Conférence Européenne des Directeurs des Routes

Conference of European Directors of Roads

WATCH

CEDR TRANSNATIONAL ROAD RESEARCH PROGRAMME

Call 2015

WATer management for road authorities in the face of climate CHange

D3.1

Protocol for Adapting SuDS systems for Climate Change:

March 2018

CEDR Call2015: From desk to road

WATCH

WATer management for road authorities in the face of climate CHange

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Protocol for Adapting SuDS systems for Climate Change:

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Executive Summary

In this report, specific attention is paid to SuDS systems as an answer to the challenges of climate change. SuDS philosophy is to mimic the natural hydrological cycle. Urbanisation causes land to be covered with large areas of impermeable surfaces that alter the natural drainage regime. SuDS offer an integration with nature, by promoting: the temporary storage of surface water (ponding), infiltration, the harvesting of rainwater at source, evapotranspiration, groundwater recharge and the re-use of stormwater (Roy et al. 2008). SuDS can increase morphology, provide amenity and biodiversity value, minimise the rate and quantity of discharge and protect or enhance the quality of receiving watercourses.

Nowadays, flooding and water pollution, arising from Climate Change, are key drivers of SuDS policy. Their mitigation is underpinned by legislation (both national and international), principally the Water Framework Directive (WFD). This directive indirectly encourages the retrofitting of SuDS to improve water quality. SuDS, after all, have been touted as a significant part of the solution to all drainage problems.

<u>Design of SuDS</u>

The SuDS philosophy, and effective stormwater management in general, requires a series of measures incorporating source, site and regional controls to be applied to form a stormwater management train, that will ensure that specific runoff quality and quantity aspects are addressed. O'Sullivan et al (2011) found that understanding of this concept was not widespread amongst drainage practitioners, suggesting that experience is generally limited to SuDS installations for single infrastructure developments. Often only specific SuDS features are in place, not covering all aspects of the stormwater management train.

There is no unique solution and each situation has to be evaluated on its own merits and suitable SuDS solutions applied. The means to achieve these objectives are many and varied. Factors such as site suitability, available space, cost, maintenance regimes and community acceptance must be considered to ensure successful implementation (Dublin Drainage Consultancy, 2005).

The various SuDS features can generally be categorised as 'hard' SuDS and 'soft' SuDS. Soft SuDS resemble natural features and include techniques such as swales, ponds and wetlands. Hard SuDS are more similar to traditional methods, but incorporate SuDS principles. Examples of these are attenuation crates/tanks, permeable pavements and proprietary SuDS features such as filtration systems and vortex separators (Kirby 2005).

Figure 6: typical SuDS features (from left to right: filter strip, swale, wetland)

Treatment processes and effects of climate change

The principal treatment processes in a SuDS system are described below. In the description the effects of climate change on these treatment processes is described.

- Sedimentation is one of the primary removal mechanisms in SuDS. Most pollution in stormwater runoff is attached to sediment particles and therefore the removal of sediment will achieve a significant reduction in pollution loading to receiving water bodies. Sedimentation is achieved through reduction in flow velocities to a level at which the sediment particles fall out of suspension. However, care must be taken through design and appropriate maintenance regimes to ensure the risk of re-suspension is minimised during extreme rainfall events that may occur more frequently and/or more intensely in the future due to climate change.

- Biodegradation is a natural biological treatment process that is a feature of several SuDS systems - systems that are subject to both wet and dry conditions. The most recent published literature suggests that ponds and wetlands do not seem to benefit from the enhanced biological treatment of hydrocarbons found in the oxygen-rich conditions of the swales and basins (which are not designed to hold a permanent volume of water). Nonetheless, ponds and wetlands have been utilised extensively as the default treatment system serving roads and motorways in Ireland and UK, with little supporting literature to justify such initiatives. In the selection of the most resilient and enduring suds systems, this fact is important: only the suds features that experience both wet and dry conditions benefit from this added biological treatment. Ponds and wetlands are proposed as polishing stage options as part of a treatment train (SNIFFER, 2008).

Biodegradation is understood to be temperature dependent and probably will be affected when temperatures change in the future. In addition to the physical and chemical processes of SuDS systems, biological treatment may also occur. Microbial communities may be established in the ground using the oxygen within the free-draining materials and the nutrients supplied with the inflows, to degrade pollutants such as hydrocarbons and grease. The level of bioremediation activity is affected by environmental conditions such as temperature. The temperature dependence of these aerobic microbes (responsible for this additional layer of treatment) is beyond the scope of this study, but it is generally accepted that the chemical and biological treatment mechanisms found in SuDS systems are enhanced with increasing temperature. If a change in climatic conditions brings about significantly wetter weather, the oxygen dependent microbes could be reduced. This in turn could diminish the removal of hydrocarbons before the runoff is released into the groundwater or a watercourse.

- The presence of vegetation adds a physical filtration aspect to SuDS systems. In the case of filter strips leading to swale/basins, the majority of hydrocarbons are removed by the first stage. If vegetation has been affected by drought, this element of the treatment train will be absent (in a worst-case scenario or significantly diminished at best).

Glossary

Sedimentation

Sedimentation is one of the primary removal mechanisms in SUDS. Most pollution in runoff is attached to sediment particles and therefore removal of sediment results in a significant reduction in pollutant loads. Sedimentation is achieved by reducing flow velocities to a level at which the sediment particles fall out of suspension. Care has to be taken in design to minimise the risk of re-suspension when extreme rainfall events occur.

Filtration and biofiltration

Pollutants that are conveyed in association with sediment may be filtered from percolating waters. This may occur through trapping within the soil or aggregate matrix, on plants or on geotextile layers within the construction. The location of any filtration will depend upon the internal structure of the particular SUDS technique, for example whether a geotextile layer is near the surface or at the subgrade in a previous surface.

Adsorption

Adsorption occurs when pollutants attach or bind to the surface of soil or aggregate particles. The actual process is complex but tends to be a combination of surface reactions grouped as sorption processes:

Adsorption	Pollutants bind to surface of soil / aggregate
Cation exchange	Attraction between cations and clay minerals
Chemisorption	Solute is incorporated in the structure of a soil / aggregate
Absorption	The solute diffuses into the soil / aggregate / organic matter.

Change in acidity of runoff can either increase or decrease the adsorption of pollutants by construction materials or soils. Eventually the materials onto which pollutants adsorb will become will become saturated and thus this method of treatment will stop.

Biodegradation

In addition to the physical and chemical processes, which may occur on and within a SUDS technique, biological treatment may also occur. Microbial communities may be established within the ground, using the oxygen within the free-draining materials and the nutrients supplied with the inflows, to degrade organic pollutants such as oils and grease. The level of activity of such bioremediation will be affected by the environmental conditions such as temperature and the supply of oxygen and nutrients. It also depends on the physical conditions within the ground such as the suitability of the materials for colonisation.

Volatilisation

Volatilisation comprises the transfer of a compound from solution in water to the soil atmosphere and then to the general atmosphere. The conversion to a gas or vapour occurs due to heat, reducing pressure, chemical reaction or a combination of these processes. The rate of volatilisation of a compound is controlled by a number of its properties and those of the surrounding soil. In SUDS schemes volatilisation is primarily concerned with organic compounds in petroleum products and pesticides.

Precipitation

This process is the most common mechanism for removing soluble metals. Precipitation involves chemical reactions between pollutants and the soil or aggregate that transform dissolved constituents to form a suspension of particles of insoluble precipitates. Metals are precipitated as hydroxides, sulphides, and carbonates depending on which precipitants are present and the pH level. Precipitation can remove most metals (arsenic, cadmium, chromium III, copper, iron, lead, mercury, nickel, zinc) and many anionic species (phosphates, sulphates, fluorides).

Uptake by plants

In ponds and wetlands, uptake by plants is an important removal mechanism for nutrients (phosphorous and nitrogen). Metals can also be removed in this manner (although intermittent maintenance is required to remove the plants otherwise metals will be returned to the water when the plants die). Plants also create suitable conditions for deposition of metals, for example as sulphides in the root zone.

Nitrification

Ammonia and ammonium ions can be oxidised by bacteria in the ground to form nitrate, which is a highly soluble form of nitrogen. Nitrate is readily used as a nutrient by plants.

Photolysis

The breakdown of organic pollutants by exposure to ultra-violet light.

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1 Background to the SuDS Protocol

1.1 The WATCH Project

European NRA's have recognised for a long time that climate change will have a significant effect on their assets and operations. Many challenges exist in addressing intense rainfall events and ensuring that proper design and maintenance of water management systems occurs. These challenges exist both in the field of climate science as well as in the translation of climate predictions into proper design and maintenance of water management systems.

The CEDR funded WATCH project addresses the most important high frequency causes of road flooding, caused by pluvial and run-off flooding in the area around the road, and heavy rain on the road itself (rain intensity). The project considers the drainage facilities that are designed and maintained by/for the NRA's, and ensure adequate water management of the road and also a smooth and safe use of the road infrastructure. Drainage facilities include storm water run-off systems, storm water management facilities, culverts, carrier pipes, attenuation ponds, wetlands and SuDS. Runoff from non-porous and porous pavements will also be taken into account, since the run-off is an integral part to ensure a proper water management system.

The project is developing a number of outputs of immediate benefit to NRA's, including:

- A country comparison report showing the state of practice of existing water management and drainage approaches at different NRA's.
- Guidelines to correctly interpret and apply relevant information extracted from climate projections and scenarios, to be used in road drainage and maintenance design.
- A simple tool that shows climate analogues for rainfall extremes in Europe.
- A protocol for adapting SuDS systems for climate change, with applications for roads across Europe.
- Guidelines for a Socio-Economic Analysis of adaptation and maintenance approaches for water management

These outputs are incorporated into a comprehensive manual on how to determine the resilience of drainage systems and the consequences for inspection and maintenance as well as for the design and assessment of alternatives.

1.2 Objectives of the SuDS Protocol

The objectives of this protocol are as follows:

(a) to provide guidance for assessing the resilience of Sustainable Drainage Systems (SuDS) to climate change - during periods of drought, flash flooding, temperature extremes and periods of persistent rainfall and

(b) to propose appropriate resilient SuDS strategies to manage stormwater runoff arising from severe rainfall events now and into the future.

1.3 Drainage Challenges on a Global Scale

Man’s settlement patterns through the ages demonstrate our reliance on water. As man shares the planet with millions of species, almost all dependant on water for survival e.g. for hydration, for transport, waste disposal as well as domestic uses, this resource must be managed sustainably if we are all to co-exist.

As a result of human dependence on it, our major cities, towns and consequently our roads are often located beside water, frequently in low lying areas likely to flood. Urbanisation places a strain on this most precious resource largely as a result of the inevitable increases in hard impermeable surfaces. The traditional approach to flood prevention means that we collect surface water quickly and convey it to the nearest river or stream with little consideration of the effects on flood risk and ecology, effectively treating surface water as a waste product. In the past thirty years there has been a movement towards changing this practice (Niemczynowicz, 1999).

With changing climatic conditions and more frequent flood events, we are more conscious than ever before of the consequences of urbanisation and human consumption. However, it has taken us millennia to fully understand that the solutions to our drainage infrastructure needs are to be found in nature. In the past, a tension existed between the needs of people and responsibility towards the environment. Now, there is recognition that what is good for the environment is good for mankind and the most modern and effective drainage design solutions tend to embrace this concept.

1.4 Regional Drainage Management

As water does not recognise political boundaries, the management of large scale river catchments can require intergovernmental and regional co-operation. In fact, good governance (openness, accountability and transparency) is recognised internationally as being fundamental to achieving successful stormwater management practices to combat the effects of climate change.

The challenge to protect and enhance our built environment is driven by social, ecological, economic, political, legislative, and technical factors. There is no single organisation or sector in society that can achieve this goal independently. The pressure to facilitate economic expansion and development is often in conflict with the day to day reality of the state of our environment and the integrity of our infrastructure. It is only in recent years that we have come to realise that the quality of our streams and rivers is linked to the health of our population and the quality of our social amenity. These challenges require a multi-disciplinary approach across all sectors of society including professionals such as engineers, climatologists, architects, planners, central government, local government sectors and the general public.

1.5 What is SuDS

The SUDS philosophy is to mimic the natural hydrological cycle by promoting; infiltration, evaporation, evapotranspiration, the harvesting of rainwater at source and the temporary storage of water (ponding), through the construction of a combination or series of components to form a 'management train.' Whilst there is no internationally agreed definition for SuDS – as the understanding of the SuDS philosophy correlates to the extent to which it is embedded in policy and practice over time, the three 'pillars' of sustainable stormwater management practice are generally accepted as; (i) reducing the rate and quantity of stormwater discharge, (ii) improving the quality of stormwater discharges and receiving water bodies and (iii) providing amenity and biodiversity value. Consideration of the sensitivity of the surrounding environment and downstream water quality is fundamental to the successful implementation of SUDS systems in the face of Climate Change. As several stakeholders are involved in the design, maintenance, construction and adoption of SUDS systems, the protocol will also address the organisational and governance structures within and between these entities.

2 Introduction

2.1 The traditional Approach

Traditional surface water drainage design is relatively simple, using the Rational method to size pipes to ensure that surface water is removed as quickly as possible to ensure flooding does not take place on the road itself. Unfortunately, this philosophy is flawed as, in more rapidly transferring the surface water downstream, it provides the potential for flooding of other areas. This accelerated run-off gives rise to higher flood levels and the corresponding loss of groundwater recharge results in reduced low flows in rivers thus increasing environmental vulnerability (Dublin Drainage Consultancy, 2005). In addition, the pollution in the run-off is conveyed into the natural environment.

2.2 The New Approach

Nowadays, the “natural disasters” that are flooding and water pollution, arising from Climate Change, (through more frequent extreme rainfall events and reduced dilution in rivers during periods of drought), are key drivers of Sustainable Drainage Systems (SuDS) policy. These effects are so detrimental to life in its many forms and to the integrity of our infrastructure, their mitigation is underpinned by legislation (both national and international), principally the Water Framework Directive (WFD). This directive indirectly encourages the retrofitting of SuDS to improve waterbody status (derived from freshwater macroinvertebrate communities, chemical composition and hydromorphology) and to reduce combined sewer overflow (CSO) discharges in urban areas. A large body of literature exists on SuDS and research has been carried out in many countries around the globe.

Much of the material focuses on ‘what SuDS is’ and ‘how it can be designed’. In the UK for example, detailed guidance documents have been available for many years outlining which SuDS features are suitable for various situations – climates, soil conditions, hard and trafficked surfaces, soft landscaping and sites where water features are desirable – and how to design them (for example, Woods-Ballard *et al*. 2007). This goes to show the extent to which SuDS, as an aspect of drainage design, has become mainstream. SuDS, after all, has been touted as a significant part of the solution to all our drainage problems including the challenges posed by recent legislation coming from Europe.

2.3 The New Paradigm

Sustainable Drainage Systems (SuDS) philosophy is to mimic the natural hydrological cycle (refer to figure 2-1 below). The construction of roads inevitably causes land to be covered with impermeable surfaces that alter the natural drainage regime. SuDS offer integration with nature, by promoting: the temporary storage of surface water (ponding), infiltration, the harvesting of rainwater at source, evaporation, evapotranspiration, groundwater recharge and the re-use of stormwater (Roy *et al*. 2008).

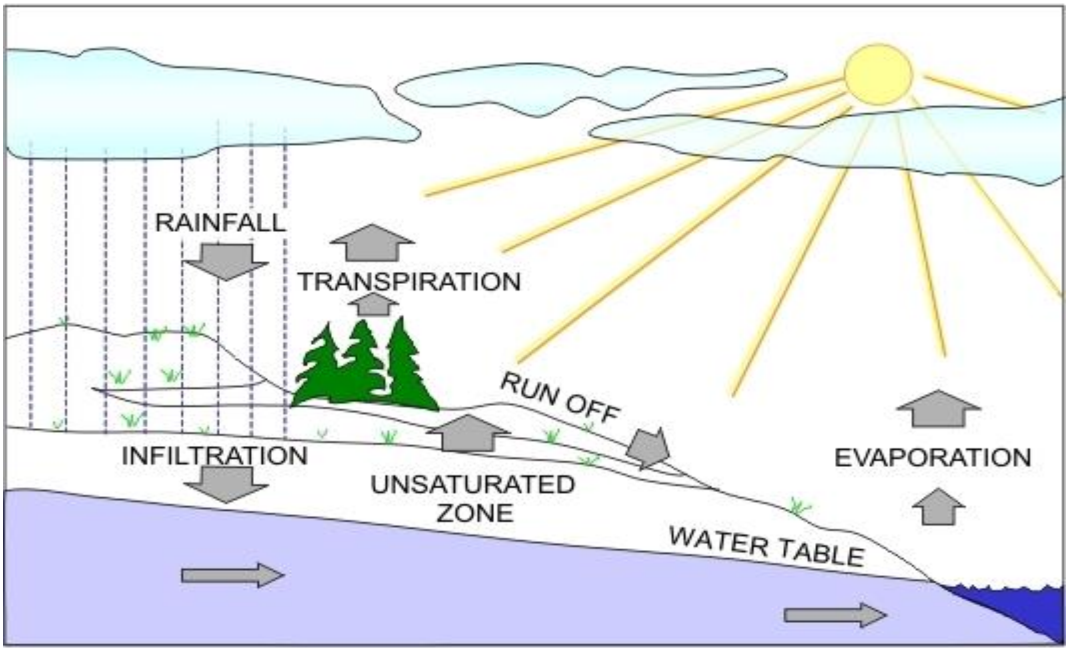


Figure 2-1 the Hydrological Cycle (Geological Survey of Ireland, 2015)

SuDS can increase morphology, provide amenity and biodiversity value, minimise the rate and quantity of discharge and protect or enhance the quality of receiving watercourses. This can be represented in part by the SuDS triangle:

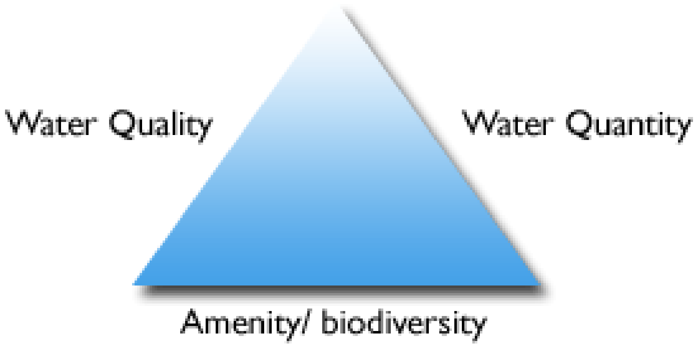


Figure 2-2 the SuDS Triangle (D'Arcy, 1998)

2.4 *Typical SuDS Features Found in Roads*

Filter Drains

A filter drain is usually a linear trench filled with permeable material. It is commonly surrounded with an engineering membrane and a perforated pipe is laid near the bottom of trench. It provides conveyance, detention, sedimentation, filtration, adsorption and biodegradation.

Filter Strips

Runoff from an impermeable area is allowed to flow across a grassed or otherwise densely planted area to promote sedimentation and filtration. Refer to the photograph below for an example of a filter strip and swale.

Swales

A swale is a shallow, wide channel with grass or other vegetation growing in the channel. It is normally unlined, but if necessary it can be lined with an impermeable membrane. It provides conveyance, detention, sedimentation, filtration, adsorption and biodegradation.

Detention Basins

During a rainfall event, runoff drains to a landscaped depression with an outlet that restricts flows, so that the basin fills and provided attenuation. Generally, basins are dry, except during and immediately following a rainfall event. If vegetated, runoff will be treated as it is conveyed and filtered across the base of the basin.

Ponds

A pond is a depression containing a permanent pool of water, with aquatic vegetation growing at the edges. It provides detention, sedimentation, filtration, adsorption and biodegradation.

Wetlands

Sometimes called a constructed wetland, it consists of an artificially constructed vegetated marshy area, which collects and treats water before discharging to a watercourse. It is similar to a pond but shallower. It provides detention, sedimentation, filtration, adsorption and biodegradation.

Practical maintenance actions for the aforementioned SuDS components are outlined below in Table 2-1.

Table 2-1 Maintenance measures for SuDS Components (CIRIA, 2015)

Maintenance Schedule	Require Action	Typical Frequency
Filter Strips		
Regular maintenance	Remove litter and debris	Monthly (or as required)
	Cut the grass to retain grass height within specified design ranges	Monthly (during growing season), or as required
	Manage other vegetation and remove nuisance plants	Monthly (at start then as required)
	Inspect filter strip surface to identify evidence of erosion, poor vegetation growth, compaction, ponding, sedimentation and contamination (soils)	Monthly (at start then half yearly)
	Check flow spreader and filter strip surface for even gradients	Monthly (at start then half yearly)
	Inspect gravel flow spreader upstream of filter strip for clogging	Monthly (at start then half yearly)
	Inspect silt accumulation rates and establish appropriate removal frequencies	Monthly (at start then half yearly)
Occasional maintenance	Reseed areas of poor vegetation growth alter plant types to better suit conditions, if required.	As required or if bare soils exposed over > 10%of the filter strip area.
Swales		
Regular maintenance	Remove litter and debris	Monthly (or as required)
	Cut the grass to retain grass height within specified design ranges	Monthly (during growing season}, or as required
	Manage other vegetation and remove nuisance plants	Monthly (at start then as required)
	Inspect inlets, outlets and overflows for blockages, and clear if required.	Monthly
	Inspect infiltration surfaces for ponding, compaction, silt accumulation, record areas where water is ponding for > 48 hours.	Monthly (at start then half yearly)
	Inspect vegetation cover	Monthly for 6 months, quarterly for 2 years, then half yearly.
	Inspect silt accumulation rates and establish appropriate removal frequencies	Monthly (at start then half yearly)
Occasional maintenance	Reseed areas of poor vegetation growth alter plant types to better suit conditions, if required.	As required or if bare soils exposed over > 10%of the filter strip area.
Dentation Basins		
Regular maintenance	Remove litter and debris	Monthly
	Cut the grass for spillways and access routes	Monthly (during growing season), or as required
	Cut grass - meadow grass in and around basin	Half yearly (spring - before nesting season and autumn)
	Manage other vegetation and remove nuisance plants	Monthly (at start then as required)

Maintenance Schedule	Require Action	Typical Frequency
Dentation Basins cont,		
Regular maintenance	Inspect inlets, outlets and overflows for blockages, and clear if required.	Monthly
	Inspect banksides, structures, pipework etc for evidence of physical damage	Monthly
	Inspect silt accumulation rates and establish appropriate removal frequencies	Monthly (at start then half yearly)
	Check any penstocks and other mechanical devices	Annually
	Tidy all dead growth before start of growing season	Annually
	Remove Sediment from inlet, outlet and forebay	Annually or as required
	Manage wetland plants in outlet pool - where provided.	Annually
Occasional maintenance	Reseed areas of poor vegetation growth	As required
	Prune and trim any trees and remove cuttings	Every 2 years or as required
Ponds and Wetlands		
Regular maintenance	Remove litter and debris	Monthly (or as required)
	Cut the grass - public areas	Monthly (during growing season), or as required
	Cut the meadow grass	Half yearly - spring - before nesting season and autumn
	Inspect marginal and bankside vegetation and remove nuisance plants (for first 3years)	Monthly (at start then as required)
	Inspect inlets, outlets, banksides, structures, pipework etc. for evidence of blockage and for physical damage	Monthly
	Inspect water body for signs of poor water quality	Monthly (May -October)
	Inspect silt accumulation rates in any forebay and in main body of the pond and establish appropriate removal frequencies: undertake contamination testing once some build-up has occurred, to inform management and deposition options	Half yearly
	Check any mechanical devices e.g. penstocks	Half yearly
	Hand cut submerged and emergent aquatic plants (at minimum of 0.1m above pond base; include max 25% of pond surface)	Annually
	Remove 25% of bank vegetation from water's edge to a minimum of 1m above water level	Annually
	Tidy all dead growth (scrub clearance) before start of growing season.	Annually
	Remove sediment from any forebay.	Every 1-5 years or as required
	Remove sediment and planting from one quadrant of the main body of the ponds without sediment forebays.	Every 5years, or as required
Occasional maintenance	Remove sediment from the main body of big ponds when pool volume is reduced by 20%	With effective pte treatment. This will only be required rarely, e.g. every 25-50 years

2.5 Benefits of SuDS

SuDS offer multiple benefits over traditional drainage practices managing discharge rates, volumes and diffuse pollution as well as providing the flexibility for adaption to future drainage needs through a modular implementation. Climate change predictions suggest that some types of extreme events will become more frequent, such as heat waves, flooding caused by extreme rainfall and drought. The SuDS approach is more robust and adaptable than the traditional approach of underground piped drainage systems. In shallow surface based systems, such as swales, water levels rise gradually and visibly. When the capacity of the SuDS feature is exceeded, the excess water can be directed to safe storage zones. This allows the general public, and road owners and operators to prepare for flood events more effectively. Conversely, flooding from underground piped drainage systems can occur suddenly and rapidly when the design capacity is exceeded. Furthermore, shallow, visible surface based systems can be designed to offer greater flexibility to adapt to Climate Change. SuDS systems can enhanced more readily and cheaply, compared to underground drainage systems. Lower River flows; caused by drought, result in reduced dilution of pollutants following rainfall events. The treatment of surface water runoff, through SuDS, helps to protect and enhance the quality of receiving watercourses.

2.6 Factors Influencing the Design of SuDS

There is no unique solution and each situation has to be evaluated on its own merits and suitable SuDS solutions applied, although the means to achieving these objectives are many and varied. Factors such as site suitability, available space, cost, maintenance regimes and community acceptance must be considered to ensure successful implementation (Dublin Drainage Consultancy, 2005). The various SuDS features can generally be categorised as ‘hard’ SuDS and ‘soft’ SuDS. Soft SuDS resemble natural features and include techniques such as swales, ponds and wetlands. Hard SuDS are more similar to traditional drainage methods, but incorporate SUDS principles. Examples of these are attenuation crates/tanks, permeable pavements and proprietary SUDS features such as filtration systems and vortex separators (Kirby 2005).

2.7 The Management Train

The individual components described in Figure 2.3 below above do not constitute SuDS, if applied in isolation. The SuDS philosophy, and effective stormwater management in general, requires a series of SuDS features, linked together, to form a stormwater management system to treat and attenuate surface water runoff as close to the source of runoff as possible, before being conveyed downstream for further treatment and storage.

Figure 2-3 Suitability of SuDS Features Within the Management Train for Roads

SuDS Component	Interception (*See note 1)*	Close Source/primary treatment	Secondary Treatment	Tertiary Treatment
Filter Strip	Y	Y		
Swale	Y	Y	Y	
Filter Drain	Y		Y	
Bioretention	Y	Y	Y	
Detention Basin	Y	Y	Y	
Pond			Y	Y
Wetland			Y	Y
Infiltration system (soakaway / trenches / blankets / basins)	Y	Y	Y	Y

Note 1 Interception components are also normally a treatment component

The SuDS manual (CIRIA, 2015), describes the six specific functions of SuDS features. These are:

Rainwater harvesting systems – not usually applicable to roads but are components design to capture rainfall close to where it falls for re-use;

Pervious surfacing systems – these are not typically used in NRA roads, but can be used in roadside verges for maintenance and access vehicles. These allow water to penetrate the surface and subsurface storage layers before infiltrating into the underlying subsoil thereby reducing the proportion of the runoff entering the drainage system;

Infiltration Systems – features that allow runoff to infiltrate into the subsoil. These often include temporary storage zones to accommodate runoff volumes from extreme events, or when the capacity of upstream SuDS components has been exceeded, before slow release into the soil;

Conveyance Systems – features that convey flows to downstream storage systems. However, subject to design considerations, these systems can often provide flow and volume control and treatment e.g. swales.

Storage Systems – features that control the flow and where possible, the volume of runoff through the temporary storage of water (attenuation). These features may also provide further treatment, egg ponds, wetlands and detention basins;

Treatment Systems – features that remove or facilitate the degradation of contaminants found in the runoff.

O'Sullivan *et al* (2011) found that understanding of this concept was not widespread amongst drainage practitioners, suggesting that experience is generally limited to SuDS installations for single infrastructure developments. This suggests that there is a fundamental lack of understanding of the philosophy underpinning SuDS. This could be due to the fact that the current institutional structures do not support such a holistic approach to stormwater management, and may also suggest a failing in the policies underpinning SuDS.

2.8 SuDS Policy in NRA's across Europe – Key findings from the Listening Process

2.8.1 Methodology

The data collection method utilised was face-to–face interviews with stakeholders (Kennedy, 2011). Given the comparative nature of the study the interviews were structured in design, leading to a reliable source of quantitative data.

Non-probabilistic sampling and expert sampling was used to identify research participants (Miles & Huberman 1994). Non-probabilistic sampling refers to the individual selection of research participants that is not random or based on a statistical probability distribution. Hence, research participants are not a representative selection of the general public. The participants are senior stormwater management experts (expert sampling) responsible for the promotion and implementation of SuDS policy in NRA's across Europe.

2.8.2 Findings

The Listening Process identified an inconsistent application and understanding of SuDS across the NRA's in Europe. Whilst the philosophy of restricting the rate of surface water discharge was well understood, perception of the appropriate rate of discharge to receiving water bodies was inconsistent and the understanding of the SuDS philosophy was less evident.

It can be concluded that evidence of effective and widespread implementation of SuDS systems within individual NRA's is only apparent where SuDS is driven by local policies/legislation, agreed at a regional level, underpinned by a strong licensing and regulatory regime for surface water discharges.

The definition of SuDS varies throughout the globe, with the understanding of SuDS correlating to the extent to which SuDS has been embedded in policy and legislation (Ellis *et al*. 2010). It is apparent that differences exist in the type and extent of elements which constitute a SuDS philosophy and understanding of the benefits of SuDS. In Ireland and the UK, it appears that their understanding of the benefits of SuDS is largely limited to providing flood mitigation and improving the quality of surface water discharge and reducing the burden on CSOs and wastewater treatment plants in combined sewer areas.

In most European countries, the US and Australia, the management train approach to SuDS is recognised as fundamental. The benefits of SuDS are recognised as facilitating economic growth, providing a source of water supply, and wider social and ecological enhancements. In fact, much of the literature in the US and Australia on the topic of the barriers to SuDS implementation has focused on the wider socio-political barriers to SuDS implementation, such as; fragmented responsibilities, lack of institutional capacity, lack of legislative mandate, lack of funding and effective market conditions and resistance to change (Roy *et al*. 2008). In Ireland and the UK, the discussion has focused on the technical aspects of SuDS implementation, such as; responsibility for adoption/maintenance, maintenance costs, land take and capital cost which suggests that the SuDS philosophy has not been accepted to the same extent. However, even within countries where SuDS policy has been in place since the 1990s, Lee & Yigitcanlar, (2010) found that there is no shared vision or definition of SuDS and it is considered to be confined to stormwater management by some and to others it is understood to represent a fully integrated water management system. Furthermore a lack of research into the institutional and social barriers is recognised with few empirical studies having been conducted in this area.

2.9 Drivers and Barriers of SuDS Policy across Europe

Regional drainage management is complex and requires flexibility yet it requires consistency. There is international recognition that for SuDS to be effectively implemented (i.e. throughout a catchment) there is a need for consistent institutional, legislative, economic and social arrangements to apply throughout the catchment (Roy *et al.* 2008).

The policy of providing controls to the rate of stormwater runoff has been established for some time. Historically, restrictions to the rate of discharge from new roads were usually achieved through the construction of underground concrete tanks fitted with flow control devices. This approach has led to concerns in relation to cost, health and safety (particularly with maintenance) and land take. SuDS is perceived to be the alternative, and overcomes these issues whilst addressing the wider environmental effects.

The US, Australia, The Netherlands, Germany and parts of the UK, among others, have been implementing SuDS for the past twenty years, supported by legislation across all levels of Government; Federal, State and local (Roy *et al*. 2008). In these countries, the benefits of SuDS have been recognised and are more visibly supported by legislative, social and political factors. Brown and Farrelly (2007) found that the main drivers of SuDS were: environmental outcomes, public health outcomes, social amenity and community perceptions with multi-disciplinary collaboration seen as fundamental to successful delivery of SuDS. Much of the published literature in recent years in relation to enhancing SuDS adoption has focused on social and institutional barriers and the role of SuDS Champions or Change Agents to overcome these barriers.

3 Challenges and Opportunities for SuDS Systems in a Changing Climate

The principal treatment processes in a SuDS system are Sedimentation and Biodegradation.

3.1 Sedimentation

Sedimentation is one of the primary removal mechanisms in SuDS. Most pollution in stormwater runoff is attached to sediment particles and therefore the removal of sediment will achieve a significant reduction in pollution loading to receiving water bodies. Sedimentation is achieved through the reduction in flow velocities to a level at which the sediment particles fall out of suspension. However, care must be taken through design and appropriate maintenance regimes to ensure the risk of re-suspension is minimised during extreme rainfall events.

3.2 Biodegradation

Biodegradation is a natural biological treatment process that is a feature of several SuDS systems - systems that are subject to both wet and dry conditions. In addition to the physical and chemical processes of SuDS systems, biological treatment may also occur. Microbial communities may be established in the ground using the oxygen within the free-draining materials and the nutrients supplied with the inflows, to degrade pollutants such as hydrocarbons and grease.

The level of bioremediation activity will be affected by environmental conditions such as temperature and the supply of oxygen and nutrients. It also depends on the physical conditions within the ground such as the suitability of the materials for colonisation.

3.3 The Opportunities for SuDS in a Changing Climate

Therefore, if a change in climatic conditions brings about significantly wetter weather, it would make sense to suppose that the oxygen dependent microbes could be reduced. This in turn could diminish the removal of hydrocarbons before the runoff is released into the groundwater or a watercourse. Biodegradation is also understood to be temperature dependent. (I'm expecting to discover that there is an optimal temperature for these biological processes and that outside of that the biological treatment of the runoff will suffer... but to date little research has been conducted in this area and it requires further investigation).

3.3.1.1 'Wet and Dry' SuDS Systems Perform Best

The presence of vegetation adds a physical filtration aspect to SuDS systems In the case of filter strips leading to swale/basins, the majority of hydrocarbons are removed by the first stage. If vegetation has been affected by drought, this element of the treatment train will be absent (in a worst-case scenario or significantly diminished at best). Maintenance of filter strips, swales and detention basins typically involve grass cutting. It is worth noting that hydrocarbons are also broken down by UV light in a process called photolysis, but where increasing levels of contaminants are building up in the soil (in the swale, basin, pond or wetland) the affected soil is likely to require removal and will more than likely be classified as contaminated waste.

The most recent published literature suggests that ponds and wetlands do not seem to benefit from the enhanced biological treatment of hydrocarbons found in the oxygen-rich conditions of the swales and basins (which are not designed to hold a permanent volume of water). Nonetheless, ponds and wetlands have been utilised extensively as the default treatment system serving roads and motorways in Ireland and UK, with little supporting literature to justify such initiatives.

In the selection of the most resilient and enduring suds systems, this fact is important: only the suds features that experience both wet and dry conditions benefit from this added biological treatment. (Ponds and wetlands are proposed as polishing stage options as part of a treatment train (SNIFFER, 2008).

The temperature dependence of these aerobic microbes (responsible for this additional layer of treatment) needs to be further investigated, but it is generally accepted that the chemical and biological treatment mechanisms found in SuDS systems are enhanced with increasing temperature.

3.3.2 The Benefits of Vegetative Systems

Germida et al (2002) contends that the successful implementation of bioremediation systems requires the establishment of appropriate plants and /or microorganisms at the containment site. Factors to be considered include: (i) selection of appropriate plant species, (ii) the influence of contaminants on seed germination, (iii) the use of native versus non-native plants and (iv) the effectiveness of inoculating contaminated soils with microorganisms. Furthermore, the plant species must be well adapted to the soil and climate of the region, making soil characteristics, length of growing season, average temperature and annual rainfall important considerations in plant-assisted bioremediation/biodegradation planning. Finally, the rate of microbial degradation generally doubles for every 10 degree centigrade increase in temperature (reference).

Indirect benefits include enhanced soil quality through improvements in soil structure, increased porosity and therefore water infiltration, providing nutrients, accelerating nutrient cycling and increasing soil organic carbon. The use of plants also stabilises the soil thus preventing erosion and direct human exposure.

Note: A database of suitable ‘candidate’ plants has been created by the US EPA for selection across a range of Climate zones in the US, and will provide a useful source for the selection of appropriate vegetative systems in Europe.

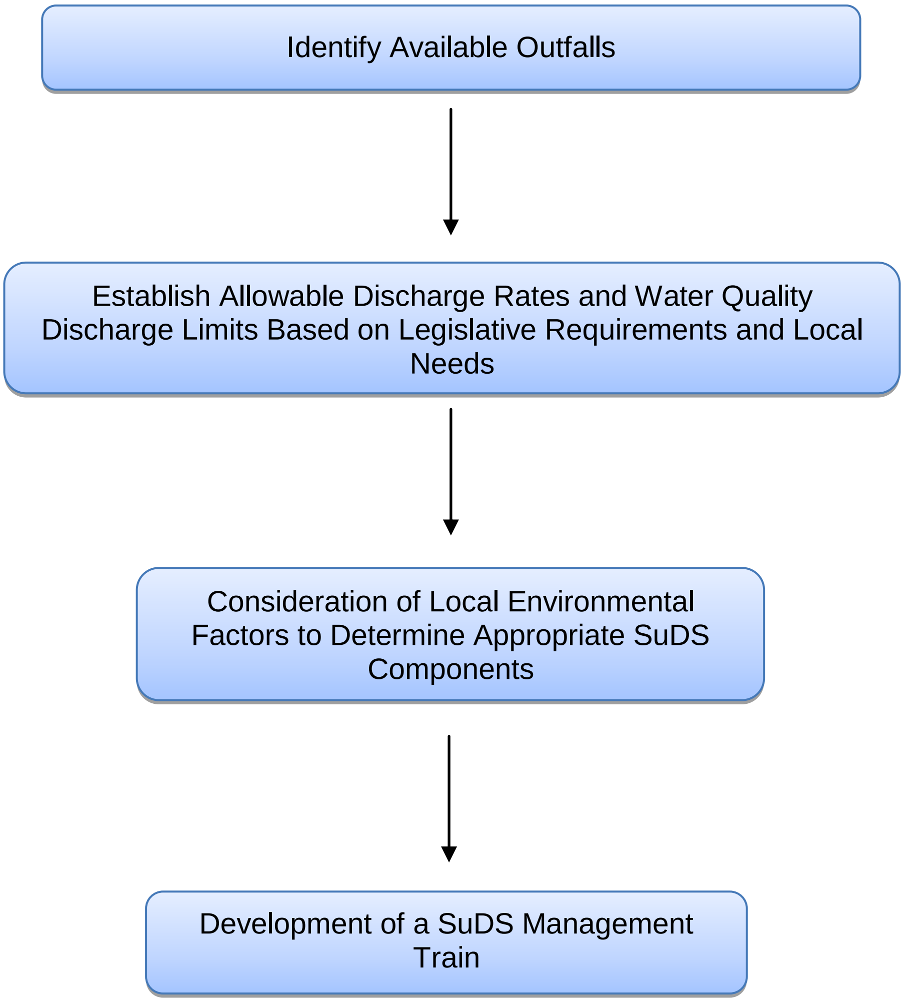
In summary, the working theory adopted to develop the SuDS protocol, substantiated by the published literature and findings from our own research is that a carefully selected treatment train of SuDS features will provide the most comprehensive treatment of Road runoff. Each appears to have strengths and weaknesses depending on the drought or flood scenario.

Table 3-1 Impact of a Changing Climate of SuDS Treatment Processes

SuDS Feature	Treatment Process	Temperature Dependence	Rainfall Dependence
Swale	Sedimentation	Increases in temperature improve the rate of deposition in waters.	Most effective in periodically wet and dry conditions
Detention Basin			
Infiltration Basin			
Filter Strip			
Sand Filter			
Pond			
Wetlands			
Swale	Biodegradation / Bioremediation	Rate of biodegradation of hydrocarbons improves with increases in temperature.	Most effective in periodically wet and dry conditions.
Detention Basin		Most effective during periods of vegetative growth.	
Infiltration Basin			
Filter Strip			
Sand Filter			
Bioretention Areas			
Swale	Filtration and Biofiltration	Plant species must be carefully selected to provide nutrient removal, with a sandy loam filter media.	Most effective in periodically wet and dry conditions.
Detention Basin			
Infiltration Basin			Periods of drought could be harmful to some plant species.
Filter Strip			
Sand Filter			Bioretention Areas must be typically sized at 2% of its catchment area, however, regions with higher rainfall intensities will require larger systems to effectively treat runoff.
Pond			
Wetlands			
Bioretention Areas			
Swale	Adsorption	Rate of adsorption generally decreases with increases in temperature	Most effective in periodically wet and dry conditions.
Detention Basin			
Infiltration Basin			
Filter Strip			
Sand Filter			
Bioretention Areas			
Swale,	Volatilisation - Primarily of concern with organic compounds in petroleum products or pesticides	Rate of volatilisation generally increases with increases in soil temperature.	Periods of drought could be harmful to some plant species
Detention Basin			
Infiltration Basin		Most effective during periods of vegetative growth.	
Sand Filter			
Filter Strip			
Pond			
Wetlands			

SuDS Feature	Treatment Process	Temperature Dependence	Rainfall Dependence
Swale Detention Basin Infiltration Basin Filter Strip Pond Wetlands	Precipitation – the most common process for the removal of heavy metals	Rate of precipitation increases in warmer waters	Most effective in periodically wet and dry conditions.
Swale Pond Wetlands	Uptake by Plants	Most effective in the growing seasons.	Required to support vegetative systems Periods of drought could be harmful to some plant species
Swale Detention Basin Infiltration Basin Filter Strip	Nitrification	Most effective in the growing seasons.	Required to support vegetative systems although most effective in periodically wet and dry conditions. Periods of drought could be harmful to some plant species
Swale Detention Basin Infiltration Basin Filter Strip	Photolysis	The breakdown of organic pollutants by exposure to ultra-violet light	

3.4 SuDS Protocol for New & Existing Roads – An Overview



3.5 SuDS Protocol for New & Existing Roads

The working assumption of this protocol is that the 'road' being considered here is a single standalone scheme, but at conceptual design stage, some thought should be given to the development of a 'Modular SuDS System', to allow for future modifications to be undertaken to respond to clanging climatic conditions, when "trigger points" are reached.

Step 1. - Identify Available Outfalls

Stream/river

Surface Water Sewer

Combined/Foul Sewer

Discharge to Groundwaters

Zero Discharge system (Reliant on Evapotranspiration Only)

Step 2. - Establish Allowable Discharge Rates and Water Quality Discharge Limits Based on Legislative Requirements and Local Needs

Considerations For New Roads

- Establish Sensitivity/Assimilative Capacity of receiving Watercourse
- Review of River Basin Management Plans to Ascertain the Relevant Pressures and Impacts
- Control of Accidental Spillage
- Is the stream/river a source of potable water

Consideration

- Establish Sensitivity/Assimilative Capacity of surface water sewer and downstream water body
- Review of River Basin Management Plans to Ascertain the Relevant Pressures and Impacts
- Control of Accidental Spillage
- Sewer Capacity

Consideration

- Establish Capacity of receiving Wastewater Treatment Plant
- Review of River Basin Management Plans to Ascertain the Relevant Pressures and Impacts
- Control of Accidental Spillage
- Sewer Capacity

Consideration

- Groundwater vulnerability
- Groundwater quality
- Review of River Basin Management Plans to Ascertain the Relevant Pressures and Impacts
- Establish Sensitivity/Assimilative Capacity of receiving groundwater
- Is groundwater a source of potable water
- Control of Accidental Spillage
- Subsoil permeability

Further Consideration for Existing Road Networks

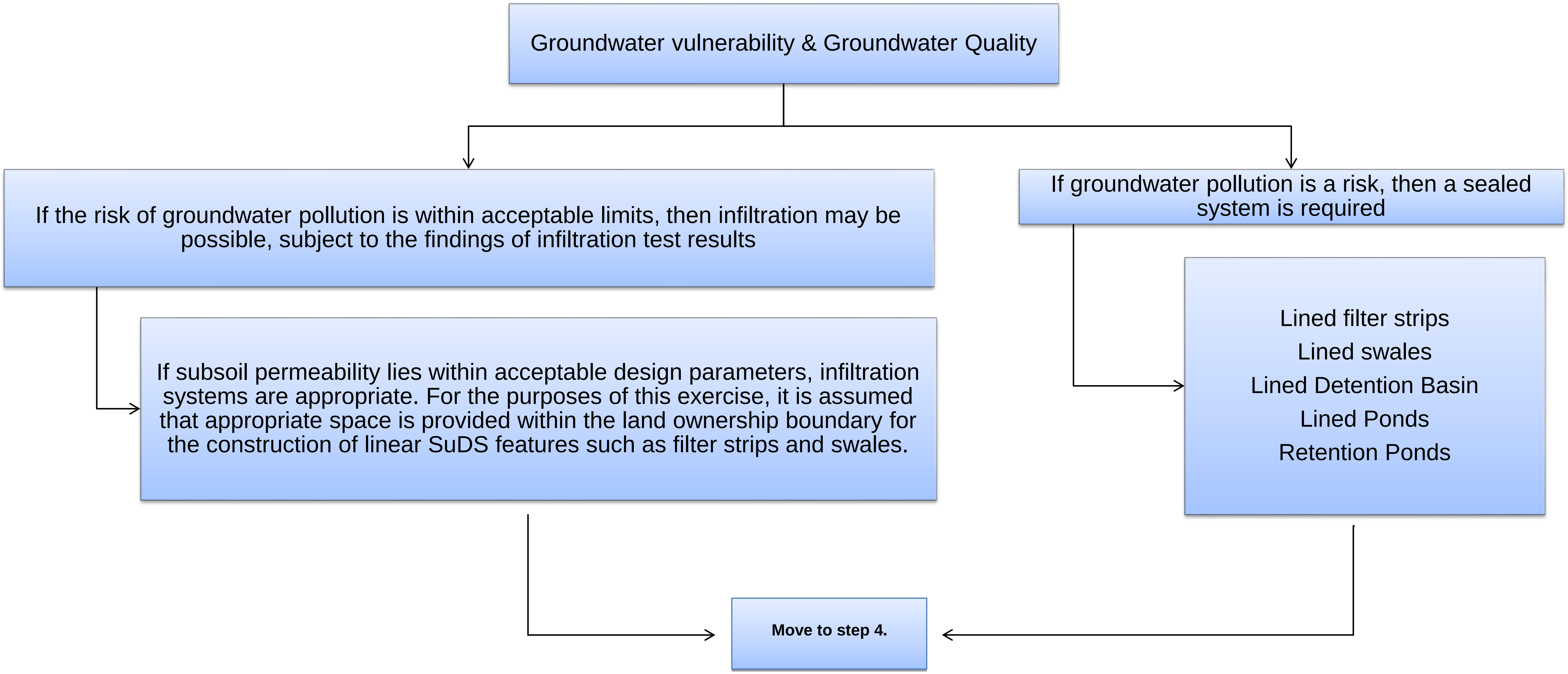
- Presence of Existing Suds Components
- Topography
- Available space
- Existing environmental pressures arising from existing roads and/or local environmental needs

Note: In existing roads, fewer 'options' may be available due to restricted availability of land, however, there is a greater opportunity for the designer to gather relevant data.

Action Prior to Discharge

Determination of Attenuation volumes and Water Treatment Parameters

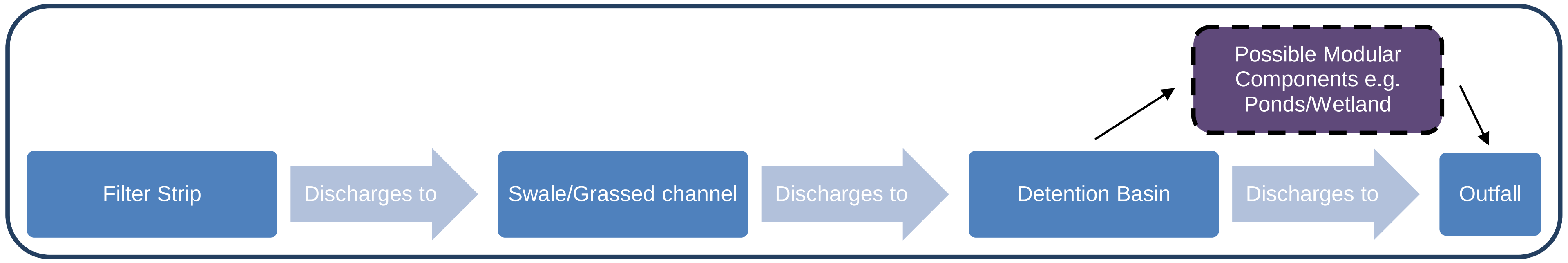
Step 3. - Consideration of Local environment – to determine appropriate SuDS Components



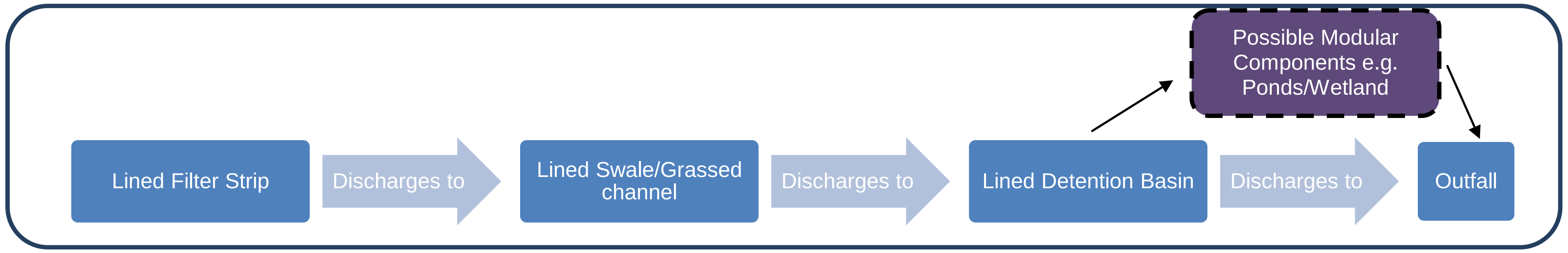
Step 4. Identify Management Train

Management Train Scenario:

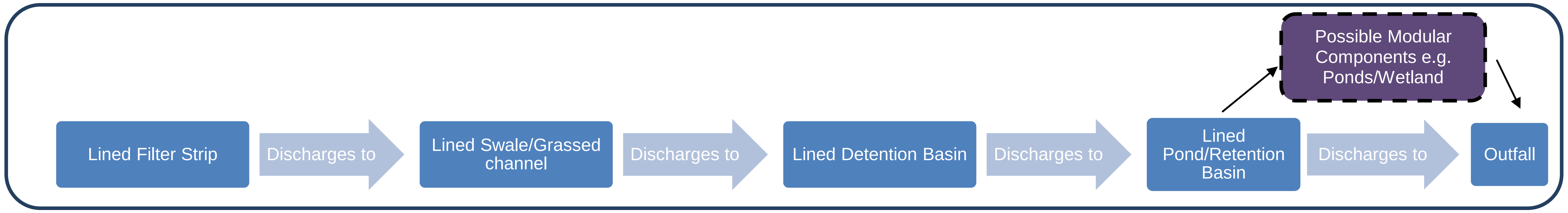
Scenario 1. 'Ideal Scenario' – Subject to Wet & Dry conditions with sufficient permeability and acceptable risk to groundwater - (additional Modular SuDS components can be incorporated to provide Tertiary Treatment):



Scenario 2. Infiltration not permitted due to risk of groundwater pollution:



Scenario 3. When infiltration is not permitted, and legislation/policy dictates that a greater standard of treatment is required than is offered by Scenario 2 above:



Scenario 4.

Subject to the findings of a monitoring regime, it may be found that more frequent maintenance of the SuDS components.

(e.g. grass cutting, disposal of contaminated soil and planting) may negate the requirement for additional SuDS components.

Modular SuDS Components

Management trains for new and existing roads should facilitate the construction of future SuDS components and/or provide for future enhancements to existing SuDS components - to mitigate the risk of flooding caused by more extreme rainfall events and the risk of pollution due to lower baseflow in receiving watercourses.

Modular components can include:

- Additional physical SuDS features e.g. swales and ponds and/or;
- enhancements to existing SuDS features by upsizing and/or;
- introducing vegetation and/or;
- Management actions e.g. changing the maintenance regime in response to findings of a monitoring regime.

4 Conclusions and Recommendations

The performance of the SuDS treatment train should be monitored over time, and NRA's should consider this as a means of confirming the performance of the SuDS system and to justify modifications to the Management Train.

Demonstration projects are a key component in garnering community acceptance. Water quality and monitoring results should be made public immediately and the local community should be consulted throughout the process.

The following key recommendations should be included for review when drafting future updates to NRA's 'Standards':

- In new roads, maintenance plans and schedules should be developed during the design phase.
- In existing roads, specific maintenance needs should be monitored and maintenance plans adjusted to suit local requirements
- SuDS systems which are periodically wet and dry should be the 'default' position.
- Space should be made available for additional SuDS components to be constructed in the future, in response to predicted climatic change and future development needs.
- Drainage designs for new and existing roads should include a maintenance regime to allow road operators to plan for and cost future maintenance requirements and upgrade works over the lifetime of the road. The 'cheapest' short-term solution may not be the most 'viable' solution, the SEA approach is fundamental here.
- Water quality discharge limits should be stipulated in the Standards as it is in other national jurisdictions such as in the United States of America and Australia. This will help to ensure that the SuDS Management Train philosophy will be fundamental to the design for roads (thus providing greater flood resilience and to help ensure compliance with the Water Framework Directive).

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