
Green roofs															
Other															
Sediment trap															
Pervious surfaces									E	E					
Sedimentation boxes						E	E	E	E	E					
Soak away							E			E					
Grip (gully) blocking										E					

6.4 Knowledge gaps

In general, information is limited for adapting the design of SuDS components that have been commonly utilized in the urban environment to rural applications. This is particularly true for infiltration systems such as infiltration trenches, filter drains, soak-away, pervious surfaces and sediment traps. Performance data for these, along with other measures which may be applicable to farm buildings (e.g. green roofs), are also either limited or targeted more towards pollutants of interest in the urban environment (e.g. heavy metals, hydrocarbons) rather than agricultural diffuse pollutants, although there is information on suspended solids in some cases.

There appears to be little data to demonstrate the impacts of a large number of measures on flow at the site or catchment scale. For example, no flow attenuation data was identified for infiltration trenches and filter drain,s, and flow attenuation information was particularly poor for in-ditch and buffer strip approaches. Some flow information was available for direct local impacts of measures, but impacts at a larger e.g. catchment scale were poorly quantified if at all.

Overall, both water quality and flow data were more readily available for ponds and wetlands, for which there is a substantial volume of research material, although it frequently focuses on more heavily contaminated waste waters rather than run-off alone. This in itself can present problems for performance extrapolation as, for example, treatment in constructed wetlands often depends on having sufficient and balanced nutrients in the wastewater to drive the microbial processes. Given the general paucity of data for RSuDS performance, information on developing combined RSUDs e.g. planted buffer strips with berms vs. simple buffers was even less evident, with the exception of a handful of case studies.

Measurement of farm scale changes in flow and water quality as a consequence of implementation of measures would provide a starting point for further research.

7 Potential delivery mechanisms

Agri-environment schemes and guidance are available to encourage and fund land managers to adopt rural SuDS. A recent review identified sixteen current agricultural stewardship schemes which include measures likely to affect raw water quality (Table 7,1)[1].

Table 7.1 Potential delivery mechanisms (*E* indicates a scheme only available in England, *Ws* indicates a scheme only available in Wales)[1]

Compulsory	Voluntary (with financial incentives)	Voluntary (without financial incentives)	Others
Nitrate vulnerable Zones (NVZ)	Single Farm Payment (SFP) Entry Level Stewardship Scheme (ELS) - *E* Higher Level Stewardship Scheme (HLS) - *E* Organic Entry Levels Stewardship Scheme (OHLS) - *E* English Woodland Grant Scheme (EWGS) -*E* Tir Cynnal - *Ws* Tir Gofal - *Ws* Better Woodlands for Wales - *W* Hill farming allowance Catchment Sensitive Farming - *E*	Codes of Good Agricultural Practice (COGAP) The Voluntary Initiative (VI) Farm assurance schemes	Organic farming (Soil Association Certification)

Table 7.2 identifies how the six main relevant voluntary schemes which have financial incentives cover the identified rural SuDS.

The schemes, apart from capital options included under HLS and Tir Gofal, mostly relate to the management of these features if they are in existence, rather than their implementation. Existing mechanisms have not been identified for all of the RSuDS listed, specifically in-ditch options other than wetlands, the majority of farm ponds, farm building measures and the majority of schemes identified under the "other" category.

Table 7.2 also provides information on RSuDs covered by Environment Agency Best Practice Guidance which identifies the key measures which can be tackled in practical ways and gives examples of cost savings which can be achieved by the measures[2].

Table 7.2
Summary of mechanisms with the potential to deliver Rural SuDS[2,3]

Rural SuDS Component (results for basic version of system)	Delivery Mechanisms: Single Payment Scheme	Entry Level Stewardship	Higher level stewardship	Catchment sensitive farming	Tir Cynnal	Tir Gofal	Environment Agency Best Practice Guidance
In-ditch options							
Swales			X				
Infiltration trench							
Barriers & traps (basic)			X	X			
Wetland			X	X		X	X
Ponds[3]							
Detention			X				X
Infiltration							X
Retention			X	X			X
Woodland/Forestry							
Woodland shelter belts			X		X	X	X
Buffer strip/headland technology							
Hedges/dry stone dyke	X	X		X	X	X	X
Dry grass filter strips		X	X	X	X	X	X
Buffer strip (dry)		X	X	X	X	X	X
Buffer strip (wet)[1]			X	X	X	X	X
Contour bund							
Filter Berm							
Wetland (constructed or otherwise)							
Artificial			X			X	X
Biobeds				X			
Restoration			X			X	X
Farm buildings							
Rainwater harvesting				X			
Cut off drains							
Green roofs							
Other							
Pervious surfaces							
Filter (French) drains							
Horseshoe drains							
Sedimentation boxes							X
Reactive barriers							
Soak away							
Mole gripping			X				

8 Summary and conclusions

The aim of this report is to provide practical examples of sustainable drainage options and to review their effectiveness as a measure for resource protection. By doing this, they will enhance rural economy opportunities, for example, improving water quality for fishing; and through capturing pollutants will help meet the objectives of the Water Framework Directive. Rural SuDS are a good example of a group of measures that have many environmental benefits and will help land managers adapt to climate change.

Agriculture is a major source of diffuse pollution. It is responsible for the majority of silt entering water in England and 28% of phosphate entering surface waters in England and Wales. Agriculture is partly responsible for reduced bathing water quality due to bacterial contamination from manures and pesticide pollution. Rural SuDS sit within a broad range of measures which can often be successfully applied to control the delivery of contaminants between the site of mobilisation and impact.

Like their urban counterparts, Rural SuDS are measures that primarily intercept run-off and drainage pathways. They comprise of individual or multiple structures that replicate natural processes. They are designed to attenuate water flow by collecting, storing and improving the quality of run-off within rural catchments. They will reduce localised flooding; recharge groundwater and provide valuable wetland habitats. They are best used as a component of the solution alongside other land use measures rather than a last attempt to control run-off and sedimentation.

The means of reducing diffuse pollution in order of preference, is to:

1) control the source and reduce mobilization;
2) to intercept the pathway,
3) protect the receptor as a final option.

The measures vary in design to suit different scenarios relating to the source, the physical transport properties of the pollutants in question, the soil type, topography and weather impact. Due to the multiple variables, it is important to choose the correct measure or adapt and develop a measure from the examples enclosed to try and address the problem.

Rural SuDS have a number of other ecosystem benefits for water resources, flood risk management, biodiversity, and are a key adaptation measure for climate change.
By intercepting run-off and holding back water they can increase infiltration of water through the soil profile and can help recharge groundwater supplies.

Some of the attached measures have been incorporated into agri-environment schemes such as the England Catchment Sensitive Farming Delivery Initiative (ECSFDI), Glastir Targeted Element for Wales and soon to be in the Higher Level Stewardship scheme for England.

Rural SuDS have an important role to play to help modern farming, forestry and environmental protection co-exist so as to help protect people, places and wildlife.

9 Technical Annex

CHAPTER 4 - Existing Rural Drainage Systems in England and Wales

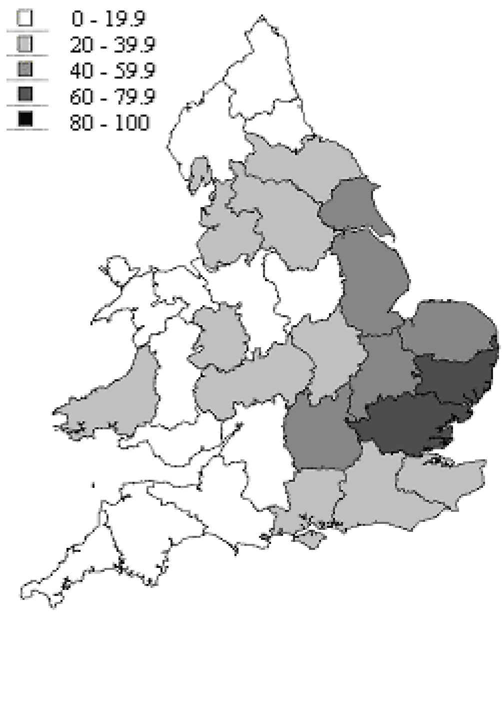
In 2002, Defra contracted ADAS to develop a database of agricultural drainage systems in England and Wales (ADAS 2002). This study included all information available on drainage that took place in England and Wales between 1950 and 1993. Taking account of the demands placed on soil by modern farming, this was taken to constitute the 'effective modern drainage area' for which data is available. The majority of older schemes will contribute to the drainage effect at some points in the year, but there input is not considered significant to the full effectiveness for drainage purposes in the current era. In addition to the consultation of experts data sets used by this study included:

- National Survey of Drainage Need (Belding 1970 and 1971)
- MAFF Drainage statistics 1951-1971 (Green, 1973)
- MAFF/ADAS FCG3UD Access database (1971-1985)
- Hydrology of Soil Types (HOST) (Boorman *et al*., 1985)
- Farmland Cultivation Practices Survey 1996 (ADAS, 1996)
- Land Drainage Contractors Association (LDCA) data 1980-1998 (Harris & Pepper, 1999)

Limited information is available on the standards of maintenance of drainage schemes e.g. ditch clearance, free outfall discharges and necessity/frequency of secondary treatment.

Review of the data showed that in addition to soil type/cropping requirement, the rate of grant and prevailing weather conditions, affected farmers' decisions as whether to drain (ADAS 2002).

ADAS (2002) estimated that 2.0 million hectares of agricultural land in England and Wales are drained by pipe drainage schemes that received grant aide, involving approximately 272,000km of drainage pipe (Table 1.2) Data clearly indicates a consistent trend for the concentration of drainage activity in the East of England on clay soils, with the majority of schemes in this area using moling (Figure 1.1 and Table 1.1).



(ADAS 2002)

Figure 1.1 Percentage of the agricultural land in each old MAFF division requiring drainage that is drained by surviving pipe drains installed in the period 1950 to 1992.

Table 1.1 Maximum area of agricultural land pipe drained with grant-aid, based upon the full database, compared with the estimated area of surviving or non-replacement drainage (minimum area). Data expressed as a percentage of agricultural land (crops and grass, excluding rough grazing)

MAFF Region	Crops and grass (Ha)	Maximum drained area (%)	Minimum drained area (%)
East Midlands	1,307,000	39	31
Eastern	1,461,000	50	44
Northern	978,000	17	14
South Eastern	1,216,000	19	17
South Western	1,712,000	10	9
Wales	1,052,000	11	11
West Midlands	1,147,000	19	16
Yorkshire and Lancashire	875,000	27	20

Table 1.2 Field drainage information reported by ADAS 2000 for MAFF regions/division.

Old MAFF Region/Division	Average drain spacing (m)	Average drain depth (m)	Pipe length		% in-field drainage schemes			Maintenance of secondary treatment	
			clay (km)	plastic (km)	Without secondary treatment	Moled	Sub-soiled	Average molling freq. (yrs)	Average subsoiling freq. (yrs)
Esatern									
Bury St. Edmunds	31	0.83	12641	2199	23	74	2	8	5
Chelmsford	48	0.84	15082	2017	20	68	12	8	5
Huntingdon and March	34	0.88	17751	1435	35	46	19	9	4
Norwich	21	1	16494	2385	71	4	25	6	4
East Midlands									
Lincoln	20	0.9	45782	3942	54	25	21	8	5
Northampton	26	0.76	7747	2320	23	48	29	8	4
Nottingham	24	0.78	5333	754	34	24	42	10	5
Northern									
Alnwick	14	1.01	2964	1414	92	0	8	7	4
Carlisle	12	0.77	7241	1377	69	0	31	Nd	Nd
Durham	15	0.81	1349	580	70	2	28	6	4
Northallerton	14	0.8	12910	2531	71	1	28	10	5
South Eastern									
Guildford	25	0.8	3602	1157	48	27	25	8	3
Maidstone	19	0.86	7790	866	69	3	28	9	3
Oxford	31	0.79	9008	1333	27	56	17	5	4
Winchester	22	0.82	1412	222	60	12	28	7	4
South Western									
Exeter	31	1.24	2205	734	93	4	3	6	6
Gloucester	27	0.86	2829	1352	36	34	30	6	5
Taunton	20	0.92	2236	1343	71	8	21	10	4
Truro	25	1.43	966	169	99	0	1	Nd	6
Wales									
Caernarvon	19	0.73	958	519	74	5	21	Nd	Nd
Cardiff	26	0.78	357	655	57	18	26	Nd	Nd
Carmarthen	24	0.84	1651	2027	54	24	22	Nd	Nd
Llandrindod Wells	13	0.75	1685	426	91	2	7	Nd	Nd
Ruthin	21	0.73	834	697	70	15	15	Nd	Nd
West Midlands									
Crewe	14	0.93	2365	1755	83	4	13	10	8
Shrewsbury	18	0.97	2785	583	67	5	29	6	4
Worcester	20	0.9	4502	2558	47	12	41	7	4
Yorkshire and Lankashire									
Harrogate	16	0.89	10209	3286	57	2	41	9	3
Preston	11	0.95	7257	1642	97	0	3	Nd	3
Beverley	16	0.9	19537	3036	73	3	24	5	5

(ADAS 2002)

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CHAPTER 6 RSUDS Options

SWALES

Costs

Study	Details
HR Wallingford (2004)	Component capital cost ranges £10-15/m^2 swale area. Annual cost for regular maintenance £0.1/m^2 of swale surface area (urban).
SWRPC (1991)	Estimate approximately \$0.25 per ft^2, not including design costs or contingencies. Maintenance \$0.58-0.75 per linear foot (urban).
CSQAs (2004)	Estimate approximately \$0.50 per ft^2, based on SWRPC and assumptions on design costs or contingencies (urban).
Caltrans (2002)	Estimated expected annual costs for a swale with a tributary area of approx 2ha at approximately \$2,700.

Performance

	Removal efficiency (per cent, unless otherwise stated)						
	Briggs et al (1999)	Horner & Mar (1982)	Center for Watershed Protection, 2000	USEPA, 2002	Atlanta Regional Commission 2001	Barrett, 1998	Claytor and Schueler, 1996
Peak flow	47						
SS		80	60-83	81	80	70	80 wet/ 90 dry
TP			29-45	9	25 wet 50 dry		20 wet/ 65 dry
Nitrogen			Negative (nitrate)	38%	40 wet 50dry		40 wet/ 50 dry
Pesticides	Av 56%						
Pathogens			Negative				
Study details	Compared to non grassed waterways	61m			Design manual		Design Mannual

	Removal efficiency (per cent, unless otherwise stated)						
	Wash et al, 1997	Highways Agency et al 1998	Macdonald & Jefferies, 2003	Luker & Montague, 1994	Winer, 2000	Schueler, 2000	CIRIA, 2004
SS	60-83	60-90	55-72		38	81	60-80 wet 70-90 dry
TP	30		7.7increase to 100 (ortho-P)	42-63	14	34	25-35 wet 30-80 dry
Nitrogen	25		45	41-51		84	30-40 wet 50-90 dry
Study details	Literature review						

	Removal efficiency (per cent, unless otherwise stated)						
	Hicks, 1995	Urbonas, 1994	EPA, 1999				
SS	50%	80%	30-65%				
Study details							

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INFILTRATION TRENCHES

Costs

Study	Details
HR Wallingford (2004)	Component capital cost ranges £55-65/m^3 stored volume. Annual cost for regular maintenance £0.2-£1/m^2 of filter surface area
SWRPC 1991, Brown & Schueler 1997	Typical construction costs, including contingency and design costs are about \$5 per ft^3 of storm water treated
Ref 4	Av. Cost of two infiltration trenches installed in S. California \$50/ft^3. In general maintenance costs are between 5-20% of construction costs. More realistic values to ensure long-term functionality are close to the 20% range.
EPA (1999)	5-20% of construction cost per annum[3]

Performance

	Removal efficiency (per cent, unless otherwise stated)					
	Urbanas, 1994	EPA, 1999				
SS	99 (max)	50-80				
TP	65-75	15-45				
Nitrogen	60-70	50-80				
Pathogens	Ecoli 98-98	Ecoli 65-100				
Study details	Urban	Urban				

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BARRIERS /TRAPS WITHIN DITCHES

Costs

Study	Details
Quinn et al, 2007	£1000 for a 5m concrete section sediment trap or £2000 for Ochre P trap + £25,000 for 5 tonne of ochre pellets. Algal Pods can cost £6000[3]
EPA, 1992	check dams constructed of rock cost about $100 per dam,
Brown and Schueler, 1997	rock check dams cost approximately $62 per installation, including the cost for filter fabric bedding

Performance

	Removal efficiency (per cent, unless otherwise stated)				
	Jonczyk et al, 2008				
TP	Av. 74				
Dissolved P	98				
Nitrogen	0.7				
Study details	Sediment & ochre trap in series				

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WETLANDS WITHIN DITCHES

Costs

Study	Details
Jonczyk et al (2008)	£5000 - Sedge wetland 30m long[1] £6000 – Willow wetland 30m long[1]
Evans et al (2007)	Conventional trapezoidal channel (2-2.5m^2 cross sectional area by 1.5m deep) $35/linear m. Costs in study to include wetland ranged from a low $7/linear m for wetland planting in existing canal, $130 to 200/linear m of channel weirs, channel excavation and planting of instream wetlands ,to over $450/linear m where flood plain construction was also required.

Performance

	Removal efficiency (per cent, unless otherwise stated)					
	Jonczyk et al, 2008	Evans et al 2007				Hunt et al (1999)
		Tull creek project	Lisa's Bottom	Ederton Airport	Golf course project	
Peak flow		Significantly lower				
SS		Significantly lower		-45	12-63	
TP	Av. 19 -61-43	Significantly lower	-55% (pot relate to reduction iron-P complexes)	0%	26%-70	
Nitrogen	Dissolved 0.46-3	General higher	20%	Nitrate 71% Amminiium 0%	Nitrate -80-100 Ammoniium -35-86	37 %
Pesticides						
Pathogens						
Study details	Sedge wetland, -61% scouring event	Controlled drainage plus wetland plants v conventional drainage. Addition wetland plants little effect v controlled drainage alone.	1ha in-stream wetland created by reconnecting floodplain, approx 400m long, runoff rural and urban approx 240ha	0.5ha mid-reach constructed wetland, Animals disturbing sediment.	Network of 12 in stream wetlands Retention 3-10 days Considerable variation from wetland to wetland. New construction	

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DETENTION BASIN

Costs

Study	Details
SEPA	Small basins typically £3000
HR Wallingford (2004)	Component capital cost ranges £15-20/m^3 detention volume. Annual cost for regular maintenance £0.1-£0.3/m^2 of basin area (urban)
Brown & Schueler (1997)	Typical construction costs $41,600 for 1 acre-foot pond, $239,000 for 10 acre-foot pond and $1,380,000 for a 100 acre-foot pond. (urban)
CSQA (2004)	$160,000 with a capture volume of 0.3 acre-foot. Maintenance approximately 3 to 5% of the construction cost (urban).

Performance

	Removal efficiency (per cent, unless otherwise stated)							
	USEPA, 2002	Atlanta Regional Commission 2001	Schueler, 2000	Winer 2000	CIRIA (2004)	Caltrans (2002)	Scholze et al, 1993	Rausch & Schreiber, 1981
Peak flow						8-60% Av 40% infiltration		
SS	61	80	71	60	65-90		70-74	85
TP	19	50	14	20	20-50			35
Dissolved P								77
Nitrogen	31	30	26	31	20-30			37 (total) 40 (dissolved)
Study details	Urban	Urban	Urban	Urban	Urban Design values	Urban	Urban	Urban

	Removal efficiency (per cent, unless otherwise stated)							
	EPA, 1999	Nascimento et al 1999	Fiener et al, 2005					
Peak flow								
SS	30-65	49-90	54-85					
TP	15-45	20-70						
Dissolved P								
Particulate P								
Nitrogen	15-45							
Pesticides			Terbutylazin 50					
Pathogens		Total coliforms 47-73						
Study details	Urban	Review of UK detention basins (urban)	Rural, 4 ponds monitored over 8 years.					

Cost effectiveness

Study	Details
SEPA	Using an annual P export coefficient of 0.66kg/P/ha/yr and a 50% efficiency or total P removal estimate efficiency £430/kg P for simple sedimentation assuming costs spread over 10 years. Excludes cost of land[6]

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INFILTRATION POND

Costs

Study	Details
HR Wallingford (2004)	Component capital cost ranges £10-15/m^3 detention volume. Annual cost for regular maintenance £0.1-£0.3/m^2 of basin area (Urban)
SWRPC (1991)	Total construction costs $2 per ft of storage for a 0.25 acre basin (Urban)
EPA (1999)	Two infiltration basins $18/$ft^3$, extra cost related to need to change drainage system to rout runoff to basin.(Urban)

Performance

	Removal efficiency (per cent, unless otherwise stated)					
	USEPA 2002	Urbonas, 1994	CIRIA, 2004	EPA 1999		
SS	75	0-99	45-75	50-80		
TP	60-70	0-75	60-70	50-80		
Nitrogen	55-60	0-70	55-60	50-80		
Study details						

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RETENTION POND

Costs

Study	Details
SEPA	construction expected to be under £5000 but can increase significant if liner required[15].
HR Wallingford (2004)	Component capital cost ranges £15-25/m^3 treatment volume. Annual cost for regular maintenance £0.5 to £1.5/m^2 of retention pond surface area
Brown and Schueler (1997)	Typical construction costs are $45,700 for a 1 acre foot facility, $232,000 for a 10 acre-foot facility and $1,170,000 for a 100 acre-foot facility.
Caltrans (2002)	$448,000 for a pond with total permanent pool plus water quality volume of 1036m^3. Maintenance costs of $17,000.
CSQA (2004)	$584,000 (including design) for a pond with permanent pool volume of 3,100m^3 Typical maintenance costs estimated at 3-5% of the construction costs

Performance

	Removal efficiency (per cent, unless otherwise stated)							
	Urbanas 1994	EPA, 1999	North Carolina CES, unknown	Novotnv & Olem, 1994	CIRIA 2004	USEPA, 2002	Atlanta Regional Commission, 2001	D.Arcy 1998
SS	91	50-80	90	40-87	75-90	67 (20-99)	80	90
TP	0-79	30-65		40	30-50	48 (12-91)	50	50
Nitrogen	0-80	30-65		30	30-50	31 (-12-85)	30	
Study details							Design guidelines	

	Removal efficiency (per cent, unless otherwise stated)							
	Commings et al, 1998	Schueler 2000a	Schueler 2000b	Schueler 2000c	Jefferies, 2001	Winer, 2000	Mikkelsen et al 2001	Gouriveau et al, 2008,
SS	61-81	78	83-93	75-86	+0.3	61 +/- 32	70-84	72%
TP	19-46	49	50-55	56-67		20+/- 13	40-74	20%
Nitrogen		-12	52-87	-1-18		Total 31+/- 1 16	7-33	Nitrate 59% Ammonium 44%
Bacteria						78		
Pathogens								Feacal coliforms 93%
Study details						Dry, extended detention basin		

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WOODLAND SHELTER BELT

Performance

	Removal efficiency (per cent, unless otherwise stated)			
	Wheater, H. (unknown)	Ryszkowski *et al.* (1990)	Ryszkowski & Kędziora (2007)	Pavliakiaviczius 1981
Peak flow	29% for frequent events, 5% for extremes			
Dissolved P		0%-73%.		400% increase to 30% decrease
Nitrate/ nitrogen		0% Ammonia 90-96% Nitrate	76- 98% Nitrate groundwater increase ammonium	Ammonium 800% increase to 82% decrease Nitrate 62-86%
Study details	Adding tree shelter belts to all optimum locations in all grazed grassland sites – Pontbren experiment Wales	Afforestation belts on flat arable land – 70m forest belt and 0.6ha forest patch.		Forest belts on lake-ward slopes in glacial landscape, 90m Alder, spruce, 40m alder, 60m alder, 70m aspen, ash, alder

	Removal efficiency (per cent, unless otherwise stated)			
	Nikolayenko, (1974)			
SS	30 10m wide 90% 15-30mwide			
Nitrate/ nitrogen	30-50% ammionia 30-45mwide			
Pathogens	50-90% 20-30m wide			
Study details	Review			

References

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NEW HEDGES/DRY STONE DYKE

Costs

Study	Details
SEPA	Stone dyke – 1.4m high £12-22/m excluding materials
SAC (2004)	£1.56/m/y for 10 years (planting, maintenance, ditch clearance

References

SAC (2004) Grant aid for trees and woodlands on farms TN556 technical note http://www.sac.ac.uk

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DRY GRASS FILTER STRIPS

Costs

Study	Details
HR Wallingford (2004)	Annual cost for regular maintenance £0.1/m^2 of filter surface area (urban)
SWRPC, 1991	Cost of seed or sod, 30¢ or 70¢ per ft^2, $13,000 to $30,000 per acre of filter strip. Typical maintenance costs about $350/acre/year
Cranfield University (2006)	Cost of seed for sowing 100m buffer – 2m wide £1.15, 4m wide £2.29, 6m wide £3.44, 10m £5.73 and 24m with £13.75. Estimated cost of cutting grass strips is £13 per ha (HGCA, 2005). For a 1ha field under wheat capital cost in the first year would be in the region of £32, £49, £66, £100 and £219 for a buffer of 2,4,6,10 and 24 m width respectively. In subsequent years cost would be £27, £40, £54, £81 and £176.

Performance

	Removal efficiency (per cent, unless otherwise stated)					
	MAPC (unknown)	Regehr et al (1996)	Otto et al 2007	Mickelson et al (2003)	Rankin et al 2001	Humberto et al (2004)
Peak flow					46-76%	18%
SS	40-90%	75		56-96	Min 66%	92%
TP				0-87		
Nitrogen				0-85		
Total pesticides		25 Hydrophilic max 100%	Hydrophilic 100%	Atrazine 28-35% 15ft strip 51-60% 30 ft strip	Flumeturon min 59% Norflurazon 63-86%	
Details of study			Two strips Italy one 4m and one 6m	Review		Within first 4m of burffer strip

	Removal efficiency (per cent, unless otherwise stated)					
	Hubbard et al (1999)	Tate et al (2006)	Dilaha et al (1989)	Ghaffarzadeh et al (1992)		Borin et al (2005)
Peak flow						78%
SS			70-84%	85%		
TP			54-73%			
Nitrogen			61-79%			
Pathogens	75-91% Feacal coliforms 68-74% Fecal streptococci	94-99% E-Coli				
Details of study	Runoff from manured plots	Cattle Fecal Deposits on grassland	4.6-9.1m 13 degree slope rainfall events	9.1m		

	Removal efficiency (per cent, unless otherwise stated)						
	Cranfield University (2006)	USEPA (2002)	Atlanta Regional Commission (2001)	Walsh et al (1997)	Walsh et al (1997)	Claytor & Schueler (1996)	CIRIA (2004)
Peak flow	64 %						
SS	76.8%	54-84	50	28-70	85-87	70	50-85
TP		-25-20	20	-21-40	34-44	10	10-25
Nitrogen		-27-20	20		33-44	30	10-20
Details of	Literature	23 – 46m	Design	Literature	Monitoring	Design	Design

study	review (25 papers)	strip	manual	review	of sites	Manual	manual

	Removal efficiency (per cent, unless otherwise stated)					
	Patty et al 1997	Cole et al 1997	Parsons et al 1990	Barfield et al, 1992	Young et al, 1980	Doyle et al , 1977
SS	87-100%					
TP			26%		88	
Soluable P	22-89%					8-62%
Nitrogen	47-100%		27% (total)	92-100% (NH_4-N)	97	57-68% (NO_3)
Total pesticides	Atrazine 44-100% Isoproturon 99% Diflufenican 97%	Chlorpyrifos 62-99% Dicamba 90-100% 2,4-D 89-98% Mecroprop 89-95%		Atrazine 93-100%		
Details of study	Cropland runoff, ryegrass, 6, 12, and 18m	Bermuda grass, 4.8m, cropland runoff	Bermuda/ crab grass, 4.3-5.3m, cropland runoff	Bluegrass & fescue sod, 9% slope, 4.6-13.7m	Corn-oat or orchard grass mix, 4% slope, 13.7m	Fescue, 10% slope, dairy waste on silt loam, 1.5-4m

	Removal efficiency (per cent, unless otherwise stated)					
	Dillaha et al 1988-W	Moore et al 2001 - W				
TP	39-52%					
Nitrogen	43-52%					
Total pesticides		Atrazine 98% Pyrethroid 100%				
Details of study	Orchard grass, 5-16% slope, 4.6-9.1m					

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RIPARIAN BUFFER STRIP (DRY)

Costs

Study	Details
SAC (2003)	Seed mix @ £50/ha, fencing £3.08-4.26 per meter (depending on the complexity) Cutting and selective herbicide use £0.025/m
EPA (1999)	Copping & grazing/cutting grass $790/ha

Performance

	Removal efficiency (per cent, unless otherwise stated)					
	Borin et al (2004)	Patty et al (1999)	Arora et al (2003)	Atwill et al (2002)	Hussein et al (2008)	Duchemin and Madjoub (2004)
Peak flow		43-99.9%	30-39%			
SS	93%	87-100%	86-90%			90%
TP	80%					87%
Dissolved P	78%	22-89%				
Particulate P						5%
Nitrate/ nitrogen	72%	47-100%				85%
Pesticides	60-90% terbuthylazine, alachlor, nicosulfuron, pendimethalin, linuron	72-100% Lindane 44-100% Atrazine 99% isoproturon, 97% diflufenican	47-52% atrazine 48- 54% metolachlor 77-83% chlorpyrifos			
Pathogens				*99.9% Crypto. parvum* Oocysts	*>99% Crypto. parvum* Oocysts	
Study details	strip of grass (next to the field) and a row of old woodland vegetation (confining with the stream), for a total width of 6 m	Grass buffer strips 6-18m	Simulated runoff, 1.52m wide drainage area to buffer are ratio 15:1 and 30:1	slope of ≤ 20% and a length of ≥3 m		3m buffer, 5 years

	Removal efficiency (per cent, unless otherwise stated)							
	Cole et al (1997)	Doyle et al (1977)	Dillaha et al (1986)	Syversen (1995)	Schmitt et al (1999	Lowrance et al (1995)	Petterjohn & Correll (1984)	Schwer & Clausen (1989)
SS			91%	61-91%	63-93%	92%	89.7%	95%
TP				45-73%	48-79%	70%	73.7%	89%
Dissolved P	93%	62	58-69%	0-88%	19-50%		58.1%	92%
Particulate P								
Nitrate/ nitrogen				54-91%		74%	60.4%	92%
Study details	4m, rainfall events	4m, rainfall events	4.6-9.1m rainfall events	5-15m rainfall events	8-15m rainfall events	19m	19m	26m, 3 to 7 years

	Removal efficiency (per cent, unless otherwise stated)							
	Young et al (1980)	Lowrance et al (1995b)	Uusi-Kamppa et al (2000)	Wong & McCuen (1982)	Lim et al (1998)	Vinten (2006)	Magette et al (1989)	Schmitt et al 1999
SS	78%			90-95%				
TP		77-79%	-64% - 14%			30-40% (5m)		
Nitrate/ nitrogen							TN -15-35%	TN – 35-51%
Pathogens	70% (10m)				100%			
Study details	21.3m	23.6 – 28.2m	27-97m	30.5-61m			Grass buffer width 4.6-9.2,, surface flow, sandy loam soil	Grass buffer width 7.5-15, surface flow, silty, clay loam soil

	Removal efficiency (per cent, unless otherwise stated)							
	Dillaha et al (1988)	Dillaha et al (1989)	Zirschky et al (1989)	Vidon & Hill (2004)	Martin et al (1999)	USEPA (2005)		
Total Nitrogen			38%					
Nitrate	-27- -15	27-57%		60-99%	80-100			
Nitrogen/nitrate						*Surface:* 33.3%,3m 50%,28m 75% 112m 90% *Subsurface* 89.6%, *Forest* 90% *Grass* 85% *Grass/forest* 80.5%		
Study details	Grass buffer width 4.6-9.1,, surface flow, silt loam soil	Grass buffer width 4.6-9.1,, surface flow, silt loam soil	91m grass buffer strip, surface water	Grass, grass forest, and forest buffer strip, 24-66m, various soil types	Grass and grass forest buffer strip, width 50-70m, subsurface	Review of 66 studies		

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BUFFER STRIP (WET)

Performance

	Removal efficiency (per cent, unless otherwise stated)					
	Evans et al (1996)					
SS	85-90% in wooded transition area					
Nitrate/ nitrogen	85% annually					
Study details	Review					

Cost effectiveness

Study	Details
Tippett and Dodd (1995)	Cost effectiveness range from 40 - 100 $US/kg P reduced on the basis of a 30-90% efficiency for P for filter strips 5-10 m wide

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CONTOUR BUND

Costs

Study	Details
Frost et al (1990)	In the order of £1400/ha, direct function of gradient [4]

References

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FILTER BERM

Costs

Study	Details
McCoy, 2005	The TCEQ reports that compost filter berms cost $1.90 to $3.00 per linear foot when used as a perimeter control and $3 to $6 per linear foot when used as a check dam ()!
Faucette et al 2009	Total cost of instillation was estimated for each sediment control device based oil product + freight from distributor + staking materials + labor to install. Total cost for sediment control devices ranged From $1.75 to $2.87 per linear 30 cm (1 ft) - straw bales, mulch filter berms, compost filter socks, and compost filter socks + polymer used as perimeter sediment control devices

Performance

	Removal efficiency (per cent, unless otherwise stated)					
	W&H Pacific 1993	Caine 2001	Faucette et al 2009			
Peak flow						
SS	90%	67%	60-89%			
TP						
Dissolved P						
Particulate P						
Nitrate/ nitrogen						
Pesticides						
Hydrophilic Pesticides						
Hydrophobic Pesticides						
Pathogens						
Study details						
	Compost filter berm	Compost filter berm	Straw bales, mulch filter berms, compost filter socks			

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CONSTRUCTED WETLANDS

Costs

Study	Details
Vymazal (2002)	Capital costs: 40% filtration material inc. transport; 30% excavation; 15% liner; 5% plants. O&M low.

Performance

	Removal efficiency (per cent, unless otherwise stated)				
	(NCCES)	EPA (1999)	Wheater et al (2006) - SEPA	Jordan et al (2003)	Vymazal (2002)
Peak flow				Detention times 0.5-19d/ Indefinite when no inflow	
SS	90 (max)	76		13	62-89
TP		46		27	21-61
Dissolved P		23-28			
Particulate P					
TN		26	0	14	21-45 (NH_4-N-N 9-74; org-N 56-60)
Dissolved N		46	0		
Particulate N					
Total pesticides					
Pathogen indicators					>95
Details of study	SEPA BMP	SEPA BMP	SEPA BMP	US, Restored wetland, primarily agricultural surroundings. Means of dat for yrs 1 and 2.	Range of mean CWs Europe (UK, Eastern Europe, Denmark, Germany) and N. America (mostly wastewater)

Table (after Jordan et al, 2003). Annual N and P removal by wetlands receiving unregulated inflows. Also shown are wetland areas expressed as a percentage of watershed area, annual mean hydraulic loading rates (inflow/area), and annual mean detention times (volume/inflow rate). Studies are listed in order of hydraulic loading rate. Ranges are shown when more than one wetland or year was studied

Reference	Area as % of Watershed	Hydraulic load	Detention time	Total N removed		Total P removed		
	%	mm d^{-1}	d	Kh ha^{-1} yr^{-1}	% of influx	Kh ha^{-1} yr^{-1}	% of influx	
Jordan et al, 2003	9	12-20	12-19	-11-45	-8.4-38	-2.8-18	-11-59	
Kovacic et al, 2000	3-6	17-30	22-38	127-678	27-52	-76-8.5	-54-90	Tile drain effluent from cropped fields
Magner et al, 1995	2	ND	ND	ND	ND	1-3	27	restored prairie pothole wetland in an agricultural watershed
Hunt et al, 1999	0.8	97	9.1	1100	37	ND	ND	
Raisin et al, 1997	0.05	250	2	230	11	28	17	
Reinelt and Horner, 1995	1-2	620-720	3.3-20	ND	MD	4.4-30	7.5-82	Groundwater
Braskerud 2000, 2002	0.03-0.4	670-1800	0.39-1.0	500-2850	3-15	170-710	20-44	Stream water carrying agricultural runoff with high particulate loads
Fleisher et al, 1994	0.02-0.3	360-4800	0.32-4.2	730-6800	2.6-9.5	ND	ND	

It should be noted that constructed wetland performance is strongly correlated with hydraulic retention times (influenced by flow rate and bed volume) and with influent pollutant concentrations. CWs are frequently used to treat contaminated wastewaters with substantially greater influent loadings than those found I lightly contaminated run-off. Consequently removal rates are lower for runoff (e.g. Jordan et al 2003; Kadlec and Knight, 1996).

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RAINWATER HARVESTING AND DIVERSION

GREEN ROOFS

Costs

Study	Details
Regent Park Plan (2004)	Total (average) cost installed ($)89761 (extensive)-120948(intensive)

Performance

Table. (after VanWoert *et al* 2005). Percentage of total rainfall retention over a 14 month period)28th August 2002-31st October 2003) from three roof platform treatments replicated three times. Treatments were: Gravel – convention roof with gravel ballast; Media – non-vegetated green roofs with media only; vegetated – vegetated green roofs.

Treatment	Light	Medium	Heavy	Overall
	% total rainfall			
Gravel	79.9	33.9	22.2	27.2
Media	99.3	82.3	38.9	50.4
Vegetated	96.2	82.9	52.4	60.6

Table(after VanWoert *et al* 2005). Percentage of total rainfall retention over a 14 month period)28th August 2002-31st October 2003) from four roof platform treatments replicated three times. Treatments were: roof slope and media depth.

Treatment		Light	Medium	Heavy	Overall
Slope	Media depth	% total rainfall			
2%	2.5cm	95.1	82.9	64.7	69.8
2%	4 cm	97.1	85.5	65.1	70.7
6.5%	4 cm	94.9	83.1	59.5	65.9
6.5%	6 cm	95.8	84.6	62.0	68.1

The authors highlighted that:
Runoff was not only delayed during heavy rainfall events but was also spread out over time – last measured runoff from platforms occurred 14h after the rain event ended.

Table(after Mentens *et al* 2006). Substrate layer depth and runoff (% total annual precipitation) characteristics of the literature data on an annual level

	Intensive green roof (n=11)	Extensive green roof (n=121)	Gravel covered roof (n=8)	Non-greened roof (n=5)
Substrate layer				
Depth (mm)				
Min	150	30	50	/
Max	350	140	50	/
Median	150	100	50	/
Average	210	100	50	/
Runoff (%)				
Min	15	19	68	62
Max	35	73	86	91
Median	25	55	75	85
Average	25	50	76	81

Table(after Mentens *et al* 2006). Estimated annual runoff reduction in Brussels (Belgium) under the assumption that 10% of the roofs have an extensive green roof with a soil depth of 10cm.

Region	Runoff reduction (%)
Capital region	2.7
City Centre	3.5
All buildings	5.4
Single building	54

Getter and Rowe (2006) summarised literature on green roofs and highlighted the following:

- Kolb (2004) reported that 45% of all rainfall can be recycled using green roofs.
- Green roofs can reduce runoff by 60% to 100%, depending on type (DeNardo et al.,2005; Liescke, 1998; Moran et al., 2004; Rowe et al., 2003; VanWoert et al., 2005a).
- Green roofs can delay runoff from 95 min (Liu, 2003) to 4 h (Moran et al., 2004), Runoff from reference roofs was nearly instantaneous.

Cost effectiveness

Study	Details			
Regent Park Plan (2004)	Life cycle cost (LCC) analysis of different types of green roof. Energy for heating was 0.27$/m^2 less than reference roof Energy for cooling was 0.35 $/m^2 less than reference roof Comparison of other costs is given below based on a roof area of 385 m^2 In this study, stormwater retention wasn't considered. Based on sots/energy savings, this study concluded that the traditional inverted roof had the lower LCC i.e. energy ascribed to green roofs are insufficient to warrant higher initial, maintenance and replacement cost. The extensive roof had lower LCC than the intensive roof.			
	Type of roof	Inverted roof (Benchmark)	Extensive Green Roof	Intensive Green Roof
	Lifespan (yrs)	22	40	40
	Annual maintenance cost ($)	390	8069 (1st 2 yrs only)	9460 (1st 2 yrs only)
	Annual energy cost ($)	2884	2370	2133
	Total (average) cost installed ($)	38952	89761	120948
	Cost/m2 ($)	113	260	351
Wong et al (2003)	LCC analysis of rooftop gardens in Singapore. The study found that LCC of extensive green roofs with or without energy costs considered, were lower than that of exosed flat roofs, despite higher initial costs. For accessible roof tops, LCC costs of intensive systems are not less than normal flat or build up roofs. Initial costs/m2: Extensive Green Roof; $89 Intensive Green Roof (shrubs); $179 Intensive Green Roof (trees); 197 Exposed flat roof; $49 Built-up roof; $132			

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PERVIOUS SURFACES

Costs

Study	Details
Schueler(1987), CWP (1998)	$2-3 per square foot
UKPRWire (2009)	Recycled plastic paving grids <£200 for 10m^2
Wood Energy Ltd. (2009)	Woodchip £40-£50 per tonne

Performance

	Removal efficiency (per cent, unless otherwise stated)					
	Castro et al (2007)	Abbott and Comino-Mateos (2003)	Scholz and Grabowiecki (2007)	Woods-Ballard et al (2007)	Schluter and Jefferies (2001)	Abbott et al (2000)
flow	91.4-99.9 (no silt on surface) 80.2-99.9 (500g silt present) 16.2-100 (791g silt present) 60.1-99.1 (665 g silt present) 23-99.9 (620g silt present) 32-98.8 (797 g silt rpesent)	Peak outflow At rainfall intensity of 12 mm/h was 0.37 mm/h. Mean of 22.5% of runoff during a stormevent. 2h storm event took 2 days to drain out of the system. Mean % run-off 67% on event basis		Good	Outflow volume 50% of rainfall	4-47 % (mean 22.5%) rainfall volume drained from sub-base during rainfall events. In some cases 2-3 days before outflow occurred following cessation of rainfall.
SS			“Good track record”	High		
TP				High		
Dissolved P						
Particulate P						
TN			“Good track record” (provided underdrain present)	High		
Dissolved N						
Particulate N						
Total pesticides						
Pathogen indicators						
Details of study	Infiltration capacity of pervious paving – effects of silt, slope and block shape	*In-situ* hydraulic performance of a permeable pavement sustainable urban drainage system			Porous concrete block surfaced car park, Edinburgh.	Porous concrete block surfaced car park, Wheatley Service area, Oxfordshire

NB – data mainly relates to flow characteristics or pollutants related to urban environment e.g. heavy metals and hydrocarbons which are less relevant to rural scenarios

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CROSS/CUT-OFF DRAINS

Limited design data and no performance data readily available

BIOBEDS

Costs

Study	Details
ADAS (2006)	Bunded loading area, with drain and trap – concrete £ 40-50 per m^2 Small pump chambers £250 each Pumps £60 each Electrical supply, time switches etc £350 per site Liner and membrane 5 x 4 m, nominal Biobed with drain £800 1.5m^3 plastic water storage tank-double skin £650-1500 Drive over grid – suited to self propelled 24 m sprayer £90 per m^2 Drip irrigation – Biobed distribution and disposal area £300 Roofing area – single span, mono pitch £20-25 per m^2
SEPA BMP	£3,500 and £7,000

Performance

Table(after Torstensson, 2000). Results of sampling in a biobed in Sweden in spring before the start of the spraying season. The biobed had been used for 6 years at the farm. Samples were taken on the most contaminated part of the bed, right under the tank of the sprayer.

Pesticide	Residues found (µg/g dw)				
	Surface 20cm	20cm clay layer	Clay la yer 0-5 cm	5-10cm	Level of detection
Diflfenican	0.7	0.08	<0.05	<0.05	0.05
Esfenvalerate	0.4	0.01	<0.01	<0.01	0.01
Fenpropimorph	0.24	0.04	<0.04	<0.04	0.04
Fluroxypyr	0.01	<0.01	<0.01	<0.01	0.01
Isoproturon	0.45	0.25	0.05	<0.01	0.01
Metazachlor	0.13	0.04	<0.04	<0.04	0.04
Metabenzthiazuron	0.22	<0.05	<0.05	<0.05	0.05
Pirimicarb	0.23	0.04	<0.02	<0.02	0.02
Propiconazole	0.25	0.05	<0.05	<0.05	0.05
Terbuthylazine	0.30	<0.04	<0.04	<0.04	0.04

Biobeds effectively reduce pesticide concentration to below the level of detection (Torstensson, 2000). Little or no data on removal efficiencies as inputs are largely irregular and unquanitified.

Cost effectiveness

Study	Details
SNH TIBRE (accessed 2009).	Significant savings, high net benefits (small capital investment, no significant running costs)

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SEDIMENTATION BOXES/SEDIMENT TRAPS

Costs

Study	Details

Performance

	Removal efficiency (per cent, unless otherwise stated)					
	Pandit and Gopatakrishnan (1996)					
flow						
SS	90% removal of sediment for sandy clay soil, 28% for fly ash. Coarse particle efficiencies remained constant in ranges of 50 to 1000 mg/L suspended solids and fine particle efficiencies increased with load concentrations					
TP						
Dissolved P						
Particulate P						
TN						
Dissolved N						
Particulate N						
Total pesticides						
Pathogen indicators						
Details of study	Physical modeling of a stormwater sediment removal box					

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SOAKAWAYS

Costs

Study	Details

Performance

	Removal efficiency (per cent, unless otherwise stated)				
	Woods-Ballard et al (2007)	Abbott and Comino-Mateos (2001)	Mikkelsen (1997)		
Peak flow	Good	Time delay to inflow <0.08h-5.25h % run-off 46-85% Water infiltrated after 143h 37-54%			
SS	Medium		Particulates likely to adsorb/be filtered out by sludge layer accumulating at base of pit		
TP	(Unspecified nutrients) Low				
Dissolved P	(Unspecified nutrients) Low		Likely to pass through - low		
Particulate P	(Unspecified nutrients) Low		Likely to adsorb/filter in sludge layer – med-high		
TN	(Unspecified nutrients) Low				
Dissolved N	(Unspecified nutrients) Low		Likely to pass through - low		
Particulate N	(Unspecified nutrients) Low		Likely to adsorb/filter in sludge layer – med-high		
Total pesticides			Soluble pesticides likely to pass through		
Pathogen indicators			Likely to adsorb/filter in sludge layer – med-high		
Details of study	CIRIA guidance	Soakaway at school, 300m2 catchment (255m2 roof; 45 m2 paving). Soakaway made from 2.4m dia. Pre-cast perforated rings; bse 3.1m below ground; inlet 1.61m above base with sediment trap.	Highway runoff into 3m deep soakaways		

Table (after Imbe *et al* 2002 cited by Pratt 2004). Performance of soakaways over 20 years in Tokyo – comparison of adjacent area with traditional piped drainage. Data are from 109 rainfall events of either >30mmm or peak intensity >20mm/h. Also shown are data from typhoon run-off (~35 hours; 220mm)

Average annual Rainfall	Catchment	Groundwater recharge		Surface run=off		Evaoptranspirat ion		Typhoon Discharge
mm		mm/year	%	mm/y ear	%	mm/year	%	%
1647	Infiltration	751	43	161	9	735	48	13
	Traditional	464	27	660	39	524	34	79

CIRIA Manual (Woods-Ballard et al., 2007) reports the following summary:

- Peak flow reduction: Good
- Volume reduction: Good
- Water Quality treatment: Good
- Ecology: Poor
- Amenity:Poor

Cost effectiveness

Study	Details
Woods-Ballard et al. (2007)	Land take: Low Capital Cost: Low Maintenance Burden: Low

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FRENCH/FILTER DRAINS – see infiltration trenches and soakaways.

French/filter drains operate on similar principles to soakaways or infiltration trenches and are often grouped. Specific data for filter drains relates primarily to heavy metals (urban relevant) e.g. Pratt (2001). Pratt (2004) reviewed literature which indicated that a sludge layer forming at the bottom of the soakaway or infiltration trench was important in retaining pollutants by filtration and sorbtion, thus particulate pollutants are more likely to be retained than soluble ones.

Maintenance requirements – dependent on source of run-off. For water directly from roofs, infiltration systems were as effective after 11 years as at day1. Where waters entered via paved areas allowing debris and silt into the system, infiltration rates fell rapidly due to blockage (Minagawa, 1990; Haneda et al, 1996 cited by Pratt, 2004).

Jefferies (2001) – 750m filter drain receiving inflow from 44 road gullies in Aberdeen - % run-off ranged from 0.8-196% (mean 42 %). Values over 100% were obtained due to snow melt events in addition.

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GRIP AND GULLY BLOCKING

Costs

Study	Details

Performance

	Removal efficiency (per cent, unless otherwise stated)				
	Holden (2005) (cited by O' Brien et al. 2007)	Armstrong et al "(005) (cited by O' Brien et al. 2007)	Holden et al (2006) (cited by O' Brien et al. 2007)		
flow	Reduced oveall discharge year following grip blocking under similar total rainfall.	Upto 90% reduced runoff in the grip, mean 70%. Significant ncrease in water table.	Partially blocked drains – flow velocity 2 orders of magnitude lower than clear drains		
SS			Blocked ditches produced similar sediment load as undrained peat and partially blocked grips produced 3 orders of magnitude less sediment than clear drains		
TP					
Dissolved P					
Particulate P					
TN					
Dissolved N					
Particulate N					
Total pesticides					
Pathogen indicators					
Details of study	Halton Lea SSSI, UK; peat moorland. Grip blocked with Heather bales	Sustainable Catchment Management Programme (SCaMP); Goyt Valley, Forest of Bowland, Peak District, UK			

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