Highways England

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Sustainable Drainage Systems – Innovation Literature Review

SPaTS 1-079

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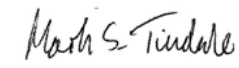
		Signature			
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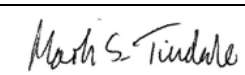
		Signature			
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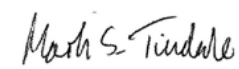
		Signature			
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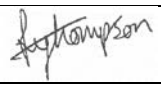
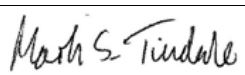
		Signature			
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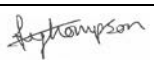
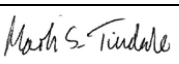
		Signature			
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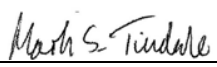
		Signature			
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List of Abbreviations

AD	Asset Delivery
ADMM	Asset Data Management Manual
AMOR	Asset Maintenance and Operational Requirements
ASC	Asset Support Contract
BBA	British Board of Agreement
BOD	Biochemical Oxygen Demand
CIRIA	Construction Industry Research and information Association
CIWEM	Chartered Institution of Water and Environmental Management
COD	Chemical Oxygen Demand
Defra	Department for Environment, Food and Rural Affairs
DiBT	Deutsches Institut für Bautechnik
DMRB	Design Manual for Roads and Bridges
EA	Environment Agency
EDF	Environmental Designated Fund
EVRI	Environment Valuation Reference Inventory
Envis	Environmental Information System
HADDMS	Highways Agency Drainage Data Management System
HEWRAT	Highways England Water Risk Assessment Tool
ICA	Instrumentation, Control and Automation
IDF	Innovation Designated Fund
KTN	Knowledge Transfer Network
LINet	Linear Infrastructure Network
NEAT	National Ecosystem Approach Toolkit
NGOs	Non-Governmental Organizations
NJDEP	New Jersey Department of Environmental Protection
SMEs	Small and Medium-sized Enterprises
SRN	Strategic Road Network
SuDS	Sustainable Drainage Systems
SW4EU	Storm Water for Europe
UKCP09	UK Climate Projections
UKCRIC	UK Collaboration for Research in Infrastructure & Cities UK Cl
UK NEA	UK National Ecosystem Assessment
UK NEAFO	UK National Ecosystem Assessment Follow-on
WFD	Water Framework Directive
WRc	Water Research council

Executive Summary

The Government's Road Investment Strategy sets out a vision and plan for developing the Strategic Road Network (SRN) targeting environmental outcomes amongst others, through improved operation, maintenance and modernisation of the SRN.

Highways England has identified 'Improved Environment' as one of its strategic outcomes. In addition the ring fenced Environment Designated Funds (EDF) has identified one priority action area, amongst another six areas, to address priority pollution and water quality issues occurring on the SRN through a greater application of Sustainable Drainage Systems (SuDS).

Arup AECOM Consortium has been appointed by Highways England to conduct a literature review to identify innovation in SuDS products and practices that could be applied to the Highways England context to improve environmental performance.

Highways England is aiming to increase the uptake of adoption and implementation of SuDS designs. It is hoped an increased application of SuDS features within highway schemes will increase environmental water quality performance indicators within receiving water bodies.

The purpose of this study is to identify and review innovation in SuDS within the context of Highways England's SRN. Following extensive global stakeholder engagement, which has encompassed suppliers, industry professionals, and academics, extensive existing products and techniques have been evaluated. A number of these products and ideas have been proposed to be taken forward for submission to the Innovation Designated Fund (IDF).

Products have been evaluated based on criteria identified; environmental performance, installation and decommissioning, maintenance, land use, cost and safety. Site specific considerations are also noted alongside existing use on the SRN, independent review, and previous consideration by British Water, at a highways focused stakeholder event, where many of the products herein had already been rated (green or amber).

This assessment has identified a number of products and techniques that could be trialled on the SRN:

- **Ponds** – Recommended reconfiguration of pond outlets and berms. Solutions such as a Nautilus PondTM configuration could be retrofitted into existing ponds and should be considered as part of new schemes.
- **Wetlands** – These systems should be prioritised as much as is reasonably practicable as they are the most effective treatment system for dealing with pollutants.
- **Floating Islands/Riverbanks** – Retrofit of products such as Biomatrix Water, Salix and Frog Environmental (BioHaven®) is recommended to improve pollutant concentration reductions in TSS, TN and TP.
- **Filters and hydraulic solid separators** – Trial and utilisation of the products detailed in this report.
- **Bioremediation** – It is recommended that this be followed up with research institutes to understand the potential for use of bacteria and fungi in bioremediation of stormwater runoff.
- **Nanotechnology** – It is recommended that consideration be given to the retrofit of products such as 'LilyPads' for pollutant removal.

- **Phytoremediation** – Further investigation into potential alternatives to typical plants is recommended, this could include plants such as water hyacinth that have been shown to be a model plant for treatment of nutrient polluted stormwater runoff.
- **Source control** – There is potential for the quality of run off to be improved through the use of different de-icing methods. It is recommended that the use of beet juice (Bee 55) and Beet Heet, or other similar products, be investigated further.
- **Oil and SuDS** – Preference for exposed soil systems and reduction of moisture content has been shown to improve water quality treatment.
- **Programmable pipes** – Advances are being made with respect to developing water pipes made of programmable materials that can reshape themselves or self-assemble over time. The water pipe are designed to act like peristaltic structures capable of pushing water through the pipe work on their own. There is an opportunity for Highways England to engage with Self Assembly lab, and utilise Innovation Designated Funding to support the development of a product specific to the SRN.

Other than the products and techniques noted above the research undertaken for this literature review has identified a number of opportunities and constraints to the increased utilisation of SuDS across Highways England. These considerations and system wide initiatives are summarised below and categorised as to whether they are likely to increase the knowledge, attitude, or practice of Highways England with respect to the implementation of SuDS.

- **Knowledge:**
    - Review data requirements of the Asset Data Management Manual (ADMM);
    - Improve the quality of consolidated data on SuDS (asset management);
    - Develop a knowledge sharing platform for the UK highways industry;
    - Coordinate a forum for discussion to foster collaborative ways of working, and new ideas;
    - Improve knowledge of the existing SuDS used on the SRN and their performance;
    - Improve knowledge of valuing nature. Potential for value analysis of benefits, including biodiversity; and
    - Investigate how changing future scenarios could impact pollution of road runoff.
- **Attitude and Practice:**
    - Change perception about the cost of SuDS relative to traditional drainage systems;
    - Clarify the cost of SuDS in comparison to typical SRN drainage operations;
    - Understand the internal and external awareness/perception of SuDS and existing barriers to implementation;
    - Promote the importance of drainage/SuDS within Highways England;

- Assessing the feasibility and appropriateness of a Highways England drainage test facility or options to collaborate with existing organisations who are already looking to do this;
- Understand institutional inertia and the mechanisms that generate and regenerate institutional inertia within Highways England to understand how best to effect change;
- Investigate the potential for catchment based approaches; and
- Reconsider the language used to describe SuDS in order to remove any barriers inherent in the perception that SuDS are 'green infrastructure' only.

1 Introduction

1.1 Project Rationale

The Government's Road Investment Strategy sets out a vision and plan for developing the SRN targeting environmental outcomes amongst others, through improved operation, maintenance and modernisation of the SRN.

Highways England has identified 'Improved Environment' as one of its strategic outcomes. In addition the ring fenced EDF has identified one priority action area, amongst another six areas, to address priority pollution and water quality issues occurring on the SRN through a greater application of SuDS.

The Arup AECOM Consortium was appointed by Highways England to conduct a literature review to identify innovation in SuDS products and practices that could be applied to the Highways England context to improve environmental performance.

Highways England is aiming to increase the uptake of adoption and implementation of SuDS designs with the objective of improving water quality performance indicators. An integrated approach to surface water management will also minimise the impact of a new drainage system on the wider catchment, retaining the balance of groundwater, surface water flow, and stream morphology and flooding.

1.2 Scope of Current Commission

The scope of this commission is as follows:

- Review existing SuDS technologies. This includes an extensive national search of proprietary products involving engagement with manufacturers, relevant suppliers, CIRIA etc.
- Review the Design Manual for Roads and Bridges (DMRB) Volume 4.2 and 11.3 and AMOR and ASC to understand how proprietary products and innovative technologies would interact with existing guidance.
- Develop a register of drainage products to document research being undertaken.
- Understand key restrictions and opportunities for SuDS within Highways England schemes.
- Determine criteria to evaluate SuDS technologies.
- Evaluate identified SuDS against a common criteria and identify innovative approaches.
- Identify potential candidate projects for submissions to the Innovations Designated Funds.

The overall objective is to provide well-founded advice on the potential SuDS products currently utilised, those in development and those with potential for trial implementation.

2 SuDS and Highways England

The purpose of this study is to identify and review innovation in SuDS within the context of the Highways England SRN. In order to provide context to the study the following section sets out the principles of SuDS and the current approaches to drainage within the SRN.

2.1 Principles of Sustainable Drainage

The SuDS philosophy is a hierarchical approach to drainage design seeking to ensure that the most sustainable range of drainage techniques are used within the context and constraints of a particular location.

SuDS focus on three key areas (Figure 1);

- Controlling the quantity of surface water that is discharged to watercourses.
- Improving surface water quality of the discharge.
- Providing added amenity and biodiversity benefits.

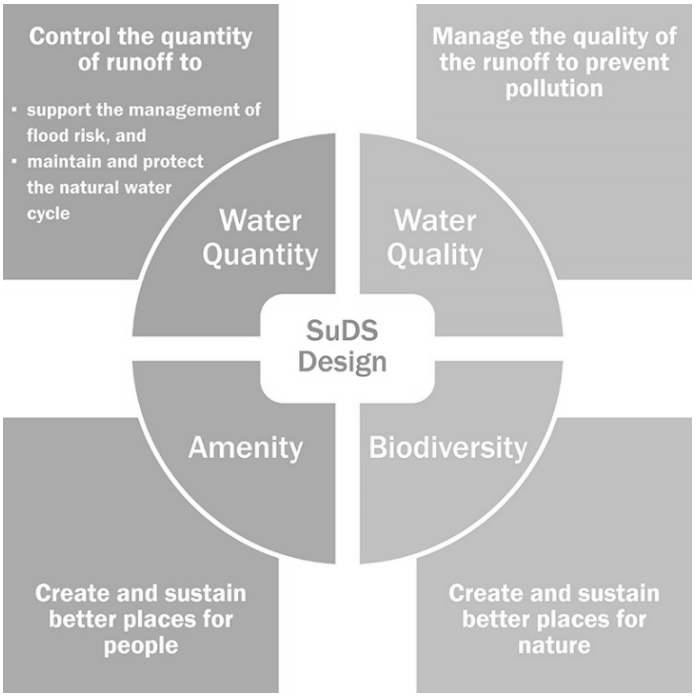
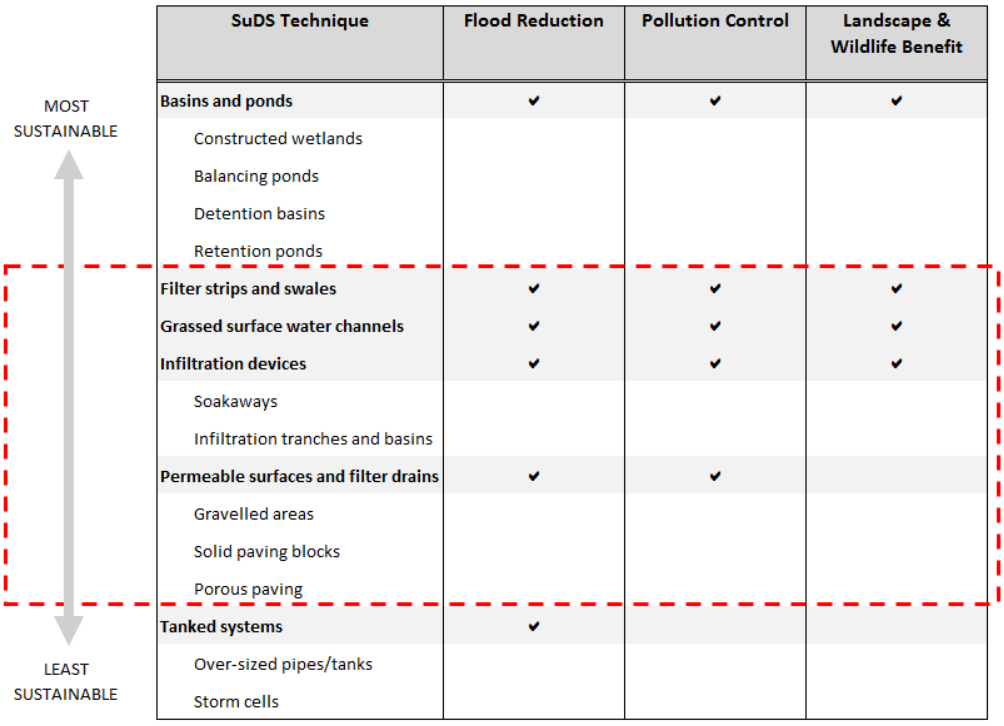


Figure 1: The SuDS philosophy[1].

This leads to a generic hierarchy of interventions as illustrated in Figure 2, with the least sustainable solutions being traditional pipes and tanks or with the most sustainable being vegetated systems and wetlands. Highways drainage has traditionally focussed on solutions at the lower end of the hierarchy (e.g. pipes and storage) although a greater emphasis has been placed over the last 15 years on the use of solutions that are more sustainable and within the top part of the hierarchy.

[1] http://www.hrwallingford.com/projects/the-suds-manual



SuDS Technique	Flood Reduction	Pollution Control	Landscape & Wildlife Benefit
Basins and ponds	✔	✔	✔
Constructed wetlands			
Balancing ponds			
Detention basins			
Retention ponds			
Filter strips and swales	✔	✔	✔
Grassed surface water channels	✔	✔	✔
Infiltration devices	✔	✔	✔
Soakaways			
Infiltration tranches and basins			
Permeable surfaces and filter drains	✔	✔	
Gravelled areas			
Solid paving blocks			
Porous paving			
Tanked systems	✔		
Over-sized pipes/tanks			
Storm cells			

Figure 2: The SuDS hierarchy.

2.2 Principles of Highways Drainage Design

The underlying aims of highways drainage design are summarised in HD33 as follows:

*"The primary aims of the highway drainage systems are to provide **rapid removal of surface water** from the road services to provide effective sub-surface drainage, it is important that drainage systems do not **increase flood risk to downstream receptors**, and **do not cause pollution** to receiving water courses and environments."*

This is illustrated in Figure 3 which emphasises the approach to highways drainage and the need to achieve an integrated design that balances the criteria of:

- Managing carriageway run-off
- Managing flood risk
- Managing pollutant risk

Current practice in treating road runoff on the existing SRN largely consists of conveying road runoff to a single point at the end of each highway catchment and discharging to a river, stream or ground. The primary collection system, typically gullies and filter drains, are designed to intercept and remove rainfall from short duration, high intensity events. Historically these discharge into secondary conveyance systems of ditches, however in the last 15 years, flow attenuation using more sustainable systems has become more prominent, with these being more frequently incorporated to reduce peak runoff rates, and reduce forward transmission of pollutants (DEFRA 2015). Some more sustainable systems such as

ponds have been used for longer than 15 years, however many of these were installed at the initial construction of the roads; i.e. over 40 years ago or more.

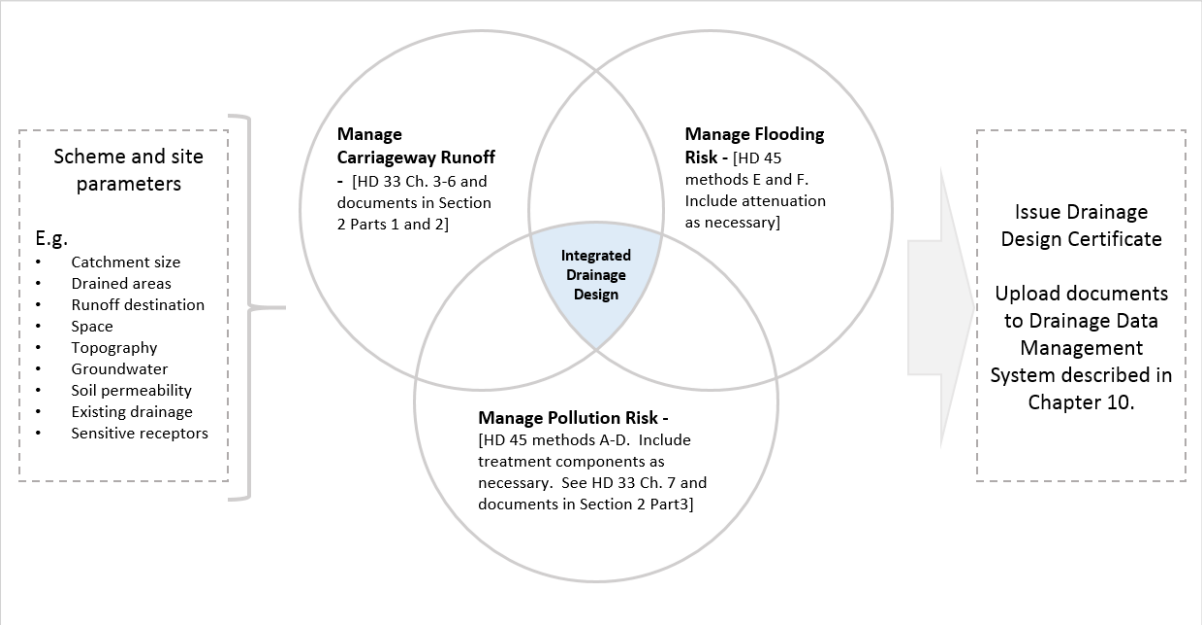


Figure 3 : Summary of Integrated Drainage Design adapted from DMRB HD 33/16 Figure 2.1.

In line with moves to incorporate sustainable drainage philosophies the DMRB acknowledges the need for integrated drainage design, and promotes methods of managing carriageway runoff and flood risk using natural vegetated systems within DMRB HD33/16, HA103/06 and HD 45/09. Key elements of the standards and guidance include:

- DMRB HD 45/09 Chapter 5; this requires assessment of impacts of runoff on surface water and groundwater, impacts of pollution incidents and flood impacts.
- The Highways England Water Risk Assessment Tool (HEWRAT) provides a tiered approach to assessment. It allows a prediction of pollutant concentrations with some simple input parameters such as traffic counts, rainfall and climatic conditions.
- DMRB HA 103/06 advocates that the designer consider all relevant factors before deciding on a suitable drainage design.

Little guidance is provided, however, about the significance of retrofitting natural SuDS elements within existing highways or how proprietary products can be used to enhance pollutant removal.

2.3 Application of SuDS for Highway Drainage

The key tenets of a sustainable surface water management strategy for highways are summarised below:

- Minimise highway runoff through infiltration techniques wherever feasible (manage surface water at source as far as practicable).
- Attempt to reduce the total volume of carriageway runoff discharged while controlling the peak flows and manage residual flood risk.

- Maximise surface water runoff quality improvements during conveyance through natural bioremediation and proprietary techniques. Improving the quality of discharge from the highway network.

The application of vegetated SuDS or proprietary filtration devices within a highway drainage system will therefore seek to attenuate flow and minimise the forward transmission of pollutants during conveyance. Barriers such as space constraints or excessive maintenance requirements will limit the application of retrofitting many natural SuDS features within the SRN. In this instance, emerging proprietary products that attempt to provide sedimentation and pollution reduction benefits may help to achieve some of the key tenants of SuDS approaches within a smaller footprint.

As part of the government's Road Investment Strategy, Highways England is being assessed against a number of metrics to show an increased performance of the SRN. Of these, the mitigation of flooding hotspots and culverts, and outfalls and soakaways, have been highlighted as a performance indicator for the current road period, therefore it is important to assess the impact sustainable drainage techniques can have to provide insight into how they can inform improvements in relation to the KPIs on the SRN. The KPI Performance Indicators for Road Period 1 and Road Period 2 are documented in Appendix A.

Road runoff pollutants can be broken down into six types of contaminants (CIRIA, 1994), and the potential effects of these on receiving watercourses are shown in Table 1.

Table 1: Road runoff contaminants and their potential impacts on receiving watercourses.

Contaminant	Impact on Environment
Suspended Solids	Increased turbidity and therefore reduced light. Settlement, erosion and the effects on the hydraulic characteristics of receiving watercourses. Increased Biochemical Oxygen Demand (BOD) from organic materials.
Nutrients	Excessive plant growth Increased BOD
Hydrocarbons	Increased Chemical Oxygen Demand (COD)
Metals	Impact on the physiology of plants, chronic and acute effects on animals.
Microbes	Potential impacts on human/animal health through pathogens or indirect contamination of food.
Other	Toxic effects on water ecology

Each type of pollutant has its own removal mechanisms, therefore it should be understood that the effectiveness of a particular drainage option will vary for different types of pollutant.

Moy et al (2003) investigated the impact of pollution from highway runoff. The study identified determinands present during monitoring of six sites, and identified determinands that were 'Not Detected' (not present above the limit of detection) during a number of monitored rainfall events at one or more sites. These determinands were noted as being not significant in non-urban highway runoff. A number of determinands were detected at concentrations well above the limit of detection for all monitored rainfall events at all sites. Some determinands were detected at concentrations greater than the prescribed maximum and annual average concentrations identified for Drinking Water and Freshwater Environmental Quality Standards. These determinands were identified as being 'key determinands' and are considered to be potentially significant pollutants in non-urban highway runoff. The not significant and key determinands identified by this study are noted in Table 2.

Table 2: Not significant and key determinands.

Determinands	
Not significant	**Key**
Platinum	Copper (Total and Dissolved)
Palladium	Zinc
Simazine	Lead
Amitrole	Glyphosate
Diuron	Benzo(b)fluoranthene
Bromacil	Benzo(k)fluoranthene
Atrazine	Benzo(a)pyrene
Acenaphthylene	Indeno(123-cd)pyrene
Acenaphthene	Benzo(ghi)perylene
Fluorene	Na
Phenanthrene	BOD
Anthracene	TSS
Dibenzo(ah)anthracene	

Literature reviews have previously been commissioned by Highways England on the efficacy of treatment systems. These are Thorburn Colquhoun (2000), Atkins (2003), URS (2004) and Escarameia et al (2006). These reviews remain excellent sources of information. HA 103/06 (Vegetated Drainage Systems for Highway Runoff) incorporates much of the advice contained within these literature reviews and is also an excellent source of information.

The most recent review for Highways England, undertaken in 2011, and updated in 2016, by Ramboll carried out a literature review of treatment system efficiencies for Highways England, looking at the effectiveness of various drainage solutions at removing pollutants from highway effluent. They were commissioned to conduct a review of SuDS with the objective of determining their treatment efficiency regarding removal and retention of pollutants.

Revitt et al (2003) also review available literature and report many treatment efficiency values for various systems.

3 Our Approach

3.1 Innovation in SuDS

Innovation in SuDS can be defined as new products or applications that will enable the achievement of the desired integrated drainage design outcomes across a wide range of Highways England contexts with increased betterment. Some of the products and techniques that have been identified are incremental improvements to systems that are currently commonly available. Others are products that are not commonly utilised or are emerging technologies.

3.2 Data Sources

As part of this study an extensive review of SuDS products has been undertaken, some of the sources utilised are listed below:

- Internet search for suppliers and technologies. This informed the basis of the product spreadsheet that accompanies this review, and informed the choice of suppliers for tailored discussions or invitation to the initial proposed workshop.
- Academic search through libraries and research services.
- Initial organisation of a workshop to engage UK suppliers, key stakeholders, other linear infrastructure providers and academics.

  A workshop was planned to inform this assessment. However, following a similar British Water event and initial stakeholder engagement it was decided that other means of gathering information would be better placed at this time. The case studies that were issued to suppliers to facilitate discussion are attached in Appendix B.
- One to one discussions with specific industry/research experts, including CIRIA, Environment Agency (EA) and Water and Wastewater Knowledge Transfer Network (KTN). Following on from the decision not to continue with a workshop event these more focused discussions were held.
- Reaching out to international colleagues, organisations and key stakeholders to understand global perspectives, and approaches.

Key findings from these sources are described in the subsequent chapters. A full list of organisations that have been engaged with through this study is provided in Appendix C.

In parallel with this commission British Water has developed a *Guide to Sustainable Drainage Products and Services* (March, 2017). The Guide has been prepared by the British Water Sustainable Water Management Focus Group, whose participants are drawn from the designers, manufacturers, practitioners and regulators of contemporary drainage solutions. Highways England forms part of this focus group and this guide should be utilised to aid in the selection of SuDS. British Water have published a number of documents that are of interest in relation to SuDS which can be found within their document library[2]. Of particular interest is the code of practise regards *Assessment of Manufactured Treatment Devices Designed to Treat Surface Water Runoff.*

[2] http://www.britishwater.co.uk/Media/Default.aspx?CategoryId=25&page_num=2

4 Evaluation Approach

Current and emerging SuDS systems take on a variety of different forms, and are often focused towards different uses, therefore it is difficult to find common metrics to make a direct comparison between systems and different categories of systems. Nevertheless, the aim of this evaluation approach is to investigate SuDS solutions that have particular suitability to the SRN and Highways England context. Consequently, a range of assessment criteria have been discussed and their consideration noted herein. Safety is a consideration that is embedded within all of the criteria.

4.1 Environmental Performance

SuDS mimic natural drainage processes to reduce the negative effect on the quality and quantity of runoff and provide amenity and biodiversity benefits. The focus presently for Highways England is on the quality and quantity benefits they can provide, with amenity and biodiversity having to be considered in the context of safety and maintenance. As priority is given to passing water off the SRN as quickly as possible this potentially conflicts with the approach required when looking to implement SuDS. Because in trying to pass water out of the drainage system (to ground, outfall / receptor) as soon as possible, this is a negative driver and a potential constraint to the specification and use of SuDS.

Also, as a large constraint on the SRN is the availability of space, specifically in retrofit situations, the ability to provide amenity and biodiversity benefit is sometimes limited. Consideration should also be given to the definition of amenity benefit in a highways context, and this will vary to that of developments and other urban schemes.

Quality is based on the ability of a system to remove pollutants, and in assessing products, the ability of a system to remove certain pollutant loads has been evaluated. Products rated highly achieve a high level of pollutant load removal.

Quantity is based on volume and discharge rate attenuated but the performance of a SuDS system is based on the volume attenuated compared to the space it requires. A product that has been rated highly in the assessment will have a high volume attenuated compared to the space it requires. In the event of extreme rainfall and inflows, exceedance flows must be managed in a sustainable way that will not pose a residual flood risk to the local or downstream environment.

The assessment of the performance of products, both from a quality and quantity perspective is based largely on manufacturer’s data.

Also whilst all products in this review fit within the SuDS design approach, there is still an inherent carbon footprint associated with the product and the activities required to install or maintain it. Some may be constructed using recycled materials and others may be 100% recyclable after their design life. This is not considered explicitly at this time in the product assessment, but is noted for consideration.

4.1.1 Ecology

By providing alterations to the drainage system or discharge regime, ecology may be adversely affected. Generally SuDS seek to maintain the natural catchment characteristics by attenuating runoff to existing rates. Provision could be required for controlled drawdown of a

SuDS basin water for extraordinary maintenance, such as sediment removal or liner repair. Consultation with an ecologist is essential prior to rapid drawdown in areas of very sensitive ecology, and any maintenance of vegetated SuDS should be carried out in consultation with an ecologist.

4.2 Installation and Decommissioning

The ease of installation is of particular importance when looking to retrofit SuDS products to existing highways. It is also understood that the majority of work carried out for Highways England is on the existing SRN, thus the adoption of SuDS for Highways England should also look to investigate options for retrofitting. Factors that can contribute to this include the size and weight of the product and therefore ease of transport and need for heavy machinery; any need for excavation would also be to the detriment of the practicality of installation. Also the complexity of installation is a factor in the safety of a product and has been considered throughout the product assessment. The familiarity of installing a traditional drain can also be a safer option than installing a more complex, less recognised SuDS product.

The assessment of different products and systems has been based on the ease of access and complexity for installation and decommissioning. The less complex the installation of a system the more favourable this is likely to be, and if there is a lack of existing implementation, experience and downstream analysis of a product this may impact the uptake of it as it poses more of a risk to Highways England.

It is noted that the context and location are major factors in the installation and decommissioning of a system, however as specific sites are not being evaluated for product placement this is not considered at this time.

4.3 Maintenance

Maintenance is a primary concern of Highways England when looking to use SuDS on the SRN. Any drainage proposed and maintenance required is likely to put life at risk with operatives working adjacent to high speed roads, therefore, minimal maintenance is preferable.

The complexity, speed and frequency of maintenance are the biggest factors when assessing the maintenance approach. Complexity refers to the skill required to complete maintenance of a system and can range from grass cutting to replacing filters and periodic desilting of ponds or tanks. All drainage schemes have a maintenance regime associated with them, however, these regimes do not necessarily adhere to the required standard. A lack of maintenance of a SuDS system will in many cases be visually intrusive and may reduce its hydraulic and pollutant removal performance but the associated risk from an exceedance event is much less than the risk associated with failure of a traditional drainage system with overland flows, such as blocked or collapsed pipes for example. SuDS schemes generally increase the overall resilience of the drainage system.

Both SuDS systems and more traditional drainage systems require periodic maintenance, however, the respective operation and maintenance regimes would be somewhat different. There is a perception within the drainage sector that maintenance of SuDS is more onerous than maintenance required for more traditional drainage systems. The maintenance requirements for SuDS systems may be considered more labour intensive but more traditional drainage systems often require more complex maintenance. SuDS also have the advantage

that within open systems problems can be seen more easily than in underground pipe systems and these tend to be easier to survey, inspect, access and clean. Access is typically easier due to the SuDS systems being located offline from the main carriageway, this in turn brings safety benefits.

An assessment across the whole life regards maintenance would need to be considered for both types of systems as a natural system may provide all the benefits of a proprietary option without the need for multiple filter replacements and over a lifetime may prove more cost effective with a greater ecological benefit. But this needs to be considered in comparison to traditional systems which require more frequent but cheaper interventions.

A change in consideration of operation and maintenance is required for SuDS systems, and how these are fed back into maintenance regimes for future scheme. There is potential to look at how SuDS products and technologies impact spend profiles and the cost of maintenance.

Maintenance for proprietary products is likely to be based on the individual manufacturer's advice, such as the anticipated design life of filter media. Sediment separation devices, for example, will require regular inspection to assess accumulation of solids after major storm events and consideration must be given to the disposal of sediment and plant waste in both vegetated systems and more traditional drainage systems as this will retain contaminants from the highway runoff.

A product that received a high score in the assessment will perform well in terms of maintenance; it will require minimal non-complex maintenance, in comparison to other products and traditional drainage systems. Products requiring the lowest frequency of maintenance received a higher ranking as this reduces the recurrence of people accessing the road side and therefore, improves the safety level of the product.

4.4 Land Use

The amount of land taken up for drainage is of primary importance on the SRN, especially on retrofit projects as space, both physical space and an allowance for maintenance, is one of the biggest constraints on the road network.

It is becoming increasingly clear that new schemes often have less space for vegetated systems due to increased climate change allowances (which result in increased volumes of water required to be stored) and so proprietary systems are more likely to be used. In particular proprietary treatment products are commonly utilised in retrofit schemes where space or ground conditions prevent vegetated systems from being considered.

The products reviewed in this document have been assessed against the benefit provided by a typical vegetated SuDS system. A product received a good score if it was able to provide the same benefit as a vegetated system using less space. The indicative metric for this assessment was benefit versus land take.

4.5 Cost

A number of tools and reports exist to cost SuDS systems, and inform on the comparison of SuDs to traditional drainage solutions. Work has previously been undertaken internally by Arup to understand this which noted that derivation of simple high level costs early in a project is challenging. Arup's assessment resulted in four reports and tools being signposted and chosen to represent a relatively recent cross-section with a UK focus. The report 'Final

Surface Water Drainage Report' (WSP for Defra, 2013) provides a cost comparison of SuDS and typical drainage solutions. This notes a number of key outcomes:

- SuDS construction costs are generally lower.
- Generally the larger the site the bigger the differential in favour of SuDS.
- Maintenance costs can be higher but may be covered by existing maintenance activities such as grass cutting and litter picking.
- The layout and design approach of SuDS is a key factor in managing cost particularly with respect to land take.

For the purpose of this assessment, the cost metric is based on relative capital cost, but an opportunity for further work exists for Highways England to evaluate the whole life costs of comparable systems and how SuDS products and technologies impact spend profiles and the cost of maintenance.

4.6 Other

Other elements that have been considered in the product assessment include:

- Whether a product has been considered previously for use on the SRN, or if trials have also been considered.
- Whether there has been an independent review of product information, and testing.
- Product evaluation at previous British Water event. If a product was showcased at this event the rating (amber or green) has been noted, with any additional comments.

4.7 Site Specific Factors

The applicability of SuDS is highly dependent on the local context. Factors with significant effect on the ability to install or retrofit a system include:

- **Hydraulics** – surface mounted SuDS systems require more consideration in the design process as they are less flexible to gradient changes when compared to traditional drainage schemes. As a result, SuDS systems often result in an increased number of outfalls.
- **Ground conditions** – there may be a number of impediments from a lack of infiltration potential particularly in the presence of a high water table. Where contaminated ground is present, the construction and residual issues of certain SuDS soakaways must be carefully considered and may prove technically infeasible, limiting the volumes that can be lost to infiltration.

5 Evaluated Products and Systems

Details of all of the products and systems that have been collated as part of this study are provided in Appendix D. In the following sections a selection of example products are noted that have been reviewed. The examples noted herein are only a small selection of products that comprise the full suite of products within Appendix D. The examples are reported in two categories according to whether their primary benefit is water quality improvements or volume attenuation. Some example products deliver a level of benefit in both categories, in this instance the product is reported against the category where the most benefit is accrued. The review includes conventional SuDS systems as well as new products.

5.1 Water Quality

5.1.1 Vegetative Systems

Natural SuDS systems are often designed with source control as the primary focus, attenuating flow whilst removing pollutants prior to discharge to a watercourse or surface water sewer. Typical source control within new SRN schemes include ditches, filter drains and filter strips. An outline of pollution removal effectiveness for common vegetated features is given in HA103/06.

5.1.1.1 Filter Strips

Whilst few highway runoff studies have been undertaken on filter strips they are commonly used as buffers to reduce agricultural runoff to rivers reducing suspended solids in the UK and are promoted by Defra. In the USA Ebihara et al (2009) have reported 70% of particles 20μm or greater were retained in vegetated filter strips for three field sites in Kansas. An increase in pollutant removal is achieved with an increase in time of flow to receptors through dense vegetation. Research demonstrates the importance of filter strip design to detain flow which can greatly moderate the total sediment load, such as width and density.

Essential features of suitable grass species are a stiff stalk, which does not bend under the pressure of the water flow, and a high stalk density in order to reduce the flow velocity and cause ponding (van Dijk, Kwaad, & Klapwijk, 1996). Runoff that accumulates against the barrier is released gradually to the downslope. Sedimentation mainly takes place in the ponds upslope of the barriers. The runoff itself is affected in three ways by the barriers (van Dijk, Kwaad, & Klapwijk, 1996): 1).The catchment discharge is delayed as a result of water storage in the ponds along the barriers and the subsequent delivery of this water. Peak discharge will also be reduced. 2) If barriers follow the slope contours accurately, the water will spread out against the barriers thus reducing the risk of gully erosion. 3) The combination of these two effects will lead to an increase in infiltration, where soils allow.

5.1.1.2 Swales/Grass Channels

Most sources reviewed by Ramboll (2016) report vegetated swales removing ~80% of suspended solids, however it is thought that only ~50% of dissolved metals are removed in conveyance. Swales can be designed to be more effective through the implementation of shallow slopes, infiltration, vegetation and larger dimensions, all resulting in a slower flow when swales are most effective. Walsh et al (1997) found that a residence time of greater than

9 minutes would result in greater than 83% removal for total suspended solids. Achieving very shallow swale gradients within a new or existing SRN scheme will impact conveyance, constructability and space requirements, with a balance needing to be struck between all components.

A large component of maintenance within a vegetated swale will be the cutting and disposal of grass and litter accumulated within the feature to maintain hydraulic capacity. This may be an issue in highway regions with poor access, the CIRIA SuDS Manual gives further guidance on these suggested maintenance intervals.

Clearly greening existing highway ditches with water tolerant grasses should be explored where hydraulics, space and maintenance access allow to provide similar levels of treatment as a fully vegetated swale system. Some retrofit products provide biodegradable coconut soil reinforcement matting within which a water tolerant seed mix can be applied to promote the uptake of grass growth.

HA 119/06 *Grassed surface water cannels for highways runoff*[3] provides guidance on the hydraulic and structural design of grassed surface water channels for highway drainage. This is applicable to vegetative systems also discussed in Section 5.2.1.

5.1.1.3 Wetlands

Wetlands are reported to remove up to 95% of suspended solids. Theoretically, Revitt et al (2008) considers wetlands to be the most effective treatment system for dealing with pollutants, however these are very unlikely to be incorporated into even new SRN schemes due to space, maintenance and ownership issues. Consideration should be given to the potential for retrofitting wetlands into existing ponds, or other existing vegetative outfalls. Floating islands may be able to achieve some of the outcomes. These are discussed in Section 5.1.3.1.

5.1.2 Proprietary Products

An emergence of advanced proprietary treatment technology systems adopt a single point treatment concept by integrating highly efficient screening, sedimentation and filtration technologies in a single chamber to eliminate the need for multiple SuDS treatment devices. These single-point end-of-pipe solutions are perfect for retrofit installations and have been used as such with great success in the USA.

Certain proprietary SuDS techniques will likely have a big future role to play in the surface water management train by providing highly efficient screening, sedimentation and filtration technologies, as Water Framework Directive (WFD) implementation requires strict water quality improvements similar to the American Clean Water Act 1987. These may be especially relevant if single-point end-of-pipe solutions prove to be the solution of choice for new or existing schemes, due both to their high performance and relative economic installation requirements.

5.1.2.1 Filter Drains

These are clearly beneficial to road schemes whereby surface flows are required to be captured before running onto the highway, or alternatively where piped runoff is introduced

[3] HA 119/06 Grassed surface water channels for highway runoff, Highways England, May 2006

to stone filters to provide additional volume. Two studies (Hilton et al (2003) and Revitt et al (2003)) found swale and combined filter drains to remove between 37% and 85% of total suspended solids and should reflect similar losses as swales. Overall there are few conclusions that can be made with regards to pollutant removal however there is some reduction in PAH and potentially dissolved metals over a simple swale.

Filter drains tend to clog up quickly in areas of high suspended sediment loads, which can result in runoff bypassing the filter system altogether, reducing the potential for infiltration and continued effectiveness but screening upstream flows can minimise this. HA 217/08 *Alternative filter media and surface stabilisation techniques for combined surface and sub-surface drains*[4] covers alternative media options and Highways England are looking to also introduce the use of ground penetrating radar (GPR) surveying of filter drains to this guidance.

5.1.2.2 Filters

Stormwater filters collect the water and pass it through a bed of media to remove contaminants from the water. The most common type of stormwater filter is a sand filter, which may be constructed in a concrete structure or designed into a small detention area. Alternative proprietary products aim to provide filtration enhancing water quality coupled with ease of maintenance by changing of filter cartridges. Reactive filters are focused upon the removal of dissolved metals which has seen greater than 80% being taken out through the use of iron hydroxide. Reactive filters can also remove suspended solids, however this would lead to clogging, therefore they should ideally be used in conjunction with other drainage solutions that can remove suspended solids before residual runoff reaches the filters. Experiments on reactive filters has largely been lab-based and therefore, there is a lack of data for its use in practice in the UK. A number of proprietary product filters have been identified for trial on the SRN:

- **Jellyfish® Stormwater Treatment -** The Jellyfish filter claims to remove floatables, trash, oil, debris, TSS, fine silt-sized particles and a high percentage of particulate-bound pollutants; including phosphorus, nitrogen, metals and hydrocarbons. Contech are an American company and currently don't have a UK supplier, however, the product has been tested both in the laboratory and in the field and is performance verified by a number of stormwater regulatory agencies.
- **Smart Sponge -** Smart Sponge is currently being used on the network near Bedford. It is a proprietary combination of synthetic polymers with claims to have a unique molecular structure that is chemically selective to hydrocarbons. It can be retrofitted into existing systems, however, it requires maintenance approximately every 6 months.
- **Re-Medi8 -** Re-medi8 is a combination of soil and filter media that comprises of 4 layers. The material claims to clean surface water runoff using filtration, absorption, ion exchange, phosphate and retention. Re-Medi8 retains sediments by depth filtration, resulting in pollutants being retained in the upper 5-10cm of the filter media. There is a proposed trial for its use on the SRN in the UK, however, the product is currently already used on the European road network.

[4] HA 217/08 Alternative filter media and surface stabilisation techniques for combined surface and sub-surface drains, Highways England, Aug 2008

- **StormFilter® -** StormFilter by Contech utilises media filled cartridges that can be customised to target specific pollutants. It claims to trap particulates and absorbs pollutants such as dissolved metals, hydrocarbons, metals and other pollutants found in stormwater runoff.
- **STAR Water** - STAR Water solutions provide advanced bio-filtration and bio retention systems. They use treatment and reuse technologies that claim to deliver efficient performance for urban stormwater, industrial, mining and agricultural runoff and industrial waste water systems. They have developed a reactive filter media to treat polluted stormwater and low flow industrial waste water by way of filtration. One of its unique strengths is its ability to removed dissolved contaminants including nutrients and metals (including copper, lead and zinc,), bacteria and hydrocarbons from stormwater. Treatment of dissolved contaminants is achieved by chemical and biological processes created by the selected components in the filter media. Both a vegetated range and non-vegetated range has been designed and these can be used in a number of different applications including in swales, wetlands, around permeable pipe, in detention basins, under permeable paving systems and pavement sub bases. These filtration technologies have been used throughout Australia since 1997.

Particles in highway runoff arise from roadway maintenance operations, atmospheric deposition, corrosion and erosion, and various kinds of traffic activities such as tire abrasion, vehicular wear, fluid leakage, and pavement degradation (Li, Lau, Kayhanian, & Stenstrom, 2005). Studies like (Li, Lau, Kayhanian, & Stenstrom, 2005) have shown 90% of particles in highway runoff to be less than 30µm, whilst others (Toronto and Region Conservation, 2012) note that on average, 90% of particles measured in field testing are finer than 55µm.

5.1.2.3 Hydraulic Solids Separation/Vortex Separation

These devices use hydraulic separation to remove coarser particles, reducing suspended sediment loads passed downstream. Hydraulic solids separators and vortex separators function similarly with the main difference being the centrifugal flow around the circular structure between the inlet and outlet in vortex separators. Instead of throwing grit to the outside of the separator for collection, the cyclone action draws solids to the centre of the structure. A number of each of these proprietary separators have been identified for trial on the SRN. Two examples of hydraulic solids separators are:

- **QuadraCeptor -** Quadraceptor HT 500 (Heavy Traffic) is a specialist rainwater and surface water runoff filtration system for the removal of sediment and harmful pollutants. It uses an upflow filtration process and treats the rainwater by these four processes: sedimentation, filtration, absorption and precipitation. Maintenance access is required approximately between 2-5 years.
- **Dual Porosity Filtration (DPF) -** DPF is an emerging water treatment solution that in theory can provide high hydraulic capacity and a high level of pollutant treatment through the use of sedimentation layers. A pilot plant claims to retain between 92% and 99% of suspended particles from storm water runoff. The system is considered suitable for low flow rates and requires flushing once or twice a year. No cost examples of the system are given but this is expected to be unsuitable for highways.

Two examples of vortex separators are noted below. The first of which has current application on the SRN and the second has been identified for trial:

- **Downstream Defender –** The downstream defender is an advanced hydrodynamic vortex separator that removes sediment, oil and floatables from stormwater runoff that can be used as a standalone or pre-treatment device. Maintenance consists of removing sediments from the sump and floatables oil, litter and other debris from the floatables capture zone. In areas of high sediment load, maintenance can be required 4 times a year.
- **CDS** – The CDS hydrodynamic separator uses swirl concentration and continuous deflective separation to screen, separate and trap trash, debris and sediment from stormwater runoff. The indirect screening capability of the system claims 100% removal of floatables with a self-cleaning screen to ease maintenance. Maintenance access is required twice a year.

5.1.3 Natural Solutions

The soft estate describes the natural habitats and wildlife that have evolved along the edges of motorways. It provides a stark contrast to the intensity of the urban carriageway with more space and opportunity for more natural, 'soft' vegetated SuDS systems. These natural solutions sit at the top of the SuDS hierarchy and are a means to enhance biodiversity. This is in line with Highways England's Environmental Objectives for Road Period 1 and should be promoted wherever possible on new SRN schemes.

5.1.3.1 Floating Islands/Riverbanks

Floating islands/riverbanks for downstream treatment could be suitable for retrofit to existing pond assets in highway drainage systems. These systems are proven technologies in tertiary and polishing wastewater treatment applications, and are effective in providing removal of pollutants through settlement of solids and biological treatment of pollutants including hydrocarbons and oils, phosphates and nitrates. They combine the latest developments in ecological engineering with new biofilm research and traditional wastewater treatment processes, having the additional benefit of providing improved aquatic and terrestrial habitat.

These systems are versatile modular structures that can be customised to varying shapes and sizes, and these tough floating systems can withstand varying flood conditions and allow unique connection systems for easy customisation to existing channels.

Although they would require some level of permanent water retention to remain biologically active, this type of system could be suitable for installation to receiving watercourses downstream of a highway outfall, and may be a suitable downstream treatment option. Consequently, this option may potentially involve a third party landowner, the Environment Agency, or other organisation responsible for the watercourse, however this fits with the promotion of Natural Flood Management techniques being promoted and adopted in the UK, where catchments should not be dealt with in isolation. If water quality treatment is better placed outside of Highways England land ownership, and this allows for better remediation, solutions like this are ideal. Example suppliers include Biomatrix Water, Salix and Frog Environmental (BioHaven®). An image of a floating island can be seen in Figure 4.

The interim results from a study into Floating Wetland Treatment (FWT) systems provides substantial promise in the use of these systems for total suspended solids (TSS), total nitrogen (TN) and phosphorus (TP) pollutant removal. In Queensland, Australia, a research study is underway to assess the ability of FWT's to treat stormwater (Walker et al, 2014). The

efficacy of the system was assessed in variable flow conditions and real-time water sampling was undertaken to evaluate the pollutant removal performance. The preliminary results from the study show that on average the FWT system demonstrates pollutant concentration reductions from the inlet to the outlet of 68% for TSS, 13% for TN and 63% for TP showing substantial promise. The modular nature of the device allows for flexibility in design and construction and also easy maintenance. These systems have the potential to provide greater stormwater pollution removal rates per unit compared to constructed wetlands and other systems.

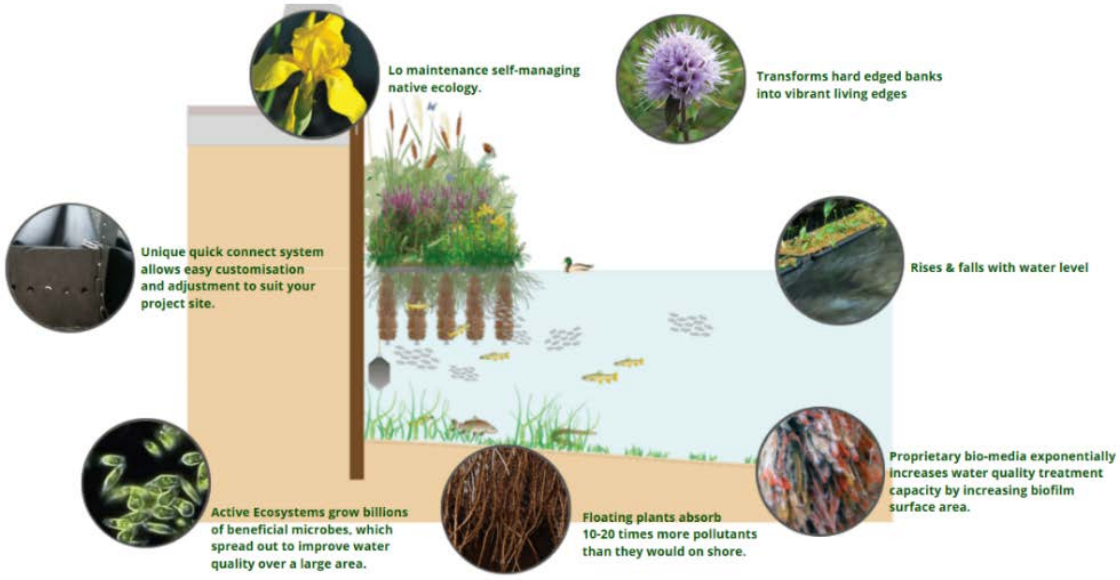


Figure 4: Biomatrix Floating Islands[5]

5.1.3.2 Bioremediation

Bioremediation is an increasingly common process for treating contaminated soils and is being considered as an option for treating oil spills. Using Fungus and biomaterial for processing pollutants could be considered as a relevant option for dealing with pollutants in highways drainage. Conventional filters cannot effectively remove hydrocarbons from road runoff, however, bioremediation is an effective and viable method of mitigating hydrocarbons. Bacteria and Fungi could both be used to decompose PAH in bioremediation, although studies have shown that bacteria are more effective, the mycelia of fungi are capable of permeating more of the soil matrix, enabling fungi to clean more area while bacteria clean more thoroughly. An ideal system should utilise the metabolisms of fungi and bacteria to break down the contamination to maintain a healthy environment. Recommended bacteria include Acinetobacter, Arthrobacter and Pseudomonas and recommended fungi are Trichoderma, Mortierella and Pleurotus ostreatus (DuBoi et al, 2012).

Plant waste-products have been shown to be capable of remediating oil by physically absorbing it in quantities greater than their own weight, and degrading the oil being degraded by their associated microbial communities (Dashti et al, 2017). Experiments have also been undertaken by researchers looking at fungus for similar oil treatment applications [1]. This could be a potential alternative to applications which require a dosing unit e.g. Clean Water Service Environmental additives for biological treatment of oils, organic contaminations and

[5] http://www.biomatrixwater.com/floating-riverbanks/

odours [2]. Consideration needs to be given to extremes in flow: both shock loading and times of low flow, and how the biological system performs in these.

However, there could be potential for a collaborative research project with leaders in academic research in this area. Recent literature originating from The University of Tuscia, Italy looks relevant if the treatment of hydrophobic persistent pollutants is of interest (D'Annibale, 2012).

5.1.3.3 Nanotechnology

Nanotechnology has been described as a concept with several examples of emerging techniques for application to polluted stormwater. This is presented comprehensively in the Application of Nanotechnology in water and wastewater treatment article (Qu et al, 2013). The timing of the highest concentrations of pollutants in large precipitation events is variable but generally understood to be a wash-off effect or 'first-flush' as runoff water takes the pollutants deposited on the road surface off the road and out into the environment. One of the problems with treating stormwater runoff is that there are large volumes making it hard to treat without retention of flows.

A potential opportunity could be to introduce adsorbent particles to the pollutants on the road surface before it gets washed out in high volumes. The application through regular dusting for example, of heavier adsorbent particles either set into the surface or loose as granules resident on the highway surface could be able to interact with the pollutants over the long term, being retained during low intensity rain events so that the concentration of harmful compounds and elements is reduced for the higher runoff events. If such a method for removal were to prove effective, and the substrate particles or granules consisting of sufficient mass to prevent them being blown or washed away, then they could be recovered by a sweeper, processed and reused.

Nanotechnology has been considered effective in solving water problems related to both quality and quantity. Nanomaterial's have unique characteristics such as large surface area, shape, dimensions and size that make them appropriate for water and wastewater treatment applications including disinfection, membrane separations and adsorption. The current and potential applications of nanotechnology in water and wastewater treatment can be seen in Table 1Table 1: Road runoff contaminants and their potential impacts on receiving watercourses. The field of nanomaterial's for treatment of wastewater and water is promising for current and future research (Amin et al, 2014).

Although nanotechnology enabled water and waste water treatment processes have shown substantial promise in lab studies, their readiness for commercialisation varies. Many materials require more research whilst some are currently on the market already. A specific product identified as part of this study is detailed below:

- **Lilypads** - A United States-based start-up has created a floating "lily pad" that uses solar-activated nanotechnology to break down water contaminants. The device could treat stormwater pollution before it reaches nearby waterways, if deployed in retention ponds or ditches alongside roadways and parking lots. The LilyPads are made of plastic and contain a mesh with a titanium dioxide coating. When activated by the sun, a chemical reaction is triggered that breaks down the broadest range of contaminants using 5 simultaneous processes[6]. The technology has been used on a smaller scale to

[6] http://www.opb.org/news/blog/ecotrope/this-nanotech-lily-pad-could-obliterate-stormwater-pollution/

create drinking water purification systems in developing countries. Further investigations are required into the use of LilyPads as one study showed that its' contribution to the removal of pollutants was difficult to ascertain as pollutant removal was similar during periods where the LilyPad was present versus periods when the LilyPads were not. The LilyPads were also shown to become 50% fouled after 122 hours in stormwater with the percentage rising to 80% after 800 hours, which would require a frequent maintenance regime to ensure continual performance (Lopez, 2015). There is potential for application in attenuation ponds and ditches off the main carriageway either in new SRN schemes or easily retrofitted into existing systems, however, frequent maintenance may be an issue.

Future studies are required in more realistic conditions to assess applicability and efficiency of different materials. As the long term efficacy of many materials is unknown, further studies are required to address the long term performance of these materials (Qu et al, 2013). The challenges faced by water/wastewater treatment nanotechnologies are important, but many of these challenges are perhaps only temporary, including technical hurdles, high cost, and potential environmental and human risk. To overcome these barriers, collaboration between research institutions, industry, government, and other stakeholders is essential.

There is work ongoing already which is looking to explore the potential for nanotechnology in Highways England SMART motorway schemes.

Table 3: Current and potential applications of nanotechnology in water and wastewater treatment (Qu et al, 2013).

Applications	Representative nanomaterials	Desirable nanomaterial properties	Enabled technologies
Adsorption	Carbon nanotubes	High specific surface area, highly assessable adsorption sites, diverse contaminant-CNT interactions, tunable surface chemistry, easy reuse	Contaminant preconcentration/detection, adsorption of recalcitrant contaminants
	Nanoscale metal oxide	High specific surface area, short intraparticle diffusion distance, more adsorption sites, compressible without significant surface area reduction, easy reuse, some are superparamagnetic	Adsorptive media filters, slurry reactors
	Nanofibers with core–shell structure	Tailored shell surface chemistry for selective adsorption, reactive core for degradation, short internal diffusion distance	Reactive nano-adsorbents
Membranes and membrane processes	Nano-zeolites	Molecular sieve, hydrophilicity	High permeability thin film nanocomposite membranes
	Nano-Ag	Strong and wide-spectrum antimicrobial activity, low toxicity to humans	Anti-biofouling membranes
	Carbon nanotubes	Antimicrobial activity (unaligned carbon nanotubes)	Anti-biofouling membranes
		Small diameter, atomic smoothness of inner surface, tunable opening chemistry, high mechanical and chemical stability	Aligned carbon nanotube membranes
	Aquaporin	High permeability and selectivity	Aquaporin membranes
	Nano-TiO_2	Photocatalytic activity, hydrophilicity, high chemical stability	Reactive membranes, high performance thin film nanocomposite membranes
	Nano-magnetite	Tunable surface chemistry, superparamagnetic	Forward osmosis
Photocatalysis	Nano-TiO_2	Photocatalytic activity in UV and possibly visible light range, low human toxicity, high stability, low cost	Photocatalytic reactors, solar disinfection systems
	Fullerene derivatives	Photocatalytic activity in solar spectrum, high selectivity	Photocatalytic reactors, solar disinfection systems
Disinfection and microbial control	Nano-Ag	Strong and wide-spectrum antimicrobial activity, low toxicity to humans, ease of use	POU water disinfection, anti-biofouling surface
	Carbon nanotubes	Antimicrobial activity, fiber shape, conductivity	POU water disinfection, anti-biofouling surface
	Nano-TiO_2	Photocatalytic ROS generation, high chemical stability, low human toxicity and cost	POU to full scale disinfection and decontamination
Sensing and monitoring	Quantum dots	Broad absorption spectrum, narrow, bright and stable emission which scales with the particle size and chemical component	Optical detection
	Noble metal nanoparticles	Enhanced localized surface plasmon resonances, high conductivity	Optical and electrochemical detection
	Dye-doped silica nanoparticles	High sensitivity and stability, rich silica chemistry for easy conjugation	Optical detection
	Carbon nanotubes	Large surface area, high mechanical strength and chemical stability, excellent electronic properties	Electrochemical detection, sample preconcentration
	Magnetic nanoparticles	Tunable surface chemistry, superparamagnetism	Sample preconcentration and purification

5.1.3.4 Pond Design

Design of most pond systems allows for an inlet at one end and an outlet more often than not directly opposite. However, recently ideas have emerged where the core "pond" portion of the environment is specifically designed to allow water that is resident in the pond prior to a stormwater inflow event to be displaced toward a central drain rather than mixing with the inflowing stormwater. Resident water is then preferentially flushed in favour of retaining newly inflowing stormwater to a greater degree than is typically possible using designs consistent with current stormwater best management practices. The result is a longer average stormwater retention time and better opportunities for achieving sediment and nutrient removal objectives.

The pond can be combined with other water treatment methods. Frog Environmental case studies of Nautilus Pond^{TM} (refer Figure 5) include retrofit to treat highways stormwater

runoff in Canada, and also treatment of stormwater runoff from a large industrial rail yard also.

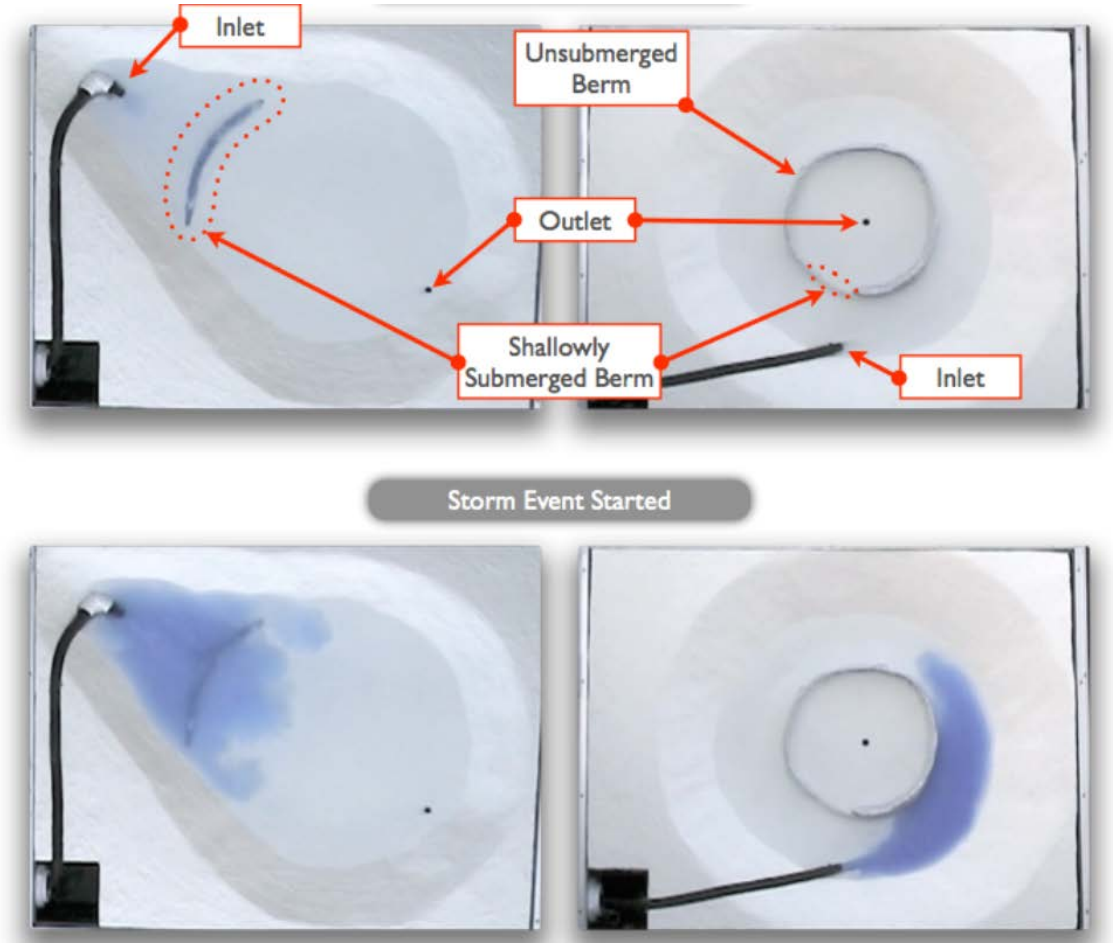


Figure 5: Nautilus Pond™ configuration and operation shown on the right, compared to a typical pond design, shown on the left.

5.1.3.5 Phytoremediation

Phytoremediation is the use of living plants to remove pollutants from soil and water. The choice of plant species is critical for the treatment of polluted runoff. However not the primary focus of this review, plant species such as water hyacinth have featured prominently in literature review searches regards vegetative treatment and are therefore noted for completeness.

Water hyacinth has been noted as a model plant for phytoremediation of nutrient polluted stormwater runoff (Fox, 2009). However, its uncontrollable growth makes it one of the most problematic plants worldwide leading to its ban in the UK in 2016 (Rezania et al, 2015). Further research is required to determine if any other plant species could have a similar effect as water hyacinth in the phytoremediation process for stormwater treatment.

5.1.3.6 Source Control – Beet Juice

There is potential room for innovation in source control of pollutants e.g. de-icing salts. For example rather than looking to treat runoff, there is potential to reduce the processes that cause this runoff. In Canada, beet juice is being trialled as an additive to typical de-icing

salts as it is claimed to reduce the amount of salt required by 30%, and associated costs and environmental impact[7]

Canadian municipalities including Toronto have also used the organic material Beet 55[8] in lieu of traditional road salt. A similar product, Beet Heet, is seeing massive success in the U.S. So far this year, the company has sold nearly 5.7 million litres, reported Time Magazine[9].

5.1.3.7 Oil and SuDS

Oil has been identified as a major contaminant of highway runoff, and perhaps the most significant diffuse source urban pollutant. The paper 'Oil and SuDS: managing a priority urban pollutant' (Napier et al, 2008) assesses the trapping and degradation of road runoff derived oil, in soft engineering SuDS. Outcomes of this assessment could inform soft engineering SuDS design for the SRN:

- **Submerged systems versus exposed soil -** While SuDS facilities of various kinds can be effective in trapping oil from diffuse sources, this study showed oil remaining in submerged sediments, whereas oil contamination of intermittently dry systems, such as detention basins, degrades and is less likely to accumulate to harmful levels.

  The inference from the outcomes of this study showed that whilst similar quantities of oil were entering all the systems, more degradation or volatilization was occurring in the soil based systems than in the submerged sediments.

- **Oil degradation and moisture content -** Results from the laboratory degradation experiment also show increased moisture content in soils to have an inhibitory effect on hydrocarbon degradation. Studies have suggested that oxygen content is a limiting factor in the breakdown of oil in soils. The more saturated a soil, the less oxygen it will hold, and, consequently, the less potential there will be for aerobic microbial degradation. The most extreme example would be submerged sediments in ponds, and this is borne out by the field data gathered during this project.

[7] http://www.cbc.ca/news/canada/montreal/beets-cowansville-road-salt-quebec-1.3926225
[8] http://www.huffingtonpost.ca/2017/01/10/beet-juice-roads-canada_n_14060390.html
[9] http://time.com/5761/salt-shortage-triggers-beet-juice-cheese-brine-alternatives/

5.2 Water Quantity

5.2.1 Vegetated Conveyance Systems

5.2.1.1 Ditches

Ditches are widespread throughout the existing highway network and are generally used for their hydraulic capabilities due to efficient cross sectional shape.

When considering retrofit options for existing ditches, simple in line baffles may be used along steeper or deep sections of ditch to promote the use of storage and attenuation within the ditch system. This would slow the flow of runoff to the watercourse and maximise storage volume where there is not space for a dedicated attenuation pond downstream. This is similar to the principles of natural flood management, where debris or small dams are placed in streams prone to flood downstream catchments. Use of ditch attenuation may also promote sediment reduction and biodiversity as the underlying soil may be less prone to drying out if shallow pools are retained.

5.2.1.2 Terracing

In this context terracing is used to mean a series of regularly spaced embankments across a slope that form a channel on the up-slope side of the embankment to retain water behind the bank improving infiltration and sedimentation. It is normally accompanied by contour and/or strip planting and acts as a check on any contour row failure (Tippett & Dodd, 1995). Manyatsi (1998) suggests that it is applicable on slopes from 2-14%.

This may be applicable on areas of highway embankment suffering from erosion and mobilisation of sediments.

5.2.2 Regional Control Features

Site control is the treatment of attenuated flow prior to discharge to a watercourse or surface water sewer typically performed within a pond or wetland that may include infiltration. This creates a second opportunity to remove sediment and pollutants not removed by the conveyance system, and infiltrate volumes of runoff over intervals between storm events.

Within the SRN the majority of large road schemes completed within the last 15-20 years have included some forms of attenuation ponds at the lower ends of catchments to reduce runoff and contain pollution before entering a downstream watercourse.

5.2.2.1 Attenuation Ponds (Wet Pond)

Attenuation ponds are commonplace amongst newer SRN areas, and are primarily used to attenuate highway runoff to Greenfield rates. As well as intercepting sediment and some dissolved pollutants, ponds also reduce the velocity of runoff and therefore help to limit downstream sediment losses (Hawkins & Scholefield, 2003) (Hilton, Hornby, & Moy, 2003). Various studies show attenuation ponds to remove around 60% of suspended solids though this number can vary depending on the design and site characteristics. Around 40% of dissolved copper and 30% of dissolved zinc tend to be removed using this method. The useful

life of ponds for pollutant or sediment removal is therefore very short unless they are frequently dredged (Verstraeten & Poesen, 2000).

Attenuation ponds may be improved through the use of multiple ponds or multiple functions included within a single pond such as forebay areas, specifically designed to trap sediment.

5.2.2.2 Detention Basins (Dry Pond)

In theory, Revitt et al (2008) predicts dry detention basins to be relatively poor at removing contaminants compared to other sustainable drainage solutions. Around 50% of suspended solids can be expected to be removed however different studies have shown a wide variation in sediment removed over multiple events. Basins have a finite functional life for drainage or wetland values. The build-up of sediment will need to be monitored and the removal of trapped sediment planned for. Consider multiple cells for areas of high sediment deposition.

Offline detention basins can be used to temporarily store additional floodwater during a storm event, however these are less common in highway schemes as space requirements typically dictate a single pond attenuation system is constructed using a wet pond.

5.2.2.3 Infiltration Basins (Soakaways)

Infiltration basins are unlikely to be used solely within the SRN without reliance on other means of storage, as the rate of infiltration is very slow compared to design storm events a pond is required to hold and empty within a set time period. Given the design of infiltration basins, it is not possible to sample the effluent from these systems in the same way as other methods. Revitt et al (2008) does rank infiltration basins as being the outright best solution for removing pollutants in theory and research supports their effectiveness. There is a potential risk to groundwater contamination with infiltration of highway runoff however, this can be mitigated through the provision of a greater thickness of unsaturated zone or vegetation.

5.2.3 Proprietary Products

5.2.3.1 Porous, Pervious and Permeable Pavement

Porous, pervious and permeable paving solutions can allow for direct infiltration into the subgrade. These surfaces can also provide water quality improvements by trapping and treating pollutants, and it has been shown in a number of previous studies, that porous pavements can be as effective at removing suspended solids as biofilters and wetlands, for example (Ramboll, 2016).

Case studies and applications of these products to date are focused on car parks or urban areas as the pavement is not as durable as more conventional highway constructions, and there are also concerns regarding maintenance as the full depth of construction could require excavation/cleaning. Successful highways examples do exist but there is very little information and empirical evidence for the treatment performance of pervious pavement and porous asphalt in particular. For example in 1986, the Arizona Department of Transportation constructed a 3,500ft long porous pavement experimental test section in the Phoenix metropolitan area. An article written in 1991 suggests that the test section on State Route 87 had performed well for the previous 5 years. It is unlikely that porous, pervious or permeable paving solutions would be applicable to the SRN main carriageway, however alternative

surfacing could be trialled for emergency access roads, service lay-bys or footways to improve infiltration where soil conditions permit. Clogging of the surface can result in reduced porosity and reduced infiltration rate of system, however.

To improve understanding of the performance of these systems in a highways environment there are a number of relevant examples of research facilities aimed at testing these surfaces including:

- **The Minnesota Department of Transportation** – who tested porous asphalt and pervious concrete cells, from 2008-2010, on a 2.5 mile, low traffic volume closed loop. Tests were conducted based on the international roughness index, surface rating, surface texture, noise and clogging characteristics amongst other parameters. The results showed a positive picture for permeable pavements based on the overall structure and hydrological (infiltration and quality) performance, however, this test was undertaken on a 2 lane segment with light traffic which is not applicable for highways in the UK.
- **The California Pavement Research Centre** – who measured relevant parameters in the lab and inputted them to create a computer simulation study to evaluate the structural and hydrological performance of permeable pavements particularly under medium speed and heavy load.

Based on the available products a selection of the more feasible products for application on the SRN (excluding main carriageway) are:

- **Drainasphalt** - is a permeable asphalt which allows water to pass freely through the underlying structure. Although it allows for infiltration and could be suitable in low traffic volume areas, it does not treat water quality so it is recommended that other sustainable drainage products would be used in combination to treat water quality before infiltration.
- **Truckcell -** is a heavy-duty cellular paving system designed for intensive usage and high-load traffic applications.
- **Topmix -** permeable is a product supplied by Tarmac consisting of a fast draining concrete pavement solution that rapidly directs stormwater off driveways, walkways, streets and car parks. The permeability rate of this surface is 36,000mm/hr which is said to require an unrealistic amount of dirt and clogging before it ceases to function effectively which would mean that maintenance would be minimal.
- **JW Pavement -** is a permeable pavement produced by Taiwanese company, JW Pavement EcoTechnology. The product is marketed as “Structural Pervious Pavement”, which is said to allow infiltration of surface water whilst being able to bear high loads. The JW pavement consists of arrays of interconnected vertical piping, the aqueduct grate, made from recycled plastics that conveys water into the ground and also provides evapotranspiration access on the surface. The aqueduct grate is reinforced with a specific mixture of concrete and covering stripe of the aqueduct frame will be removed after solidification of concrete and therefore reveal the holes of all aqueducts. Gravel and soil are formed below the aqueduct for filtering and storage of water.

5.2.3.2 Geocellular Storage

Geocellular systems typically comprise of plastic, modular and box-like structures that are placed underground. They can be used as storage tanks or soakaways, where a slow release of water back into the substrata can be facilitated by the use of a permeable membrane. These structures do not provide a form of water quality treatment however silt traps could be used to remove sediments before water enters the tanks. Whilst these products can be installed beneath urban highways, it is unlikely that the same would be done under the SRN due to requirements for maintenance. It is therefore more realistic to expect these systems to be used in areas adjacent to the main carriageway.

- **Drening® Chambers** - are very similar to conventional geocellular structures as they can be used for infiltration or attenuation. However, the Drening Chamber does not provide water treatment. The Drening Chamber permits a reduction of dugout depth up to the 50% allowing for a more compact installation in traffic areas with minimal cover along with an open internal structure that allows for inspection and maintenance of the system. They could be used in conjunction with Swales to provide volume and quality control to surface water. This could be installed when converting highways ditches to swales.
- There are a number of similar products including: **Stormcell, Stormblock, Aquacell, Polystorm Geocellular System, GEOlight, RigofillGeomembranes.**

Guidance on the use of geocellular storage in highway situations is well progressed and is published by British Water in *Use and design of geocellular tanks in the highway* (British Water, 2016), and such systems are recommended as part of a 'train' with separate silt capturing devices.

5.2.3.3 Flow Control

A number of control systems, vortex flow controls, orifice plates, throttle pipes etc. are commonly applied on the SRN and have been identified throughout the product review:

- **ACO SuDS Swale Inlet -** This is a low profile unit that provides a natural looking interface between proprietary and vegetated drainage solutions, complementing the surrounding environment. It manages the volume and flow rate at swale inlets but does not provide any water quality benefit. It could be used to retrofit swales solutions to existing highways.

5.3 Emerging Developments

During the data gathering stages of this research a number of emerging innovations were identified that do not sit within the typical SuDS context. However, these innovations may in future reach the stage where they could be implemented on the SRN as part of the drainage system, whether this be retro fit or proposed schemes. To ensure transfer of this knowledge these innovations and opportunities are documented below.

5.3.1 Drones

A common problem across the SRN is the maintenance of drainage infrastructure and the perception that SuDS are difficult to maintain. The use of drones equipped with high-resolution cameras and scanners could in the future enable more regular monitoring of

drainage infrastructure thus improving the environmental performance of Highways England. The commercial applications of drone technology in the road and rail sectors have recently been investigated by PwC (2017)[10]. Immediate possible applications have been identified for transport infrastructure in: investment monitoring, maintenance and asset inventory.

Although not a focus for this study there is an opportunity for Highways England to engage with the likes of Drone Powered Solutions and Cyberhawk to investigate the potential use of drones.

- **Drone Powered Solutions** - Drone Powered Solutions is a global centre of excellence located in Europe. The team helps clients from various industries to maximize the potential offered by drone technologies. Established in Poland in early 2015, it is the world's first professional services consulting team dedicated to industrial and business applications of drone technology, and its location in Poland is no accident: Poland is one of the first countries worldwide to have adopted detailed laws regulating the industrial use of drones (as early as 2013). There is an opportunity for Highways England should engage with DPS to understand the potential for drone application on the SRN, and not just in a drainage context.
- **Cyberhawk** - Network Rail has awarded a framework contract to four companies to use drones to perform infrastructure inspections and land surveys. Cyberhawk, AM-UAS, Resource Group and Richard Allitt Associates will provide Remotely Operated Aerial Vehicle services. Cyberhawk uses ROAVs, also known as Unmanned Aerial Vehicles or drones, to provide high-quality inspection and land survey information to the oil and gas, renewable and utilities sectors. The contract with Network Rail is its first foray into transport. Highways England could also engage with Cyberhawk to understand the potential for drone application on the SRN, and not just in a drainage context.

5.3.2 Programmable Materials

Today, pipes of a certain size are buried to handle a given amount of water volume and pressure flowing through them. As time goes by, these water pipes may not be able to handle the increase in demand capacity for water volume. New, larger water pipes would need to be buried to replace the older water pipes. Imagine a future where existing buried water pipes could be independently adaptive; changing their size and shape by expanding or contracting to accommodate changing water volume. These futuristic water pipes would also be able to adjust themselves to the water pressure demands flowing through them. Water pumps will not be needed because of the unique undulation properties of the self-adaptive piping material, as the pipe itself will move the water.

There is potential for using programmable nanoscale materials that can self-assemble, or build themselves, using any type of passive energy source such as; heat, magnetism, gravity, pneumatics, shaking, or water.

Advances are being made regards developing water pipes made of programmable materials that can reshape themselves or self-assemble over time. The water pipes are designed to act like peristaltic structures capable of pushing water through the pipe work on their own. GEOSyntec (Boston) has already been involved with this new paradigm for piping, and there

[10] https://www.pwc.pl/en/publikacje/2016/clarity-from-above.html

may be potential for future applications on any pipe network. Although nowhere near commercial application this may have potential in the future for Highways England.

The Self-Assembly lab[11][12] is working with academic, commercial, non-profit, and government partners, collaborators, and sponsors to make the self-assembling future a reality, and even though the lab is part of MIT, it is entirely industry-funded. Its founder notes "*Industry funding means we get to have an exploratory and open-ended attitude that allows for fundamentally new discoveries, but with the possibility of applying our ideas very quickly and with feedback on the practicality of our research.*"

Although no viable product for immediate implementation on the SRN is available, there is potential for application in the future. For example, dependant on the thickness of the pipes developed these could be used to line existing drainage infrastructure, ensuring an encasement to the system, allowing pipes to reshape to clear blockage, ensuring maintained networks and dispelling of water quickly during times of flood. These could be retrofitted in sections of the system that are not easily accessible and consequently the infrastructure is hard to maintain. There is an opportunity for Highways England to engage with Self Assembly lab, and utilise Innovation Designated Funding to support the development of a product specific to the SRN and potentially be at the forefront of guiding this thinking.

5.4 Testing Facilities

A common question for water treatment products is whether or not they can meet the % removal requirements specified in HD 33 and 45.

It appears that there is no independent UK testing organisation to verify products leaving suppliers seeking approval and certification from the following organisations:

- The British Board of Agreement (BBA)
- New Jersey Department of Environmental Protection (NJDEP)
- Water Research council (WRc)
- Deutsches Institut für Bautechnik (DiBT)

The UK Collaboration for Research in Infrastructure & Cities organisation are developing several testing facilities for drainage infrastructure products. Plans to construct a number of test facilities between Cranfield, Newcastle and Sheffield University could provide an opportunity for Highways England to get involved and test their products in a controlled condition facility.

There is an opportunity to collaborate with organisations like UKCRIC who are looking to develop several test facilities, or develop a Highways England test facility to trial products and provide confidence to Highways England that existing technologies could be implemented on the SRN.

Recently British Water, in collaboration with other industry stakeholders including Highways England and suppliers have developed *A Code of Practise for the Assessment of*

[11] http://www.selfassemblylab.net/

[12] http://ideas.ted.com/a-peek-into-the-brave-new-w0orld-of-programmable-materials/

Manufactured Treatment Devices Designed to Treat Surface Water Runoff. This is a voluntary code developed to provide the UK market with a consistent approach to assessing products.

The test methods described within the document are drawn from collective experience of having gone through formal 3rd party accreditation (predominantly in the USA or in Germany). The final test methods arrived at were seen as the combination of the best points from both the American (predominantly New Jersey) and German accreditation programmes, normalised to UK rainfall patterns with the assistance of HR Wallingford.

The Code of Practice is primarily aimed at new products entering the UK market. For existing products on the market, they should be deemed to comply if they have already been through a recognised 3rd party verification process such as the DIBt verification in Germany or the New Jersey Department of Environmental Protection verification in the USA.

The purpose of this document is to bring consistency to the market, and there is an opportunity for Highways England to adopt/make formal the acceptance of products that comply with this standard for use on the SRN, potentially removing the need for departures from DMRB.

5.4.1 Existing Test Rigs

A number of existing facilities exist in the UK for manufacturers to test products. For example HR Wallingford designed and built a test rig that was recently taken over by SPEL. Having worked closely for a number of years, SPEL have an agreement that HR Wallingford will oversee testing that requires endorsement from an approved independent body, and they will monitor future testing at the rig.

The University of Sheffield own an Advanced Manufacturing Research Facility and work alongside 100-plus industrial partners to carry out world-leading research into advanced machining, manufacturing and materials. Founded in 2001, this facility focusses on generic research, specific research and innovative projects which includes projects in the early stages of development that are often externally funded. The likes of Cranfield University have also set up a Soil Management Facility that features environmental simulation tools to study soil-plant-water interactions.

There is potential opportunity for Highways England to look at the development of a test facility. However, consideration should be given to the ability of Highways England to approve proprietary approaches and consideration of other existing facilities as noted above.

5.4.2 Data Sensing and Management

Remote sensing and automation in the drainage system has the potential to provide improved effectiveness in treatment, and lower risks in terms of human involvement and control. Opportunities include utilising increased connectivity, which actors in the water sector are already exploring for their supply and wastewater networks.[13]

Increased use of data would require a step change in the level of Instrumentation, Control and Automation (ICA) equipment utilised on drainage installations and management of the data

[13] https://www.ice.org.uk/eventarchive/revolutionary-approach-to-managing-water-using-iot

that is generated. Two examples of where a greater level of data sensing and remote operation have been used to manage water assets are:

- **Thames Water -** a demonstration site has been established comprising of 870km of distribution mains and 172km of trunk mains. A number of selected applications will be trialled on the site including leak detection and localization which will use smart meters and self-learning algorithm in order to determine the leak rate. Another aim of the demo site is to test customer interaction by aiming to influence behaviour by supplying water usage information through mobile applications and the web.
- The **Environment Agency** - currently have over 120 Meteor Nexus cameras across the UK. These cameras provide real time images from remote installations and maintenance can be kept to a minimum as camera images show only the sites that require attention. They provide early warning of blocked trash screens and monitor other flood defence features such as storm drains and pumping stations.

There are also opportunities to utilise remote monitoring to inform maintenance requirements and manufacturers are looking to provide remote monitoring as part of their optional maintenance programmes.

5.4.3 Pipe Survey Techniques

Drainage pipe surveys have traditionally been carried out using CCTV cameras mounted onto robotic vehicles which can travel along the length of a pipe and identify structural defects, blockages and connections.

A new innovation using acoustic signatures has been developed to quickly and accurately assess the condition of drains and provide greater visibility of network serviceability. It identifies defects, breaks or blockages in pipework by using acoustic signals to feed information immediately back to the operator on site and can accurately record water levels, pipe length, pipe diameter and the amount of sediment in drains and sewers.

Initial reports from acoustic survey trials on the highways network has shown that this technique can survey up to eight times more capacity per shift than the more traditional CCTV survey and acts as a 'first pass' survey tool to identify which areas require further investigation. This will remove the need to conduct CCTV surveys on the whole length of the network, instead concentrating the more time consuming visual surveys on the problematic areas.

It is claimed that use of acoustic surveying alongside a targeted visual survey can result in a 38% saving in costs due to the reduction in time required on site, and there is potential for savings in survey costs to be re-invested into service improvements of the drainage system.

A number of data sensing, management and pipe survey techniques exist that should be considered for use on the SRN. As this is not the focus of this assessment it has not been investigated in further detail.

5.4.4 Energy Generating Roadway[14]

Paved roadways vibrate as cars and trucks drive over them, and recent research has looked at harnessing this vibrational energy to generate electricity. This concept is not only possible,

[14] http://asphaltmagazine.com/advancing-asphalt-roadways-into-the-future/

but it has already been proven. A 2011 pilot study into roadway "vibration energy" generation by Holland's University of Twente and the Dutch province of Overijssel used piezoelectric roadway materials to convert vibrations into measurable power. Basically, the ongoing compression and decompression of piezoelectric crystals in the roadway material generates electricity.

The University of Twente study, which used a piezoelectric embedded strip across the N34 provincial motorway near Hardenberg, showed that enough energy could be generated to power wireless motion detectors to trigger stoplights. The 2013 paper *Piezoelectric Roads in California* estimated that a 20 mpg car using $4/gallon gas on a one kilometre stretch of piezoelectric equipped roadway would generate about 0.19MJ of electricity. Based on current West Coast electricity charges, this would be about 1/20th of the gasoline cost burned to cross this length of roadway. It was noted that "At this rate, the road will generate a revenue of $33,565 per year".

5.4.5 Catchment Based Approach

Using the river catchment to plan flood risk management is not a new idea, but it has come to the fore over the past decade. Integrated catchment management focuses both on reducing flood risk and on delivering wider benefits such as water quality improvements.

Involvement of multiple partners can offer significant advantages in terms of access to additional land, resulting in water management solutions and water quality treatment solutions that may not have been an option within the existing SRN remit.

Combining partners' adaptation actions that have less tangible and more long-term benefits, with those that have more easily quantifiable and short-term outcomes can make the combined project a lot more attractive to potential investors. However, each partner will inevitably have different motivations, remits and timescales, and negotiations to manage trade-offs and establish a shared programme of work to address all partners' motivations can be time consuming and costly.

However, Highways England should be open to understanding the potential for development of collaborative opportunities with other stakeholders that could result in SuDS being better placed outside of existing Highways England land ownership. Potential partnership funding opportunities could be investigated to better enable catchment solutions.

6 The Future Context of SuDS

The main focus of this study is on innovation in the current SuDS sector in order to improve environmental performance. It is however also likely that the context of Highways England's drainage may change in the future. In this section we have considered a number of possible developments that have the potential to influence the water quality impacts of highways runoff but also the opportunities that come with successful adaptation to a changing environment. It is split into three sections. The first describes potential future climatic scenarios that can directly affect runoff water quality and the efficacy of the drainage infrastructure; the second describes some potential technological opportunities and socio economic changes. The final section describes a few potential opportunities for improving the quality of highway runoff water**.**

6.1 Climate Change Impacts

Projected changes to the climate of the UK are a key consideration for any planned future development and the potential impacts concerning highway drainage could be significant.

6.1.1 Rainfall Patterns and Intensities

Flood levels are generally thought to be likely to increase for established return periods, with EA guidance being revised recently (Environment Agency, 2016), resulting in increased uplifts in percentage allowance for climate change to some peak river flows (dependant on river basin district), and to peak rainfall intensities in small and urban catchments.

The UK Climate Projections (Defra, 2011) also state that summer precipitation will tend to decrease across the UK, with central estimates of regional average summer precipitation change projected to be between -17% to -23% in the 2080s. And winter precipitation tending to increase across the UK, with central estimates of regional average winter precipitation change are projected to be in the region of +14% (NE) to +23% (SW), in the 2080s.

Increases in flood levels may require physical adaptations for outlet locations and outflow invert / soffit levels to ensure efficient flows during storm events. An increases in rainfall intensity will potentially require upsizing of drainage systems to cope with changing demands. The overall changes in rainfall patterns will also result in changing demands on the existing network.

6.1.2 Changing Seasons

There are however other concerns beyond the quantities of water resulting from changes in the frequency and intensity of extreme precipitation events. Qualitative impacts may also need to be considered such as the capture of vegetative material becoming more of a concern requiring a different approach as a result of growing seasons becoming longer and more productive with different plant species presenting new challenges from litter deposition. This may also present a beneficial opportunity with a greater range of plant species available to retain toxic elements at the side of the roads with more retention potential. There may however, also be implications for use of chemicals to control plant life. Climate change could also impact on plant species for vegetated channels due to potentially longer drier periods and more intense wet periods.

6.1.3 Heat

The most up-to-date land and marine climate scenarios available for the UK are from the 2009 UK Climate Projections (Defra, 2011). It concludes that all areas of the UK will get warmer, more so in summer than in winter, with central estimates of the average regional summer (June, July, August) temperature rise in the 2080s being between 3 and 4°C.

Capturing Roadway Heat[15]

The impact of increased temperature could result in a reduced requirement for de-icing, but there is also potential to harness the roadway heat and transfer it to thermal banks. This is done by installing a network of fluid-filled pipes under the asphalt road. The heat is transferred to the fluid, which is then pumped into tubes buried under insulating earth. The heat harnessed can be used to rewarm roadways during winter, by lumping the thermal banked fluid back into the under-roadway pipes. The released heat can melt snow and ice on an ongoing basis, keeping roadways clear even during snowstorms. ICAX have developed this concept of 'Inter-seasonal Heat Transfer'[16].

This concept is already in use at Heathrow Airport to keep the tarmac clear of ice and snow all year round.

6.2 Technological and Socio economic Changes

6.2.1 Alternative Fuels and Cleaner Technologies

With the development of hybrid vehicles and fully electric cars having reached an advanced enough level in the present to now be a significant market across the globe it is reasonable to expect that many of the pollutants associated with the burning of fossil fuels will be reduced considerably. A vision from the UK Government that "almost every car and van in the UK will be an ultra-low emission vehicle by 2050" (Highways Agency, 2014) would appear to be an achievable goal. This is likely to be very strongly experienced on the road surfaces around fuel station forecourts, as less fuel leakage and transfer is likely.

The materials used in the construction of electric cars and other alternative fuel combination drivetrains have the potential to be stronger but lighter as vehicle designs push for greater safety but also greater efficiency. With this scenario it is likely that the lighter vehicles would impose less wear on road surfaces, generally resulting in less degradation and loss of material to the local environment. If new materials used in the construction of cars could be stronger and less prone to degradation, then it is likely that there could be less deposition of toxic elements and compounds associated with corroded parts and lubricants. Drivetrain energy recovery systems could reduce brake dust deposition.

6.2.2 Patterns of Travel

Increasing levels of interconnectivity is expected to develop in many ways to enable exchange of information to develop to the point where work patterns may change in location and timing. It is possible that travel by car will become less of a requirement with traffic loads becoming less intensive on certain routes. Patterns of travel may also change. The primary commuter routes of today may become less used while routes between other centres

[15] http://asphaltmagazine.com/advancing-asphalt-roadways-into-the-future/
[16] http://www.icax.co.uk/Solar_Roads.html

may increase in overall numbers and intensity. Distribution logistics for transport, storage and relay of foodstuff and other goods could become more efficient, reducing the frequency of heavy goods vehicles on certain routes leading to reduced emissions and less road degradation.

6.2.3 Environmental Health

With medical and environmental sciences increasing the awareness of detrimental impacts of commonly used compounds and elements, it is possible that there may be technologies and chemicals widely used today that could become a recognised problem of the future. Diesel fuel for example has gone from being the clean fuel for better carbon emissions and greater efficiency to the source of NOx pollution resulting in poor air quality. Designs to treat highway runoff may benefit from an adaptive, cellular system with replaceable technology.

6.2.4 Changing Contaminants

Given the scenarios above suggesting the potential for reduced burden from vehicles, in the future the existing infrastructure may pose more of a quality risk than the cars as materials degrade. Replacement of old barriers, road surfaces and contaminated soils may become a preferential practice for improving runoff water quality and benefitting the receiving environment.

6.2.5 Combined Impact

This all gives rise to a number of scenarios that combine the abovementioned affects. The best of which in terms of highway runoff quality may be significantly cleaner than those of today. But with that comes the uncertainty of future developments which requires an adaptive approach to a changing climate with changing technologies bringing about changes to peoples patterns of behaviour.

6.3 Water Quality Treatment Opportunities

The road surface and the surface of the drainage conduits provide a wide area for qualitative treatment requiring surface area contact as well as storage and retention opportunities.

The porosity of a surface allows volumes of water to disperse into the local environment, reducing the burden on the transportation of larger flows to a location where it is not going to be a problem. The interstitial or minor conduit channels provide a surface area that could be used for reactive transformation of toxic elements. Porous concrete pipes with ferrous component (Dunphy & Beecham, 2008) have been considered for reactive transformation of toxic elements to benign compounds. If this works for concrete pipes, then the road surface, where practicable, could be treated in a similar manner, improving the quality of the water passing through it or retained on its surface.

7 Conclusions and Recommendations

7.1 Bringing Innovations to Implementation

This literature review has identified a wide range of developments in SuDS products and systems. The section below summarises a number of products and retrofits to natural solutions that could be considered as priorities for further investigation, trialling and implementation.

- **Ponds** – Recommended reconfiguration of pond outlets and berms. Solutions such as a Nautilus Pond^{TM} configuration could be retrofitted into existing ponds and should be considered as part of new schemes.
- **Wetlands** – These systems should be prioritised as much as is reasonably practicable as they are the most effective treatment system for dealing with pollutants.
- **Floating Islands/Riverbanks** – Retrofit of products such as Biomatrix Water, Salix and Frog Environmental (BioHaven®) is recommended to improve pollutant concentration reductions in TSS, TN and TP.
- **Filters and hydraulic solid separators** – Trial and utilisation of the products detailed in this report.
- **Bioremediation** – It is recommended that this be followed up with research institutes to understand the potential for use of bacteria and fungi in bioremediation of stormwater runoff.
- **Nanotechnology** – It is recommended that consideration be given to the retrofit of products such as 'LilyPads' for pollutant removal.
- **Phytoremediation** – Further investigation into potential alternatives to typical plants is recommended, this could include plants such as water hyacinth that have been shown to be a model plant for treatment of nutrient polluted stormwater runoff.
- **Source control** – Quality of run off could be improved through the use of different de-icing methods. It is recommended that the use of beet juice (Bee 55) and Beet Heet be investigated further. There may be other products and treatments that could be further investigated also, in the area of de-icing roads, although these were not covered through this assessment. Allowance should be made for potentially further investigation, testing and evaluation of these also.
- **Oil and SuDS** – Preference for exposed soil systems and reduction of moisture content has been shown to improve water quality treatment.
- **Programmable pipes** – Advances are being made regards developing water pipes made of programmable materials that can reshape themselves or self-assemble over time. The water pipes are designed to act like peristaltic structures capable of pushing water through the pipe work on their own. There is an opportunity for Highways England to engage with Self Assembly lab, and utilise IDF to support the development of a product specific to the SRN.

A number of these are ideas that are being taken forward as applications for Highways England's IDF along with some of the wider initiatives also discussed below.

7.2 System Wide Initiatives

The research undertaken for this literature review has identified a number of opportunities and constraints to the increased utilisation of SuDS across Highways England. These have been summarised below and categorised as to whether they are likely to increase the knowledge, attitude, or practice, of Highways England with respect to the implementation of SuDS.

7.2.1 Improve Knowledge

Review data requirements of the ADMM

Currently drainage assets are recorded and managed through the Highways Agency Drainage Data Management System (HADDMS). Routine operation and maintenance is logged under the Asset Maintenance and Operational Requirements (AMOR) system within the Asset Support Contract (ASC). The future Asset Delivery (AD) contract requires parties to consider the requirements of the ADMM[17].

The management of future SuDS systems would, where appropriate, need to be incorporated into these systems. There is an opportunity at present to prescribe what elements of SuDS data requirements would be useful to record and embed this into the requirements of the ADMM as the data management systems (HADDMS, Envis etc.) are required to comply with the manual. This would ensure the recording systems gather the appropriate data.

Improve the quality of consolidated data on SuDS (asset management)

HADDMS currently operates through the design and implementation process, and SuDS information is not explicitly recorded within HADDMS or anywhere else. There is potential to create a data record for SuDS utilised on the SRN. HADDMS also only records inventory and condition, but is not used to schedule or manage maintenance. Further understanding about the benefit of improving asset management of SuDS may be valuable, and potential modifications to HADDMS could facilitate better consolidation of SuDS data. These would link with the updates to the ADMM noted above.

This assessment reported herein has also developed a good database of information regarding existing products. The information in this database can be communicated in a number of ways and this should be continued as a live document that can be shared with Highways England's supply chain and service providers. Future consideration should be given to communicating these findings in a more visual way and how to support users in appreciating which products are more beneficial for their specific application.

Develop a knowledge sharing platform for the UK highways industry

Through conversations and discussions as part of this study it has been noted that a forum to share information is lacking. This forum would look to consolidate the types of knowledge noted above, and it would store, for example the database of products. There are opportunities to connect with repositories such as the National Flood Forum - The Blue Pages (The UKs leading independent flood directory)[18]. However, Highways England may be more open to a highways specific forum that can be internally audited.

[17] Asset Data Management Manual (ADMM) version 6
[18] http://bluepages.org.uk/

Coordinate a forum for discussion to foster collaborative ways of working, and new ideas

Although a workshop was planned as part of this assessment, due to similarities with other organised events this was postponed. Further conversations and discussions have noted the need for an open forum to discuss the products, methodologies and opportunities noted herein would be beneficial to both Highways England, its service providers and suppliers. Highways England should look to facilitate a knowledge sharing event, at which potentially the scenarios posed to suppliers can be discussed, and a round table discussion can be had on how best to deal with the issues Highways England face. There is potential to conduct regular forums for discussion, and for ease this could be undertaken in collaboration with the likes of British Water.

Improve knowledge of the existing SuDS used on the SRN and their performance

Some SuDS technologies are being applied on the SRN yet the outcomes of these products and technologies are not extensively or consistently being evaluated and utilised to inform future SuDS decisions. This results in a limited understanding of the performance of existing systems. There is an opportunity to improve this and consolidate information.

There is a requirement to strengthen the business case for SuDS and this should include evidence of their performance.

Improve knowledge of valuing nature. Potential for value analysis of benefits, including biodiversity (Ozdemiroglu et al, 2016).

Many of the potential outcomes of sustainable approaches are social or environmental outcomes which are hard to articulate, harder to quantify and may occur over the long-term. This makes it difficult to justify investment in such projects in comparison to more traditional counterparts, which have more tangible outcomes in the short-term, established methods and a long track record of outcome quantification. There is currently little evidence, beyond anecdotal evidence, to support claims for some social and environmental outcomes, which reduces investor confidence. It is particularly hard to quantify the future outcomes of, for example climate change adaptation actions, such as cost reduction and economic resilience. This is compounded by the uncertainty associated with forecasting the future effects of climate change.

However, the natural world, its biodiversity and its constituent ecosystems are critically important to our well-being and economic prosperity. As these are consistently undervalued in conventional economic analyses and decision-making[19], a number of research and organisations are looking to improve understanding of the value of nature both in economic and non-economic terms, and improve the use of these valuations in decision making.

For example the UK National Ecosystem Assessment Follow-On (UK NEAFO) was commissioned to address the UK Government White Paper on the Natural Environment – *The Natural Choice: securing the value of nature* (HM Government, 2011. The White Paper's aims for a follow-on to the UK NEA are to help put nature at the heart of our decision-making by:

- Investigating the actions most likely to secure the greatest benefits for people from our ecosystems and their services; and

[19] https://ueaeprints.uea.ac.uk/55826/1/UKNEAFO_Synthesis.pdf

- Developing practical tools to help decision-makers to apply the lessons of the UK NEA.

A wide range of academics, policy-makers, delivery agents and other interested parties from the public, private and voluntary sectors have worked together in the UK NEAFO to further understanding in the following in areas of: economic analysis, cultural ecosystem services, future ecosystem changes and tools and supporting material.

One of the most significant, and deep-rooted, barriers to access to appropriate finance is the articulation and quantification of multiple outcomes, particularly social and environmental outcomes and future outcomes. A series of responses is needed to address these barriers, including developing methods to quantify social and environmental outcomes. A robust approach to quantification is necessary to enable projects generating these outcomes to compete effectively with those focusing on economic outcomes, as below.

- **The National Ecosystem Approach Toolkit (NEAT Tree)[20]**

  The UK NEAFO provides advice for a range of audiences on how to consider all 12 principles of the Ecosystem Approach within each stage of a typical decision-making cycle: Ideas-Survey-Assess-Plan- Deliver-Evaluate. The NEAT Tree links the implementation of the 12 principles within projects, programmes and policies with tools that support the decision-making process. As such, it has the potential to improve the quality of policy- and decision making processes. In addition, the NEAT Tree identifies opportunities for decision-makers to develop their own indicators for addressing the 12 principles of the Ecosystem Approach at the beginning of any project, programme or policy.

  Other guidance, tools and repository's exist that promote the valuation of green infrastructure, and biodiversity:

  - HM Treasury Green Book – for the economic appraisal principles (and using economic value evidence within this context) officially adopted in the UK (HM Treasury, 2013).
  - Green Infrastructure – Valuation Tools Assessment (2013) by eftec for Natural England[21].
  - Environmental Valuation Reference Inventory[22] - The Environmental Valuation Reference Inventory™ (EVRI) is a searchable storehouse of empirical studies on the economic value of environmental benefits and human health effects. It has been developed as a tool to help policy analysts use the benefits transfer approach. Using the EVRI to do a benefits transfer is an alternative to doing new valuation research.

Consideration should be given to how the value of nature is incorporated into Highways England's evaluation of SuDS.

[20] https://ueaeprints.uea.ac.uk/55826/1/UKNEAFO_Synthesis.pdf
[21] http://www.naturalengland/greeninfra/valuationtoolsassessment
[22] www.evri.ca

Investigate how changing future scenarios could impact pollution of road runoff

The main focus of this study is on innovation in the current SuDS sector in order to improve environmental performance. It is however also likely that the context of Highways England's drainage may change in the future. Highways England should consider a study to look at scenario planning and how the impacts of climate change, future road use, and changing vehicle types etc. will impact future road runoff, and how SuDS solutions will need to develop to meet these ever changing scenarios.

7.2.2 Improve Attitude and Practice

Change perception about the cost of SuDS relative to traditional drainage systems

Natural SuDS or vegetated conveyance systems have historically not been incorporated into the Highways England network because of a precautionary approach to operation and maintenance. However, this risk decision making on the maintenance side is not driven by an evidence base.

It is recommended that activities are undertaken to increase the awareness of the comparative maintenance regimes for traditional systems and SuDS. This could include consideration of how maintenance is included within Highways England specific maintenance contracts, such as the agreed maintenance activities within existing ASC contracts (AD has been noted as slightly more flexible) where introduction of new methods/systems are likely to result in compensation claims. A change in consideration of operation and maintenance could be considered for SuDS systems, and how these are fed back into maintenance regimes for the future scheme. Maintenance plans should also be written to consider the careful removal and disposal (and the timing of such operations) of deposited material, in order that this important aspect (particularly on vegetated SUDs and those with filter media) is not neglected in the future.

Clarify the cost of SuDS in comparison to typical SRN drainage operations

Whilst the operation and maintenance regimes are somewhat different between a traditional piped and natural SuDS system, the whole life cost must be considered. A number of tools and reports exist to cost SuDS systems, and inform on the comparison of SuDs to traditional drainage solutions and an opportunity for further work exists for Highways England to evaluate the whole life costs of comparable systems and how SuDS products and technologies impact spend profiles specifically for the SRN.

Highways England's drainage network was originally designed with the requirement of at least a 40 year design life. SuDS, as understood now, cannot be implemented throughout the entire network. To accompany the study highlighted above, there is a potential opportunity for an asset management deterioration study to understand the maintenance and full replacement costs of the existing system, to understand the potential cost implication for varying SuDS implementation scenarios.

There should also be an understanding of whole list cost of SuDS, not just capital expenditure. The total expenditure (including capital and operational) should be considered.

Understand the internal and external awareness/perception of SuDS and existing barriers to implementation

The government let Big SuDS Survey looked at knowledge, attitude and practice with regards to SuDS. Knowledge, attitude and practice surveys reveal misconceptions or

misunderstandings that may represent obstacles to the activities that we would like to implement and potential barriers to behavioural change. A more focused survey could be undertaken internally by Highways England to better understand the barriers to SuDS, including understanding on lack of uptake and the perception of SuDS, both internally and by suppliers.

Promote the importance of drainage/SuDS within Highways England

Drainage assets are understood to make up approximately 15-20% of the overall asset value for Highways England, and in the published accounts of 2010 the overall asset value was stated to be £99bn. Whilst that figure will clearly have increased, the value of the drainage asset is likely to now be well in excess of £20bn. The importance of adequate and innovative drainage and SuDS should not be underestimated.

Assessing the feasibility and appropriateness of a Highways England drainage test facility or options to collaborate with existing organisations who are already looking to do this

Feedback from suppliers indicates that there is no independent UK testing organisation that can verify products. Suppliers have been seeking certification and approval from the following organisations: The British Board of Agreement (BBA), New Jersey Department of Environmental Protection (NJDEP), Water Research council (WRc), and Deutsches Institut für Bautechnik (DiBT). There is an opportunity to collaborate with organisations like UKCRIC who are looking to develop several test facilities, or develop a Highways England test facility to trial products and provide confidence to Highways England that existing technologies could be implemented on the SRN. Consideration should be given to the ability of Highways England to approve proprietary approaches and consideration of other existing facilities.

Understand institutional inertia and the mechanisms that generate and regenerate institutional inertia within Highways England to understand how best to effect change

Institutional inertia is the fact that an organization will remain at rest or if already moving it will continue on the same path unless acted upon by another force. The larger the organization, the more force required, and the harder it is to effect change.

In modern-day governmental agencies, such as Highways England this means that understanding institutional inertia is important. The world changes frequently meaning the requirements change, yet we see organizations often change their course to meet the need or to incorporate best practices with little agility. Some changes are quicker than others and some made rapidly, especially within smaller or more specialized organizations, but to the majority out there it seems change is impossible at worst and extremely difficult at best.

Institutional inertia may be good in some ways as it protects traditions and prevents changing just to change. The tendency of institutions to resist change and thereby stabilize policy can be understood by using the concept of institutional inertia. A focus on the mechanisms that generate and regenerate institutional inertia is beneficial for future research on institutions and climate change, as it can be used to study bottlenecks for action and address more clearly the urgency of necessary policy interventions.

Recent studies have looked at the impact of institutional inertia on climate change, with reviews of the new institutionalist literature on climate change identifying five main mechanisms that generate institutional inertia: costs, uncertainty, path dependence, power, and legitimacy (Rosenchold, Rozema, & Frye-Levine, 2014). A similar study looking at

institutional inertia for sustainable drainage systems may benefit it's uptake on the SRN for Highways England.

Investigate the potential for catchment based approaches

Highways England should be open to using the river catchment to plan flood risk management solutions, understanding the potential for development of collaborative opportunities with other stakeholders. Involvement of multiple partners can offer significant advantages in terms of access to additional land, resulting in water management solutions and water quality treatment solutions that may not have been an option within the existing SRN remit.

Reconsider the language used to describe SuDS in order to remove any barriers inherent in the perception that SuDS are 'green infrastructure' only

It was highlighted throughout this commission that there may be an issue regards the language used to describe SuDS and that this can often be seen as not inclusive. For example when referencing SuDS there is a tendency to then focus the discussion on green solutions, and there is a presumption that SuDS is green infrastructure. As 'soft' and 'vegetative' are not as appealing or practical for highways scenarios as they are for other circumstances, this presumption of SuDS as green infrastructure could potentially automatically create barriers to uptake within a Highways England context.

Consideration should also be given to the fact that if there is a perceived emphasis on 'green' solutions this may impact innovation and manufacturer willingness to invest in future research and development of proprietary SuDS.

There is potential to reconsider the language used to describe SuDS throughout Highways England and industry wide documentation, so that it doesn't create barriers to implementation, and is inclusive to designers, engineers and suppliers of all SuDS products.

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Appendix A

Key Performance Indicators and Performance Indicators

A1 Key Performance Indicators and Performance Indicators

The Government's Road Investment Strategy (DfT, March 2015)[23] sets out a vision and plan for developing the SRN targeting environmental outcomes amongst others, through improved operation, maintenance and modernisation of the SRN. The Performance Specification (DfT, Dec 2014)[24], part of the Road Investment Strategy suite of documents, sets out what Government wants from Highways England over the course of the first Road Period from 2015-16 to 2019-20.

The Performance Specification sets out a number of performance measures that seek to focus Highways England's activities on meeting the needs of all road users and the country as a whole, maintaining a reliable and effective SRN that supports the economy while also contributing to wider environmental and social aims.

The performance measures are made up of a number of Key Performance Indicators (KPIs), supported by Performance Indicators (PIs) which give additional information on Highways England's performance. Some PIs are identified in the Performance Specification, whilst others have been identified and developed by Highways England. Drainage specific KPIs and PIs are noted below.

A1.1 Existing Road Period 1 Metrics (2015-2020)

PI: The number of flooding hotspots and culverts (high risk and very high risk) mitigated

Climate change continues to have a major impact on the country, resulting in more intense rainfall events, flooding and increased runoff and erosion. Flooding in particular continues to pose significant threats to communities living adjacent to the SRN, therefore Highways England need to demonstrate that its infrastructure can withstand the effects of these extreme weather events.

Many SuDS solutions have the potential to increase storage capacity, reduce runoff flow rates and therefore mitigate flooding hotspots and culverts.

PI: The number of outfalls and soakaways (high risk and very high) mitigated

In the event of accidental spills, pollutants are able to enter the water system easily with concrete drainage systems. Water quality can also be affected by pollutants entering the system through surface water runoff and the pollution emitted by vehicles. Sustainable drainage systems could remove a substantial proportion of suspended solids and hydrocarbons before reaching the receiving

[23] Road Investment Strategy: for the 2015/16 - 2019/20 Road Period (DfT, March 2015)
[24] Road Investment Strategy: Performance Specification (DfT, Dec 2014)

watercourse and therefore increasing the number of outfalls and soakaways mitigated.

KPI: Savings on capital expenditure

The Performance Specification specifies cost savings on capital spending of at least £1.212 billion to be achieved by the end of the first Road Period on capital expenditure. The use of sustainable drainage instead of more conventional solutions could therefore have an effect on capital expenditure savings.

PI: Drainage asset – inventory and condition data coverage

In order to measure performance indicators across the SRN, drainage asset inventory records need to be provided within every 100m. Although not directly affected by the use of sustainable drainage, choosing to implement SuDS solutions could affect how this data is collected.

PI: Structure asset – inventory and condition

A1.2 Proposed Road Period 2 Metrics (2020+)

A revised hierarchy-based metric framework has been proposed that sets out three overall environmental KPIs that all other performance indicators feed into.

Flooding and Water quality incidents will therefore be used as a proxy for Natural Environment condition. The following performance indicators are influenced by the effectiveness of sustainable drainage.

KPI: Human Wellbeing

F1: Flooding impact on the SRN – based on a measure of the number of floods, total flood severity index and average flood severity index.

This is a continuation of the flooding performance indicator set out for Road Period 1 with the addition of three internal performance indicators. Sustainable drainage has potential to reduce the number of flood events, reduce the flood severity index and increase the number of mitigation measures undertaken to reduce the impact of flooding.

KPI: Natural Environment

B1: Biodiversity Condition

Highways England proposes that the biodiversity condition is measured by the total area, average condition and distinctiveness of each habitat on the soft estate. Sustainable drainage solutions have the potential to enhance local ecology through the introduction of planting and wetlands.

CH1: Percentage of cultural heritage assets in an at risk condition or in negative condition

SuDS have the potential to put cultural heritage assets at increased risk due to a greater need for space.

L1: Condition of landscape surrounding the strategic road network

Although SuDS solutions could require a greater area of land, they may improve the overall robustness and visual impact of key landscape areas surrounding the SRN compared to more conventional drainage options, this however may depend on the type of solution proposed.

WQ1: Kilometres of rivers enhanced by Highways England mitigation measures

Similar to the performance indicator for Road Period 1, the condition of outfalls are to be monitored to assess water quality. SuDS options have the potential to remove pollutants before reaching an outfall, mitigating the impact on receiving watercourses.

KPI: Carbon

SCC1: Carbon emissions associated with Supply Chain operations and activities – tonnes of carbon dioxide emitted (CO2e)

The construction and maintenance of sustainable drainage solutions will vary between differing options. It is likely that the carbon emissions associated with these activities will be different to those from concrete drains.

Appendix B

Supplier Briefing Note (Case Studies)

Innovation in SuDS

Unlocking the uptake of SuDS on the Strategic Road Network

Background

'Improved Environment' is one of HE strategic outcomes, more specifically this includes addressing pollution and water quality issues through implementation of SuDS as a key priority.

With ever increasing demands to improve the capacity of the SRN network, often within the existing highway constraints, Highways England is looking to explore innovation in SuDS technologies that could be used to supplement existing drainage design practices.

Uptake of conventional SuDs products within the SRN is typically constrained due to a number reasons, some of these include:

- Constrained space
- Significant health and safety implications for maintenance access
- High run-off of contaminant loads
- High level of established assets
- Cost effectiveness

To facilitate a step change in the use of SuDS, Highways England is implementing a number of initiatives within its own organisation, its supply chain and the broader technical community. To this end the objective of this SuDs Innovation Day is to facilitate and stimulate innovation in the sector, specific to the context of Highways England, around:

- **Innovation in application**: adapting existing SuDs approaches in the SRN
- **Innovation in technologies**: what new SuDs technologies are available
- **Emerging products**: forward-looking approach to identify emerging initiatives in SuDs
- **Barriers to uptake**; from the perspective of different groups of stakeholders
- **Opportunities to unlock SuDs**; including the HE Innovation fund and initiatives for future test installations

Issue date: 06/03/2017
Revision number: 1

Innovation in SuDS

Unlocking the uptake of SuDS on the Strategic Road Network

Supplier Engagement

A wide range of stakeholders will participate in the Innovation Day, a key focus area will be facilitating the ability of suppliers to discuss and demonstrate their innovations that are suitable within the context of the Strategic Road Network.

Guidance has been provided in the form of a number of real-life scenarios to help highlight some of the biggest challenges for SuDs uptake on the Strategic Road Network (SRN). Using these scenarios, suppliers are invited to think innovatively about how products can engage with and contribute to delivering improved environmental outcomes in the context of the SRN.

It should be noted that the session is not intended to be an opportunity for suppliers to pitch conventional SuDs products but instead discuss tailored solutions to real-life issues and think about how products can be used in different contexts.

Workshop Outcomes

The outcomes of the day will be:

Greater visibility and understanding of SuDS innovation (current and emerging) relevant to the SRN

Identification of initiatives with potential for testing within Highways England test facilities

Improved supplier understanding of the HE Innovation Fund and access routes to it

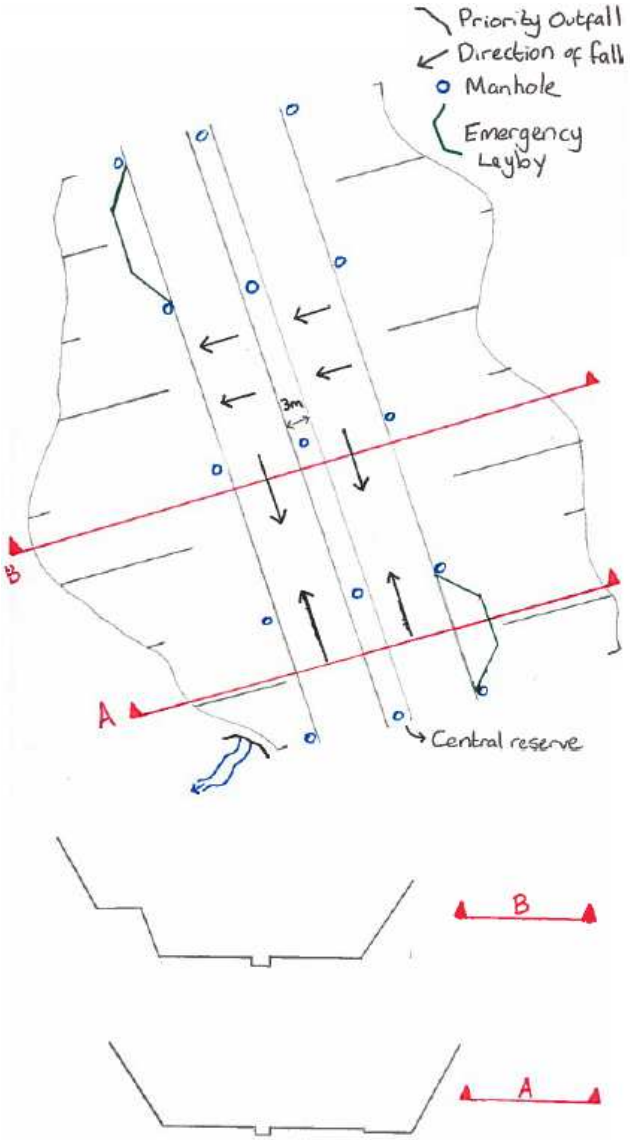
Identification of barriers to the uptake of SuDS within the SRN

Draft Agenda*

Activity	Time
Registration	09:30 – 10:00
Welcome and introduction	10:00 – 10:30
Session 1 – *Innovation in application*	10:30 – 11:45
Break	11:45-12:00
Session 2 – *Emerging solutions*	12:00 – 13:00
Lunch	13:00 – 14:00
Session 3 – *Barriers and opportunities*	14:00 – 15:15
Break	15:15 – 15:30
Plenary	15:30 – 16:00
Workshop close	16:00

*subject to change with responses from suppliers

Scenario 1
Existing highway in cutting



Details

- Existing drainage details unknown;
- Catchment in cutting;
- Emergency Refuge Areas proposed to both sides;
- Access chambers spaced at regular intervals;
- Wide central reserve.

Constraints

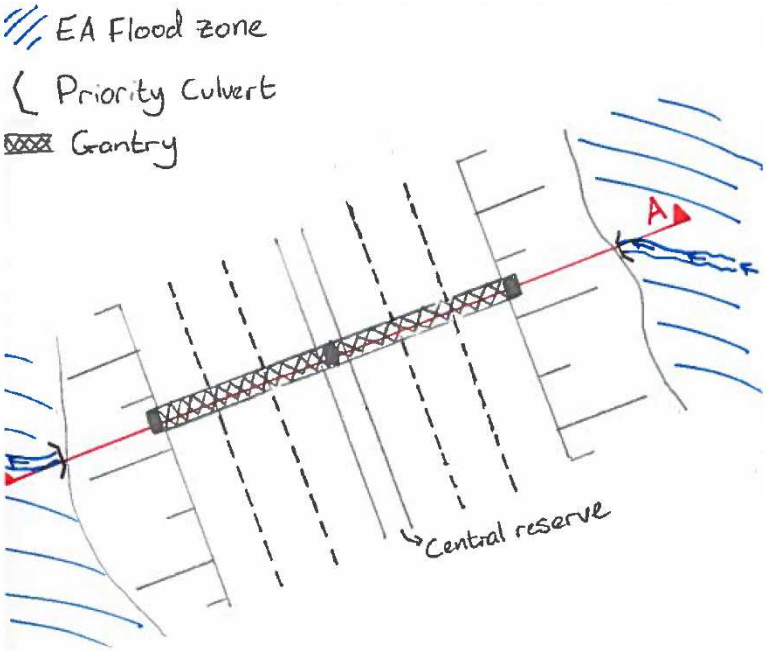
- Localised sag (between cross-sections);
- Priority outfall to sensitive watercourse;
- Site located over an aquifer; and
- No information on local drainage; and
- Carriageway has a high risk of accidental spillage.

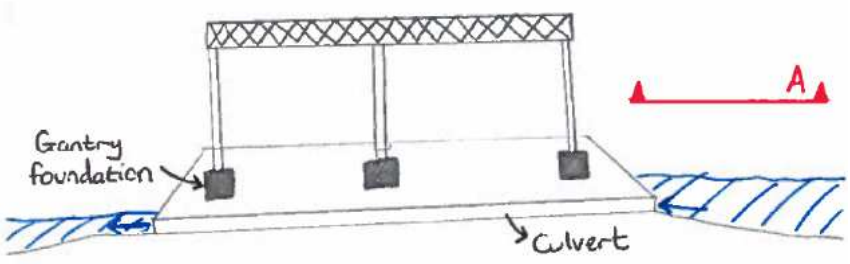
Questions:

1. How may attenuation be used to reduce the runoff rate and maximise storage volume where available space is so limited?
2. How may emergency spillage containment be provided?
3. What techniques would effectively remove/reduce sediment from the runoff?
4. When implementing the above, how would access be achieved and maintenance minimised?

Scenario 2

Existing highway on embankment





Details

- Dual 3 lane motorway;
- Catchment on an embankment;
- Wide central reserve;
- Gantry proposed; and
- Increase in traffic volume anticipated.

Constraints

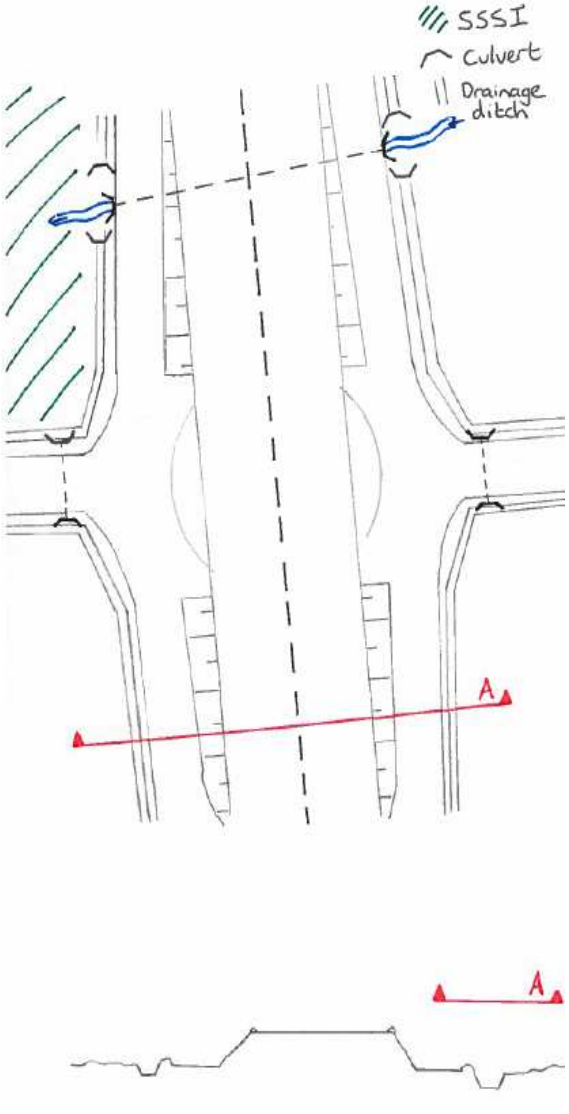
- Priority culvert known to surcharge;
- Catchment sited within a Flood Zone 3; and
- Gantry foundation obstructs central reserve and verges;

Questions:

1. How may attenuation be used to reduce the runoff rate and maximise storage volume outside the flood zone?
2. How may emergency spillage containment be provided?
3. What techniques would improve water quality, particularly in relation to dissolved copper and zinc from the runoff?
4. When implementing the above, how would access be achieved and maintenance minimised?

Scenario 3

New highway at junction/viaduct



Details

- Roundabout junction at low level;
- New highway on embankment /viaduct;
- Local watercourse to SSSI, north-east of junction;
- Junction slip road drainage needed; and
- Boundary ditches considered for low level.

Constraints

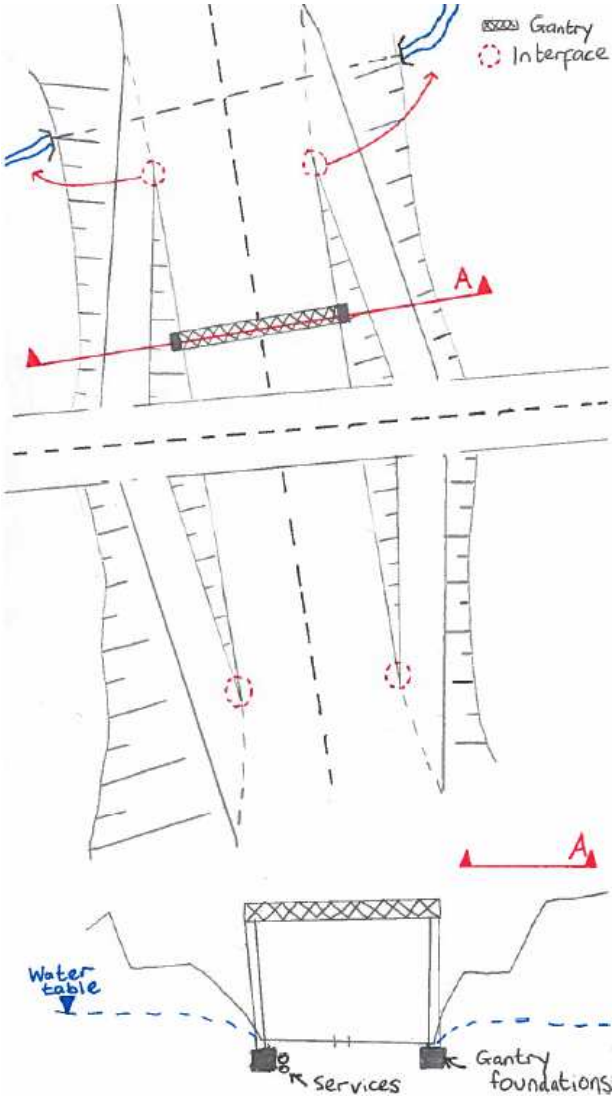
- Site located over an aquifer;
- Discharges to Watercourse through a SSSI receptor; and
- High frequency traffic use of carriageways.

Questions:

1. How may attenuation be used to reduce the runoff rate and maximise storage volume on viaduct, embankments, roundabout or ditches?
2. What techniques would improve water quality, particularly in relation to dissolved copper and zinc from the runoff?
3. When implementing the above, how would access be achieved and maintenance minimised?

Scenario 4

New highway at junction in cutting



Details

- New highway catchment in cutting below existing highway;
- Gantry proposed;
- Junction slip road drainage needed; and
- Multiple utilities proposed in new highway.

Constraints

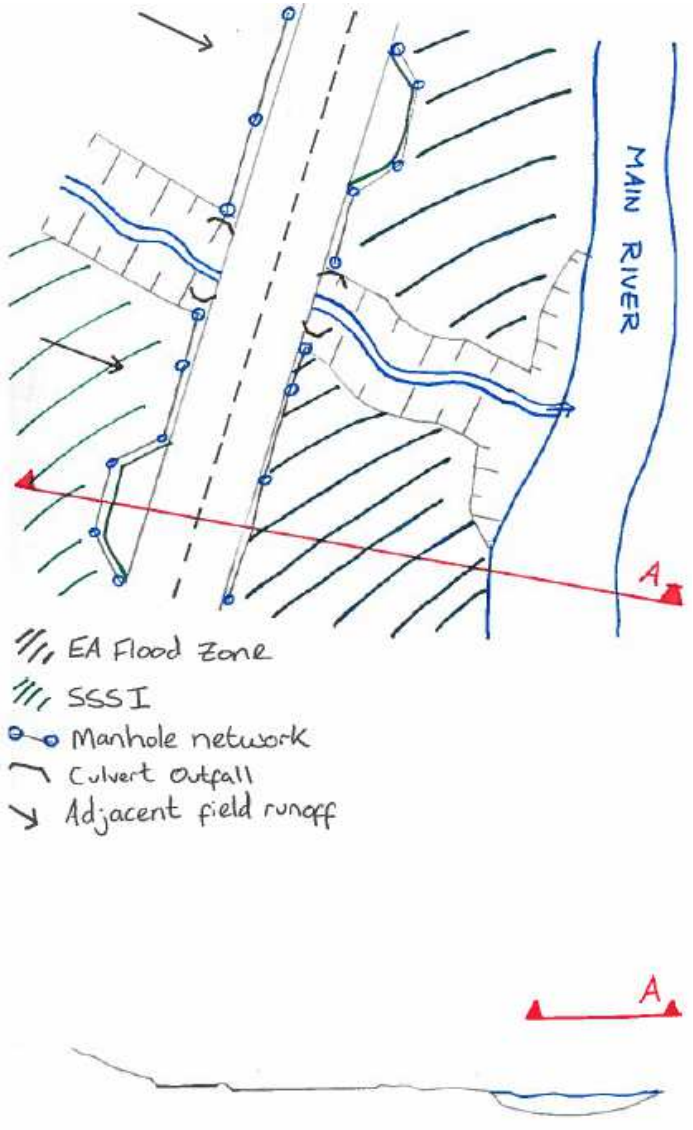
- Gantry foundation obstructs verges;
- Utilities obstruct verges; and
- Shallow ground water table;

Questions:

1. What drainage techniques would mitigate ponding at slip road/highway interface?
2. How may attenuation be used to reduce the runoff rate and maximise storage volume where available space is so limited?
3. How may emergency spillage containment be provided?
4. What techniques would effectively remove/reduce sediment from the runoff?
5. When implementing the above, how would access be achieved and maintenance minimised?

Scenario 5

New highway at grade



Details

- New highway to existing flood catchment;
- No significant earthworks proposed;
- Emergency Refuge Areas proposed to both sides;
- Surface water runoff from adjacent catchment; and
- Discharge to watercourse at local underbridge.

Constraints

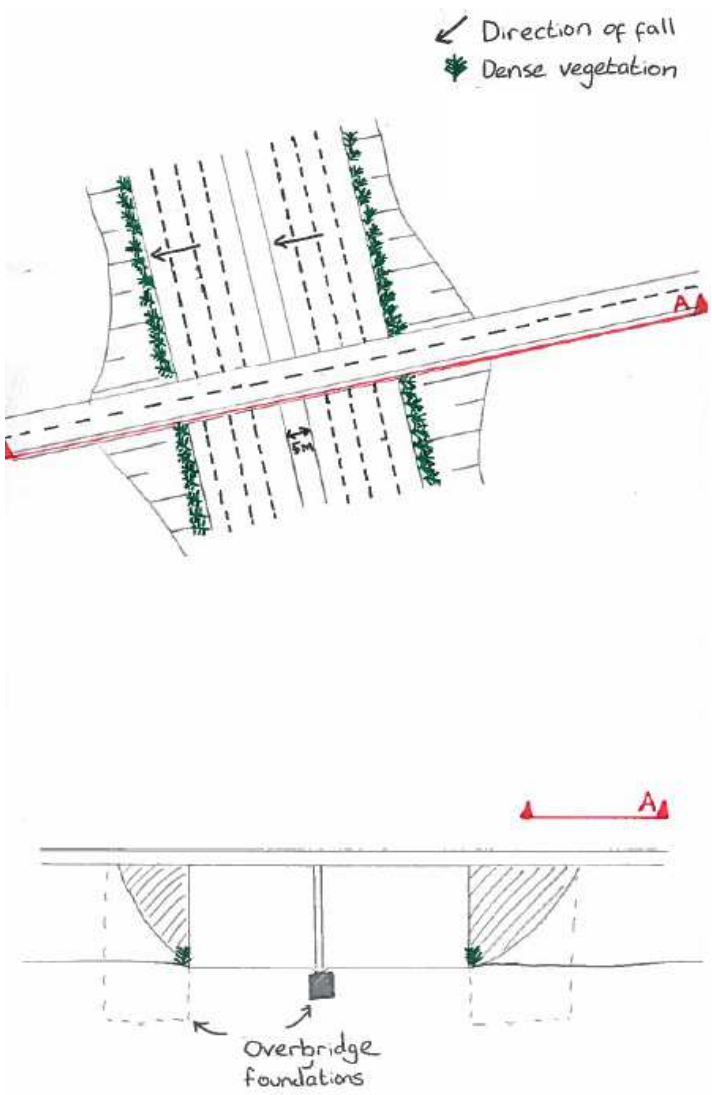
- Ordinary watercourse converges with main river in an EA Flood Zone 3;
- Discharge to Watercourse through a SSSI receptor;
- Outfalls surcharge in flood conditions; and
- Flood protection of the carriageway is needed.

Questions:

1. How may attenuation be used to reduce the runoff rate and maximise storage volume with particular reference to the bridge decking and ERA's (without compromising the flood zone)?
2. What techniques would improve water quality, particularly in relation to dissolved copper and zinc from the runoff?
3. What techniques would effectively remove/reduce sediment from the runoff?
4. When implementing the above, how would access be achieved and maintenance minimised?

Scenario 6

Existing wide highway at overbridge



Details

- Dual 4 lane motorway;
- Retrofit drainage solution required;
- Catchment in cutting; and
- Wide central reserve.

Constraints

- Dense vegetation to existing verges and cutting banks;
- Site located over an aquifer;
- Obstructions caused by Overbridge abutment and pier foundations;

Questions:

1. How may attenuation be used to reduce the runoff rate and maximise storage volume where available space is so limited?
2. How may emergency spillage containment be provided?
3. What techniques would effectively remove/reduce sediment from the runoff?
4. When implementing the above, how would access be achieved and maintenance minimised?

Appendix C

List of Organisations

C1 Organisations

A number of organisations and research institutes have been contacted throughout this assessment. The outcomes of this engagement and awareness of current and potential projects that can inform SuDS for Highways England are documented below.

C1.1 UK Collaboration for Research in Infrastructure & Cities

The UK Collaboration for Research in Infrastructure & Cities (UKCRIC) organisation is looking to develop a national infrastructure research community, spanning at least 14 universities. It seeks to engage with government, commercial organisations and academia to drive innovation in infrastructure, create greater resilience in national infrastructure to extreme events, and versatility to changing circumstances, and provide services that are more affordable, accessible and usable to the general population.

It directly addresses the first four Engineering Grand Challenges prioritised by the Engineering and Physical Sciences Research Council in 2015: (1) Sustainable engineering solutions to provide water for all; (2) Future Cities; (3) Engineering across length scales; and, (4) Identifying risk and building resilience into engineered systems.

The initiative will be supported by 11 interlinked national laboratories for research in science, technology and engineering that underpin the economic infrastructure sectors. Six national observatories, networked for rapid trialling of solutions at scale and gathering/curating large volumes of data about current and proposed infrastructure to allow evidence based analysis and innovation. This will also be supported by six modelling and simulation centres to enable high performance analysis of large scale solutions.

Founding partners include: University of Birmingham, University of Bristol, University of Cambridge, Cardiff University, Cranfield University, University of Leeds, Loughborough University, Imperial College London, University College London, University of Manchester, Newcastle University, University of Oxford, University of Sheffield and University of Southampton.

Southampton's contribution to the UKCRIC scheme is a £36m National Infrastructure Laboratory. This research facility will act as a test centre for heavy structure, geomechanics and infrastructure engineering. One of the main aims of this laboratory is to improve resilience to the effects of climate change and the increasing demands on the rail network.

There is a potential opportunity for Highways England to engage with UKCRIC and the modelling and simulation software and testing facilities that are being developed/created as part of this research.

C1.2 CIRIA / CIWEM

C1.2.1 Susdrain

Susdrain hold an extensive directory of case studies, guidance and tools. This assessment has utilised relevant case studies and information to inform potential SuDS applications on the SRN. Many of the examples are proposed for an Urban Development context and are not suitable for application on the SRN, but susdrains remains one of the largest consolidated sources of SuDS information for the UK.

C1.2.2 Big SuDS Survey

In July 2016, CIWEM launched the Big SuDS Survey in order to gather current understanding and experiences from across the industry on the current planning policy for SuDS. The online survey is believed to be the biggest survey on SuDS to date with a number of professional organisations supporting it, including the Institute for Civil Engineers, Susdrain and the Institution of Environmental Sciences for example. The survey received 539 responses and analysis shows that there is a great need to define SuDS in order to develop a national consistency in approach. One of the most significant responses showed that 70% of those involved in delivering SuDS don't believe that current planning policies encourage SuDS sufficiently.

Survey questions included: Who would you like to see responsible for adopting SuDS and why? Which are more effective at driving uptake of SuDS? Where SuDS are used in a scheme, what are the main reasons for doing so? What evidence is used to suggest that SuDS are more costly than conventional schemes? Do you consider Local Planning Authorities have the expertise in-house to check and advise on quality SuDS deployment and challenge inappropriate planning proposals?

The University of Exeter are analysing results from this survey further and more results will be published in the Water and Environmental Journal later on this year.

This survey looks at knowledge, attitude and practise with regards to SuDS. A more focused survey could be undertaken internally of Highways England to better understand the barriers to SuDS, including understanding on lack of uptake and the perception of SuDS, both internally and by suppliers. Knowledge, attitude and practise surveys reveal misconceptions or misunderstandings that may represent obstacles to the activities that we would like to implement and potential barriers to behaviour change.

C1.2.3 Delivering Green Infrastructure Along Linear Assets

CIRIA are looking to deliver a project focused upon 'Delivering green infrastructure along linear assets.' The aim of this project is to create an essential CIRIA guidance document on this subject, with the project timescale spanning March to July 2017.

CIRIA have highlighted an opportunity to create green infrastructure networks that enhance biodiversity, contribute to climate change adaptation and mitigate noise and air pollution along linear assets (water, energy, transport). Multi-functional green infrastructure can provide interconnectivity between the urban and rural landscape and contribute to reducing whole life costs whilst providing wider environmental, economic and social benefits.

CIRIA will own the project and will be supported by a project steering group comprising relevant stakeholders, experts and institutions such as the Linear Infrastructure Network group (LINet). Arup is engaged to act as consultant to CIRIA for Phase 1 of the project. Phase 1 is a scoping study summarising current and good practise, and identifying a range of case studies and critical success factors to achieve successful integration of green infrastructure along linear assets. Initial findings have helped to inform this assessment where applicable.

Highways England already form part of the stakeholder group and institutions engaged with this CIRIA project (Highways England are part of LINet). However, outcomes of this project should be monitored and any identified opportunities as part of this work potentially proposed for Innovation Designated Funding, if deemed applicable for use on the SRN.

C1.3 Linear Infrastructure Network

As noted in section C1.2.3 Highways England form part of the LINet group. LINet is engaging across organisations to share best practise, bringing together the likes of Network Rail, Highways England, the Canal and River Trust, National Grid, the Wildlife Trusts, academics, developers, government agencies and consultants, with the express purpose of improving the linear features that connect and fragment us and the natural world.

Highways England already form part of the LINet group and should continue engagement with this group to ensure best practise is shared across linear infrastructure providers.

C1.4 Blue Green Dream

The Blue Green Dream is a Climate-KIC Innovation project that ran between 2012 and 2015. It was a Europe wide, Imperial-led project launched in 2012 with a focus of narrowing the divide between the rural and the urban by bringing vegetated green infrastructure solutions to the city.

Blue Green Dream incorporates 16 other academic institutions, multinational companies, SMEs and NGOs including Sainsbury's, AECOM and Veolia Environment for example.

The Blue Green paradigm has emerged as a result of intensifying climatic extremes and rapidly expanding urbanisation. A Blue Green Solutions Guide has been created to help planners and urban developers realise the effects of changing climatic and demographic conditions and create sustainable, resilient and cost-effective solutions for existing and future developments. With the imminent threat to the quality of life in our inhabited areas, there is an increasing need to

rethink our urban systems to create an interconnected network benefitting from reduced air pollution, enhancement of biodiversity, increased urban health and enhanced resilience to extreme climatic events for example.

The Blue Green Dream developed design and optimisation tools and services to create solutions for towns and cities with multiple benefits.

C1.5 Smart Water for Europe

Smart Water for Europe (SW4EU) is a European consortium with the overarching goal of future proofing and designing Europe's drinking water supply of the future. It contributes to the European Innovation Partnership on Water by speeding up innovations and accelerating marked introduction of such innovations. Included in these innovations are things that will contribute to enhancing Europe's competitiveness, creating jobs, enhancing economic growth and solving societal challenges.

SW4EU has 4 key aims:

- To integrate and demonstrate 12 innovative solutions
- To demonstrate 4 integrated solutions
- To establish and guard integration and standardization aspects
- To establish business cases, deployment potential and market uptake routes

Sub-optimal asset management and high leakage levels have been a result of a number of different challenges facing distribution networks. These include a lack of distribution efficiency, a lack of real time monitoring and the need to improve water quality.

Four European test sites have been identified, each with different issues including ageing infrastructure and high leakage, to demonstrate potential integrated solutions for smart management of water distribution channels. With a current water supply that is reactive, ageing and not intelligent, this project seeks to provide a comprehensive, interconnected picture of the pipeline network.

SW4EU are undertaking studies into water quality management sensors. Historically, water quality locations with the focus of primarily providing early warning of blocked trash screens and monitoring other flood defence features resulting in faster, proactive responses in the event of flood conditions. Site visits monitoring has consisted of testing samples in a laboratory and has relied on customer complaints to highlight issues. Real time and online monitoring has developed over the last 10 years but still lacks the ability to test specific and generic parameters, requiring a number of different sensors. SW4EU have developed a number of specific and generic screening sensors that have been successfully tested in the laboratory.

Highways England currently have no involvement with this project. However, the innovations and technologies being developed as part of SW4EU are transferable to a highways drainage network context. For example the sensor technologies

being developed may be installed into SuDS devices to measure the water quality, and this real time monitoring could become part of a predictive, smart asset management system.

Real time monitoring can also be complimented with real time control, where drainage systems can be controlled in real time if process variables of the system are monitored and continuously used to operate actuators. Garcia et al. (2015) summarise relevant real time control strategies that can be applied to urban drainage systems. This summary shows that there are many different software tools to design and simulate drainage systems and this topic should also be further considered by Highways England, as this can aid in: reduced storage; prevention of flooding; minimisation of operational costs; and improvements in water quality and pollution loads.

C1.6 Network Rail and Leeds University

Arup is working closely with Leeds University on a PhD project entitled 'Hydrological and Environmental Processes in Railway Drainage – Sustainable Drainage Systems Approach.' The aim of the project is to establish an accurate hydrological design method allowing the storage within the system to be modelled. Water quality sampling equipment will also be installed into live drainage to assess the potential pollutants. It is hoped that the outcomes of this research will enable the design of drainage systems to minimise the flooding and pollution risk from railways. Arup is working with Network Rail to identify areas that sampling and flow measurement equipment can be installed into existing railway track drainage systems. Over the next three years of this project a number of sites within the Leeds area will be tested.

Although this research project is not highways applicable there is potential for the proposal of research studies (PhD or otherwise) that can assess potential SuDS solutions for highways

C1.7 Academic Institutions

Arup contacted a number of universities and research institutions in May 2017 regarding emerging technologies. There was correspondence with the following institutions:

- Cranfield University (UKCRIC) - Robert Grabowski
- Sheffield University - Virginia Stovin
- Warwick University - Ian Guymer
- Coventry University - Steve Coupe and Daniel Castro
- Exeter University - Zoran Kapelan
- Dublin University - Neil Higgins
- Newcastle University – Jennine Jonczyk

Further academics contacted due to suggestions by Paul Shaffer and colleagues in Arup:

- Heriot Watt University – Scott Arthur
- Sheffield University - Nigel Dunnet
- Middlesex Univeristy - Lian Lundy, Mike Revitt, Brian Ellis
- Imperial College University - Anna Mijic, Karl Smith
- Cardiff University - Tom Beach, Devin Sapsford, Elizabeth Bagshaw, Andrew Staphnill, Mari Nowell
- Glasgow University – Larissa Naylor

After correspondence with Cardiff University, they expressed an interest in exploring the possibility of using wireless sensor technology to monitor water quality parameters.

C1.7.1 Newcastle University

A piece of research has been proposed by Newcastle University that uses natural flood management methods to reduce flood risk and improve water quality.

C1.7.1.1 Approach

Increasing the resilience and reliability of the SRN by managing surface runoff during heavy rainfall, reduces maintenance costs, improves the lifespan of assets, and enables them to function in more severe weather events.

This involves a number of possible interventions across the whole system: (i) Creation of local temporary storage in verges, to slow and temporarily store runoff, will alleviate short term pressure on the drainage network; (ii) Accounting for catchment characteristics to ensure that the functionality is bespoke to its surroundings; and, (iii) Enhancement of local surrounds by creating in-situ nature-based ‘treatment opportunities’, such as sediment capture, carbon capture and air quality mitigation and habitat creation prior to discharge to the river network. This approach can be retro-fitted into existing verges and is low maintenance, by design. The multiple benefits, on top of surface water flood management, of taking this systemic view include:

- Air quality mitigation using vegetation (Tiwary, 2016)
- Physical carbon capture using amended ‘engineered’ soils. Research by EPSRC funded SUCCESS project. This shows that urban soils in which demolition waste is commonly found are capable of removing 85T CO2/ha annually. Thus 12,000 hectares, about a 6th of Highways England’s landbank, is capable of removing 1 million tonnes of CO2 annually.

- Water quality improvements by treatment prior to discharge[25]
- Reducing consequences of hard-engineered drainage failure e.g. carriageway/slope instability (Bromhead, 2012)
- Biodiversity – habitat creation

There are opportunities to provide modular testing of this approach at UKCRIC Water and Green Infrastructure lab, and case studies from 'hotspots' on SRN identified by hydro-dynamic flood models in Newcastle upon Tyne, or at regional or national 'hotspots'.

Opportunities for partnership working with Newcastle University, UTMC (Urban Traffic Management Centre), Local Authorities, EA and DEFRA.

C1.8 Industry Experts

Arup contacted a number of industry experts regarding emerging SuDS technology and ideas:

Paul Schaffer, CIRIA

- "For Highways England's context, innovation around processes more likely to be the future than individual technologies" Paul Shaffer, CIRIA (phone call 22nd May)
- Engaging with regulators and academics internationally would be valuable to Highways England.
- Don't limit the remit to engineers, broaden to include soil science, landscape for example as they will have an important role to play.
- Catchment partnerships with wildlife and rivers trust for example. Improving links with landowners and stakeholders – are any of them doing anything with Highways England? Habitat creation is not a direct driver for Highways England but there is potential for partnership funding.
- Environmental Agency policy officers could be a beneficial partner for achieving multiple outcomes (eg. flood risk) as they may have some useful research which fed into their Rural SuDS document[26].

Jonathan Abra, Water and Wastewater KTN

- Jonathan noted Network Rail have similar challenges and interests, noting the following pages all taken from the challenge page[27]
- Drainage - Efficient and effective drainage interventions (PDF)

[25] http://research.ncl.ac.uk/proactive/belford/

[26] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/291508/scho0612buwh-e-e.pdf

[27] https://www.networkrail.co.uk/industry-commercial-partners/research-development-technology/research-development-programmes/challenge-statements/

- Drainage - Improving drainage asset management decision making (PDF)
- Drainage - Improving drainage system performance (PDF)
- Drainage - Safe and efficient drainage inspections and monitoring (PDF)
- Drainage - Understanding drainage system capability (PDF)

Appendix D

Product Database

Product	Supplier	Type	Category	Function	Summary of Product	Product Link	Rating 1 to 5	Independently Reviewed	Implemented on SRN?	Case Studies	British Water Workshop RAG rating	British Water Comments	Environmental performance	Installation & Decommissioning	Land Use	Maintenance	Cost
Quadraceptor HT 500 (Heavy Traffic)	ACO	Filter/Hydraulic Separator	SuDS	Treats heavy particles, silt, nutrients and dissolved metals. Treats up to 5,000 m^2 and is said to be most applicable at outfalls direct to watercourses.	ACO QuadraCeptor is a specialist rainwater and surface water runoff filtration system for the removal of sediment and harmful pollutants. The ACO QuadraCeptor uses an upflow filtration process, resulting in minimal head loss between the inlet and the outlet. The rainwater is treated within the unit by the following 4 processes:sedimentation, filtration, adsorption and precipitation.	http://www.aco.co.uk/product_detail.php?did=96	5	DIBT, NJDEP/NJCAT	No	Not used on SRN. Supplier suggests it has been used on German Highways but no evidence provided.	Amber	Limited application on the network, only for high risk areas.	Treats heavy particles, silt, nutrients and dissolved metals. Treats up to 5,000 m^2 and is said to be most applicable at outfalls direct to watercourses.	Supplied as a standalone unit in a plastic housing, and easily installed in a load bearing shaft, either standard concrete or plastic chambers.	Small footprint. For larger areas, multiple QudraCeptor units can be manifolded together.	Requires maintenance every 2-5 years. Issues regarding maintenance may be subverted if installed at outfalls by watercourses.	Data unavailable
Jellyfish Filter	Contech	Filter	SuDS	Treats ss and particulate bound pollutants.	Jellyfish removes floatables, trash, oil, debris, TSS, fine silt-sized particles, and a high percentage of particulate-bound pollutants; including phosphorus, nitrogen, metals and hydrocarbons.	http://www.conteches.com/products/stormwater-management/treatment/jellyfish-filter	5	NJCAT, NJDEP, TAPE, MD DOE, NETE, TCEW, VA DEQ	No	The Jellyfish Filter has been tested in the field and laboratory, and is performance verified by the New Jersey Department of Environmental Protection, as well as numerous other stormwater regulatory agencies. Refer to product link for a list of case studies. Has been used on highways.	Not reviewed	Not reviewed	Jellyfish removes floatables, trash, oil, debris, TSS, fine silt-sized particles, and a high percentage of particulate-bound pollutants; including phosphorus, nitrogen, metals and hydrocarbons.	Data unavailable	Appears to take up a large amount of space - features a 'high surface area'	Cartridge replacement is said to be every 2-5 years, likely needs to be done by hand.	Data unavailable
Innolet-G	Stormwater Management	Filter	SuDS	Cartridge and filter media based filter system for treating heavy metals, hydrocarbons, PAHs and phosphates.	Innolet®-G is a cartridge and filter media system to treat stormwater runoff from trafficked surface areas from typical pollutants such as heavy metals (zinc, cadmium, copper, lead), hydrocarbons, PAH's and phosphates.	http://www.wrs-usa.com/Brochure/Innolet%20G%20english.pdf	5	No	No	http://wrs-usa.com/PDF/Study%20on%20the%20road%20runoff%20Filter%20INNOLET.pdf Hamburg Port Authorities.	Not reviewed	Not reviewed	A cartridge and filter media system to treat stormwater runoff from pollutants. Hydraulic performance; 0.5-0.7 l/sec capability.	For retro installations into existing road gullies depending on individual road gully design (plastic road gullies optional available).	No extra land is required. Placed into existing gulley network.	Filter lifetime is 1 year based on 800mm annual rainfall.	Data unavailable
StormFilter	Contech	Filter	SuDS	Utilises media filled cartridges that can be customised to target specific pollutants.	StormFilter is a stormwater treatment device comprised of one or more structures that house rechargeable, self-cleaning, media-filled cartridges that trap particulates and absorbs pollutants such as dissolved metals, hydrocarbons, nutrients, metals, and other common pollutants found in stormwater runoff. The siphon actuated, high surface area cartridges draw stormwater evenly through the filter media, providing efficient, effective stormwater treatment, while the self-cleaning hood prevents surface blinding, ensuring maximum media contact, and prolongs cartridge life. The StormFilter has been verified by some of the most stringent stormwater technology evaluation organizations in North America.	http://www.conteches.com/products/stormwater-management/treatment/stormwater-management-stormfilter	5	NJDEP, TAPE, MD DOE, TCEQ	No	http://www.conteches.com/products/stormwater-management/treatment/stormwater-management-stormfilter#1993113-case-studies	Not reviewed	Not reviewed	StormFilter is a stormwater treatment device comprised of one or more structures that house rechargeable, self-cleaning, media-filled cartridges that trap particulates and absorbs pollutants such as dissolved metals, hydrocarbons, nutrients, metals, and other common pollutants found in stormwater runoff.	Data unavailable	Multiple cartridge heights to meet site-specific hydraulic needs	1-3 years Self-cleaning hood prevents surface blinding, ensuring maximum media contact, and prolongs cartridge life. Vacuum extraction of captured pollutants in the vault is recommended	Data unavailable
Re-Medi8	Stormwater Management	Filter Media	SuDS	Treats suspended solids, dissolved metals and hydrocarbons. Can be retrofit into existing SuDS.	Re-Medi8 engineered bio-remediation soil is a unique and versatile combination of soil and filter. It performs a range of functions across a wide spectrum of applications in order to clean surface water runoff using the processes of filtration, adsorption, ion exchange, phosphate and retention.	http://www.storm-water.co.uk/wp-content/uploads/2014/10/Remedi8.pdf	5	DIBT	No, trial proposed in Area 1	See 'Supporting Information' Supplier comments: Trial proposed for Bristol. Used on European road networks. Where heavy metals involved, may be better as a secondary filter to prevent clogging.	Green	No comments	Re-Medi8 has considerably better adsorption properties. On average: 99% adsorption of zinc and 99% of copper. Re-Medi8 has a water permeability coefficient of 9 x 10-4 m/s.	Easily installed as soil is laid down and can be dug up or left after lifespan.	The media can be incorporated into vegetated SuDS. No change to the land as keeps natural appearance.	Depending on the traffic load Re-Medi8 has a service life of between 10 and 20 years. This is longer than most comparable products.	"circa £950m3 which will treat 720m2 = £0.065-£0.13 cost m2 per annum."
Smart Sponge Family	Abtech/Naylor	Filter	SuDS	Has a few options that treat hydrocarbons, bacteria and heavy metals.	Smart Sponge® is a proprietary combination of synthetic polymers with a unique molecular structure that is chemically selective to hydrocarbons.	http://www.naylor.co.uk/environmental/smart-sponge/standard/on-the-road/	5	No	Yes, Area 8	See 'Supporting Information' Examples of use sent by suppliers. Examples include Wiltshire Council Gully Trials and West Lothian River Protection Trials.	Green	Already utilised on the SRN.	Treats hydrocarbons, bacteria and heavy metals.	Has capability to be retrofitted into existing system.	Has capability to be retrofitted into existing system.	Needs to be checked every 6 months however issues regarding this are likely to be associated with where the sponge has been placed. Purpose designed Smart Pak was designed to last 12 months in a worst case scenario.	Data unavailable
SuDS Swale Inlet	ACO	Drainage Item	Drainage/Erosion	Manages flow rate and volume at swale inlets.	In comparison to traditional in-situ structures and concrete headwalls, the low profile unit provides a natural looking interface between proprietary and vegetated drainage solutions, complementing the surrounding environment.	http://www.aco.co.uk/product_detail.php?did=91	4	No	No	None noted	Not reviewed	Not reviewed	Manages flow rate and volume at swale inlets. It can reduce the erosion rate to a quarter of that of a standard pipe (CIRIA R116) – helping to protect the surrounding environment from erosion and meeting the flow rate guidance in CIRIA C697. Provides no quality benefit.	The one piece unit is placed into position and can be installed using concrete bedding or, alternatively secured with spiral ground anchors. No additional on-site shuttering or formwork is required, removing the need to return to site and ensuring the final stages of a project can be concluded quickly and without hassle.	1 in 3 profile design satisfies CIRIA C697 and can be used for construction of swales. Distributes the flow of water to 6 times the area of a standard pipe.	Low profile design allows maintenance equipment to safely pass over unit. Inspection is simplified because of the consistent design of the outlet making identification of blockages and maintenance procedures easier.	"cost effective alternative"
Up-Flo Filter	Hydro International	Filter	SuDS	Captures SS, oil, hydrocarbons, metals and nutrients.	Capture sediment, oils, heavy metals and nutrients from stormwater, reduce stormwater treatment footprint and cut maintenance costs. The Up-Flo™ Filter is an advanced stormwater treatment solution that combines sedimentation and screening with fluidised bed filtration to deliver exceptional surface water pollution removal. Verified to remove 80% suspended solids but with demonstrated removal rates up to 98%, only the Up-Flo™ Filter was developed in collaboration with the US Environmental Protection Agency.	https://www.hydro-int.com/en-gb/products/flo-filter-0	4	NJDEP	Products noted on network already at BW workshop but no SRN cases studies have been provided or observed as part of this assessment.	Used on stormwater in a port city: https://www.hydro-int.com/en-gb/case-studies/industrial-scrap-metal-terminal-cleans-stormwater-historic-port-city-0	Green	50 products on network already, needs more monitoring in-situ.	Not suited for treating large catchments, potential use for high risk areas. The products also lack documented proof that % removals meet HD33/45 standards.	Delivered to site in a pre-cast conrete manhole, complete with innovative manhole sealing system and internal components already installed. Installation is therefore similar to any other manhole installation on site.	The Up-Flo Filter's higher loading rates result in a smaller treatment footprint.	No moving parts means that there's less opportunity for treatment disruption or breakage Media bags would need to be replaced by hand therefore this process is unsafe if installed near the carriageway.	Data unavailable
First Defense	Hydro International	Separator	SuDS	Captures SS and oil	Smaller than the Downstream Defender it is unlikely that this product is suited to highway catchment areas. Maintenance is said to only require a standard vactor truck therefore should be safe. The products also lack documented proof that % removals meet HD33/45 standards.	https://www.hydro-int.com/en-gb/products/first-defense-0	4	No	No	Helped a constricted and already highly developed commercial area meet stormwater regulations in Ohio: https://www.hydro-int.com/en-gb/case-studies/heavily-developed-site-meets-stormwater-regulations-0 Nothing to indicate potential application on high speed roads	Green	50 products on network already, needs more monitoring in-situ	Works easily with single or multiple inlet pipes and inlet grates. The products also lack documented proof that % removals meet HD33/45 standards.	Every First Defense® unit is delivered to site in a chamber – so installation is as easy as fitting any chamber/manhole.	Data unavailable	Maintenance is said to only require a standard vactor truck Months to years, dependant on site conditions	Data unavailable
Aqua-Filter	SDS	Filter	SuDS	Dual filter and separator that treats ss, nutrients, heavy metals and hydrocarbons.	SDS Aqua-Filter™ uses hydrodynamic and gravitational forces to remove gross pollutants from surface water runoff. It then filters out fine sediments, nutrients, heavy metals and hydrocarbons through percolation, adsorption, biological breakdown and ionic exchange, prior to final conveyance. Size is likely to cause issues regarding space and maintenance in a highways context.	http://www.sdslimited.com/wp-content/uploads/2016/04/SDS-Aqua-Filter_DS1.pdf	4	No	No	Used in Luton Airport and Stoke Gifford Rail Depot. Nothing to indicate potential application on high speed roads. http://www.sdslimited.com/products/aqua-filter/	Amber	Maintenance and space issues	SDS Aqua-Filter™ uses hydrodynamic and gravitational forces to remove gross pollutants from surface water runoff. It then filters out fine sediments, nutrients, heavy metals and hydrocarbons through percolation, adsorption, biological breakdown and ionic exchange, prior to final conveyance.	Bespoke units can be manufactured.	Size is likely to cause issues regarding space and maintenance in a highways context.	Twin access manholes with built-in ladder Provides access to recovered sediments and filtration elements.	"offers a low cost alternative to concrete."
D-Rainclean	Stormwater Management	Filter	SuDS	Biorention channel system that utilises filter media (Stormwater offers Re-medi 8) to treat pollutants.	Requires media replacement every 10-20 years if Re-Medi 8 is used however as it is a channel based system which would be installed along the carriageway, any maintenance or inspection required in this area would be quite dangerous.	http://www.storm-water.co.uk/wp-content/uploads/2014/10/D-Rainclean-2015.pdf	4	No	No	Refer Product Link: B&Q car park	Not reviewed	Not reviewed	D-Rainclean comprises a 300mm polypropylene channel system filled with a unique engineered bio-retention filter media that treats run-off from any impermeable surface.	Simple and easy to lay. Requires concrete reinforcement in trafficked areas.	Standard drainage. Does not require any extra space. Can be driven or walked over.	Maintenance depends on the filter media used. Service life between 10-20 years.	"cost effective car park construction"
Netlon Advanced Turf System	ABG	Reinforced Grass	SuDS	Used to reinforce grass verges.	Netlon Advanced Turf System (Netlon ATS) is a high performance mesh-element reinforced natural grass rootzone system. It provides an aesthetic, SuDS compliant, compaction resistant and free-draining grassed surface, capable of sustaining heavy vehicle loadings in occasional-use applications. Increased water tolerance and accelerated recovery of damaged turf. Includes: Improved damage resistance and recovery rate (50% reduction in recovery time). Improved drainage performance (increased infiltration and percolation rate). Increased soil moisture (up to 50% increase in available soil moisture).	http://www.abg-geosynthetics.com/products/advanced-turf.html	4	No	No	Refer Product Link: York University - Emergency Vehicle, Fire Access Truck and Cherry Picker Access	Not reviewed	Not reviewed	Advanced Turf can be specified as a component of SuDS Source Control, but does not provide water quality treatment. Stated to provide excellent SuDS compliant drainage - surface is never saturated.	Data unavailable	Used as per normal grass placement - in swales - central reserve etc. But could provide a better alternative to paved central reserve if it ensures minimal maintenance.	Data unavailable	Data unavailable
CDS	Contech	Hydraulic Separator	SuDS	Treats ss and oil.	The CDS hydrodynamic separator uses swirl concentration and continuous deflective separation to screen, separate and trap trash, debris, sediment, and hydrocarbons from stormwater runoff. Likely to have similar problems as other separators (expensive and incapable of handling highway catchment areas). Contech is also based in the USA.	http://www.conteches.com/products/stormwater-management/treatment/cds	4	NJDEP, WSDE	No	Used on the I-210 Highway in California: http://www.conteches.com/knowledge-center/case-studies/case-study-details/articleid/1573/i-210-highway	Not reviewed	Not reviewed	The CDS is a swirl concentrator hybrid technology that uses continuous deflective separation – a combination of swirl concentration and indirect screening to screen, separate and trap debris, sediment, and hydrocarbons from stormwater runoff. The indirect screening capability of the system allows for 100% removal of floatables and neutrally buoyant material debris 2.4mm or larger, without binding. CDS retains all captured pollutants, even at high flow rates, and provides easy access for maintenance.	Data unavailable	Same as a standard separator	Has a self-cleaning screen which eases maintenance. Maintaining a CDS can be accomplished in less than 30 minutes for most installations using a vacuum truck, with no requirement to enter the unit. Inspections at least twice a year	Data unavailable
Smartditch	Smartditch	Ditch Liner	Drainage	Lines ditches to reduce and manage flow velocities. Implemented to reduce maintenance requirements.	The SmartDitch® system is a versatile channel lining system made from proven UV resistant HDPE, its unique corrugated design helps regulate the flow of water from flat to steep grades so that the drainage and flow patterns are maintained.	http://smartditch.co.uk/	4	No	Yes, Area 1	See 'Supporting Information' Supplier comments: A38 Refer Product Link also - A38 Bittaford, Devon usage noted.	Not reviewed	Not reviewed	Negates infiltration benefits of soft drainage assets. Has some advantages where groundwater is sensitive, can trap sediment, also helps with veg. management.	20yr life span. Very short. However, easy installation noted on A38 case study.	The land required for this product is no different to regular SUDS drainage channels as it sits in the channel.	"Routine inspection" recommended.	Data unavailable
Hydroblox	Hydroblox	Plastic Matrix	Drainage	Thermoplastic material that traps sediment whilst providing a higher drainage capacity than pipes or stone (in a filter drain).	Unique product that could be utilised in the popular filter drain, modular form provides flexibility. Product is claimed to not clog so could potentially require little maintenance.	http://www.hydroblox.com/products/index.html	4	UKAS	Yes, Area 28	http://www.hydroblox.com/projects/casestudies/index.html	Not reviewed	Not reviewed	Allows for infiltration into substrate, traps silt but does not provide water quality treatment.	Can be easily laid down as a solution for drainage, water treatment, ground stabilization, retention/detention, or permeable paving.	Can be integrated into surface.	Data unavailable	Data unavailable
Enviroflow	Naylor	Plastic Matrix	Drainage	Thermoplastic material that traps sediment whilst providing a higher drainage capacity than pipes or stone (in a filter drain).	Unique product that could be utilised in the popular filter drain, modular form provides flexibility. Product is claimed to not clog so could potentially require little maintenance. Made from 100% recycled thermoplastics, the Enviroflow product is a permanent solution that does not clog, is easy to install and handle, requires little to no maintenance and is high strength and long lasting. The planks offer an alternative to ground stabilisation with better drainage capacity than stone or pipe.	https://www.naylor.co.uk/new/catalogue/enviroflow-drainage-filtration-units/	4	No	No	M25 Junction 30 | https://www.naylor.co.uk/new/public/2017/04/ENVIRO-Enviroflow-Brochure.pdf	Amber	Good that it is demountable	35-45% porosity and per plank it can percolate 18,500mm/hr. Does not treat the water.	Described as fast and easy to install. Case of installing planks to support the earth.	They help stabilise the ground so could be used on embankments etc. to allow for steeper slopes.	Supplier states that the product doesn't clog so little maintenance is required. Product is high strength and long lasting. Further maintenance assessment required.	Data unavailable
Dual Porosity Filtration	waterCare	Filter	Filter	Dual porosity filtration uses a filter or limestone to remove heavy metals, dirt and pollutants from water.	Dual Porosity Filtration (DPF) is an innovative alternative to some methods used for filtration currently. It filters the water through the filter or natural limestone which traps the pollutants, therefore meaning it needs replacing and maintaining. The issue with DPF is that in an existing plant with 6 non-limestone units and 12 limestone units is can only deal with 3L/sec stormwater runoff.	http://watercare.dk/CustomerData/Files/Folders/6-brochure/382_dpf-rensning-engelsk.pdf	4	No	No	Refer Product Link: 18 unit DPF plant at Lynge Nord.	Not reviewed	Not reviewed	Can purify water at rates up to 100 L/sec and treats water in a natural method.	Assumed to be connected to existing pipes that flow into system. Will need infrastructure in place.	Assumed to be integrated into the surface.	1/3 of the filter is flushed 1-2 times a year and 2/3 of the filter is flushed and has its limestone replaced every 15-20 years.	Data unavailable
Floating Islands/riverbanks	Biomatrix Water, Salix, Frog Environmental.	Natural solution	SuDS	Provide pollutant removal through settlement of solids and biological treatment and provide an aquatic and terrestrial habitat.	Versatile, modular floating structures that require permanent water retention to remain biologically active. They are proven technologies in tertiary and polishing wastewater treatment applications and can remove hydrocarbons, oils, phosphates and nitrates through settlement of solids and biological pollutant treatment. Can be easily retrofitted into waterbodies. Minimal maintenance required.	tbc	4	No	No	tbc	Not reviewed	Not reviewed	Removal of pollutants through settlement of solids and biological treatment of pollutants including hydrcarbon and oils, phsphates and nitrates. Provide terrestrial and aquatic habitat.	Easily retrofit into existing waterbodies.	No land required as it is placed into existing waterbodies. Not permanent structures.	Low maintenance as self managing native ecology should be used.	Data unavailable
EcoMedia and Infiltreat	STAR water Solutions	Reactive filter media		Reactive filter media that treats polluted stormwater by way of filtration.	This reactive filter has the ability to remove dissolved contaminants from stormwater including nutrients and metals (including copper, lead and zinc), bacteria and hydrocarbons. Chemical and biological processes allow treatment. Both a vegetated and non-vegetated range has been designed for used in multiple applications and scenarios.	https://www.starwater.com.au/product-item/reactive-filter-media/	4	No	No	tbc	Not reviewed	Not reviewed	Ability to remove dissolved metals including zinc, copper and lead as well as bacteria hydrocarbons and nurtients from stormwater. Particulates can be removed through physical filtration but the lifespan of the media is far greater when particulates are removed through primary treatment. Floating plants absorb 10-20 more pollutants than they would on the shore.	Data unavailable	Data unavailable	low maintenance' quoted on website.	Data unavailable

Product	Supplier	Type	Category	Function	Summary of Product	Product Link	Rating 1 to 5	Independently Reviewed	Implemented on SRN?	Case Studies	British Water Workshop RAG rating	British Water Comments	Environmental performance	Installation & Decommissioning	Land Use	Maintenance	Cost
Topmix Permeable	Tarmac	Permeable/Porous Pavement	SuDS	Allows direct infiltration into substrata.	Topmix Permeable is a fast draining concrete pavement solution that rapidly directs stormwater off streets, parking surfaces, driveways and walkways. This minimises the cost and long-term maintenance for local authorities and developers of stormwater management.	http://www.tarmac.com/solutions/readymix/topmix-permeable/	3	No	No	Large parking areas and residential estates - see bottom page of link. Nothing to indicate potential application on high speed roads, but could be used on EABs, and off the main carriageway.	Not reviewed	Not reviewed	Unlike conventional concrete it has a high void content of between 20-35%. This allows surface water to drain through into the sub-strata and dissipate naturally, reducing the risk of surface water flooding and watercourse contamination. It is not recommended for use in areas exposed to frequent tight turning, heavy traffic areas, HGV routes or bus routes.	Assumed to be installed the same way as regular concrete.	No extra land is required, it replaces existing pavement.	Topmix Permeable has an average permeability rate of 36,000mm/hr. An approximate guide to the average permeability required to cope with a 100-year storm event is 300mm/hr. As the permeability rate of this material is so great, there would have to be an unrealistic amount of dirt applied to the surface for the pavement to cease functioning effectively so maintenance is not required.	Data unavailable
Downstream Defender	Hydro International	Hydraulic Separator	SuDS	Captures SS and oil.	Downstream Defender® is an advanced hydrodynamic vortex separator that removals sediments, oil and floatables from stormwater runoff.	https://www.hydro-int.com/en-gb/products/downstream-defender-0	3	NJDEP	Yes, Area 5	See 'supporting information' First M25 installation: http://www.highways.gov.uk/knowledge/projects/vortex-grit-and-oil-separators/ Supplier comments also note: 71 units in UK, 47 on HE SRN. 31 on M25. Little involvement with asset operation although starting to offer inspection and maintenance services alongside equipment supply.	Green	50 products on network already, needs more monitoring in-situ	Can function as either pre-treatment or as a standalone device.	Data unavailable	smaller footprint than conventional or other swirl-type devices.	Has required emptying every 3 months due to high sediment load from M25. Maintenance requires a standard vactor truck, with no need to enter the space. Maintenance consists of removing sediments from the sump and floatable oils, grease, litter and other debris from the floatables capture zone.	Data unavailable
Vortechs	Contech	Hydraulic Separator	SuDS	Treats ss and oil.	Vortechs is a hydrodynamic separator that combines swirl concentration and flow controls into a shallow treatment unit that traps and retains trash, debris, sediment, and hydrocarbons from stormwater runoff. Likely to have similar problems as other separators (expensive and incapable of handling highway catchment areas). Contech is also based in the USA.	http://www.conteches.com/products/stormwater-management/treatment/vortechs	3	WSDE	No	Used on road improvements in Indiana: http://www.conteches.com/knowledge-center/case-studies/case-study-details/articleid/1487/tilden-road-improvements	Not reviewed	Not reviewed	Vortechs is a below-ground, engineered stormwater treatment device that combines swirl concentration and flow controls into a single treatment unit. Vortechs captures and retaining trash, debris, sediment, and hydrocarbons from stormwater runoff. The Vortechs system's large swirl concentrator and flow controls work together to create a low energy environment, ideal for capturing and retaining particles down to 50 microns.	Data unavailable	Same as a standard separator	Maintaining a Vortechs can be accomplished using a vacuum truck, with no requirement to enter the unit. Inspections at least twice a year	Data unavailable
Hydrodynamic Separator	FP McCann	Hydraulic Separator	SuDS	Treats SS and hydrocarbons.	The unit has no moving parts, requires no power and is constructed within standard precast reinforced concrete chamber rings. Maintenance is said to require a year but is likely to have similar problems as other separators (expensive and incapable of handling highway catchment areas).	http://fpmccann.co.uk/content/products/precast-concrete/drainage-water-management/storm-attenuation-systems/hydrodynamic	3	WRc	No	Product link claims it's suitable in a highway setting but no case studies are presented. Newington Power Centre, Connecticut [http://www.conteches.com/knowledge-center/case-studies/case-study-details/articleid/826/newington-power-center	Not reviewed	Not reviewed	Re-suspension of the solids is minimised by provision of a GRP baffle plate positioned above the solids storage sump. Floatable debris is retained within the Hydrodynamic Separator allowing easy access for suction cleansing. The largest specification can store up to 3199 litres of oil spill.	Data unavailable	Can go up to a 2400mm diameter.	The system needs to be cleaned every 12 months depending on site conditions.	Data unavailable
Nautilus Pond	Frog Environmental	Stormwater Pond	SuDS	A pond that has been designed to give a longer retention time allowing for increased sediment and nutrient removal.	Unique product but obviously requires a lot of space. Could have potential dual use as an attenuation basin with water treatment elements.	http://frogenvironmental.co.uk/product/nautilus-pond/	3	Novatech research paper	No	East Bowmont stormwater retrofit project	Not reviewed	Not reviewed	Removes nutrients and sediment from inflowing water into the pool.	Would be a large project to install as the pond takes up a lot of land.	The case study used a 90m diameter pond so would require a lot of land.	Data unavailable	Data unavailable
Ridgistorm-XL	Polypipe	Hydraulic Separator	SuDS	Treats silt, oil and heavy metals	A 4 stage treatment device, used for the treatment of surface water run-off, providing high levels of contaminant removal, including hydrocarbons and heavy metals.	http://www.polypipe.com/civils-and-infrastructure/water-management-solutions/ridgistorm-xl-surface-water-treatment-devices	3	No	No	None noted	Not reviewed	Not reviewed	The heavy traffic treatment can deal with a maximum catchment size of 650m2.	Polypipe can supply RIDGISTORM-X4 as a standalone unit, or housed within a pre-fabricated chamber. When housed within a chamber, the units are constructed off-site and delivered to site ready to install, making installation quicker, safer and easier with a much lower development footprint.	Same as a standard separator	RIDGISTORM-X4 utilises no moving parts. The filters within the unit need to be replaced on average every two years.	Data unavailable
Fildrain	ABG	Fin Drain	Drainage/ Structural	The findrain collects and channels liquids and gases to a carrier pipe for transportation to a suitable discharge point.	Fildrain findrain drainage geocomposite is a cost effective alternative to traditional stone drainage. It collects and channels liquids and gases to a carrier pipe for transportation to a suitable discharge point. Fildrain findrain has many applications in highway and embankment drainage.	http://www.abg-geosynthetics.com/products/fildrain-findrain.html	3	No	Yes	Refer Product Link: A1 numerous examples. S5 Wroclaw - Poznan Expressway, Poland - Roadside Drainage.	Not reviewed	Not reviewed	Edge of carriageway drainage system to DFT figure F18. Already implemented in UK and Poland. No water quality treatment provided.	Ease of installation sown through case studies already implemented.	Integrates with base of channels proposed. Minimal land required.	Data unavailable	Data unavailable
Nanotech 'Lilypad'	Puralytics	nanotechnology	SuDS	Lilypad placed in lakes and waterbodies remove pesticide, herbicides and heavy metals etc through photochemical reactions.	Sun-activated lilypad, made of mesh with photochemical contaminant-removal technology. They remove a number of contaminants from water bodies using 5 chemical processes. Could be used for the treatment of stormwater before it reaches nearby waterways. USA company but has been implemented globally althought currently still in the early adoption/distribution stage of its life cycle.		3	No	No	tbc	Not reviewed	Not reviewed	Environmentally safe. The technology removes pesticides, herbicides, heavy metals, petrochemicals, pharmaceuticals and micro-organisms from water bodies without chemicals or waste discharge.	Easily placed into existing waterbodies and reusable	Retrofitted into existing waterbodies, placed on the surface	Lilypads have shown to become 50% fouled after 122 hours rising to 80% after 800 hours. Website states 'minimal maintenance requirements'	"The pads will probably cost between $100 and $500 per square metre"
Truckcell	ABG	Permeable/Porous Pavement	SuDS	Allows direct infiltration into substrata.	Truckcell™ is a heavy-duty cellular paving system designed for intensive usage and high-load traffic applications. Nothing to indicate potential application on high speed roads, but could be used on EABs, and off the main carriageway.	http://www.abg-geosynthetics.com/products/truckcell.html	2	No	No	See 'supporting information' and refer Product Link: Park and Ride, Wind Farm, HGV Truck Stop and Permeable Grassed Crane Hard Standings	Not reviewed	Not reviewed	Allows for infiltration into substrate, but does not provide water quality treatment.	Has standard problems surrounding porous/permeable paving in that it would require maintenance more frequently than conventional paving. Could have potential use off the main carriageway.	Can be integrated into existing surface.	Likely to require maintenance more frequently than conventional paving.	Data unavailable
Drainasphalt	Aggregate Industries	Permeable/Porous Pavement	SuDS	Allows direct infiltration into substrata.	A Permeable asphalt which allows water to pass freely through to the underlying structure.	http://www.aggregate.com/products-and-services/asphalt/drainasphalt/	2	No	No	Refer to product link for case studies. Nothing to indicate potential application on high speed roads, but could be used on EABs, and off the main carriageway.	Not reviewed	Not reviewed	Allows for infiltration into substrate, but does not provide water quality treatment.	Data unavailable	Can be integrated into existing surface.	Likely to require maintenance more frequently than conventional paving.	Data unavailable
Hydromedia	Aggregate Industries	Permeable/Porous Pavement	SuDS	Allows direct infiltration into substrata.	Fast draining concrete pavement solution that rapidly directs stormwater off streets, parking surfaces, driveways and walkways. Designed with a sub-base to contain typically 15 - 35% voids, water flows freely through Hydromedia at rates in excess of 100 litres per minute per square metre	http://www.aggregate.com/products-and-services/ready-mix-concrete-screed/specialist-concrete/hydromedia/	2	No	No	Refer product link for case studies. Nothing to indicate potential application on high speed roads, but could be used on EABs, and off the main carriageway.	Not reviewed	Not reviewed	Allows for infiltration into substrate, but does not provide water quality treatment. There are 4 prime versions of Hydromedia. Only the "Hydromedia under layer - Light traffic" version would be applicable in a HE environment, potentially for EABs etc.	Has standard problems surrounding porous/permeable paving in that it would require maintenance more frequently than conventional paving. Could have potential use off the main carriageway.	Can be integrated into existing surface.	Likely to require maintenance more frequently than conventional paving.	Data unavailable
Puraceptor	SPEL	Separator	SuDS	Separator that treats ss and oil.	Likely to have similar problems as other separators (expensive and incapable of handling highway catchment areas). Design means that this product would take up a large amount of space that may not be available on most schemes.	http://spelproducts.co.uk/products/fuel-and-oil-separators/spel-puraceptor-class-1-full-retention-separators/	2	No	No	National Grid Sites	Not reviewed	Not reviewed	The Puraceptor is available in two versions, single or two chamber. An automatic closure device (ACD) is fitted to close off the separator when the contained oil exceeds the maximum oil storage volume. Full retention separators treat the full flow generated by a rainfall intensity of 65mm/hour. Suitable for discharging into a surface water drain.	The large tanks will take a large amount of land when installed as they are buried. Which will also lead to issues decommissioning.	The large tanks will take a large amount of land when installed but will be buried once operational.	Maintenance every 6 months with a 25 year warranty and life expectancy in excess of 50 years.	Data unavailable
Stormceptor	SPEL	Separator	SuDS	Separator that treats ss and oil.	Likely to have similar problems as other separators (expensive and incapable of handling highway catchment areas). Design means that this product would take up a large amount of space that may not be available on most schemes.	http://spelproducts.co.uk/products/fuel-and-oil-separators/spel-stormceptor-class-1-by-pass-separators/	2	No	No	None noted	Not reviewed	Not reviewed	SPEL Stormceptors treat the flows according to the nominal size (NSB) generated by rainfall rates of up to 6.5mm/hour. This covers most rainfall events in the UK. Any excess rainfall is by-passed without treatment.	The large tanks will take a large amount of land when installed as they are buried. Which will also lead to issues decommissioning.	The large tanks will take a large amount of land when installed but will be buried once operational.	Maintenance every 6 months with a 25 year warranty and life expectancy in excess of 50 years.	Data unavailable
Sureset & SureCell	Sureset	Permeable/Porous Pavement	SuDS	Allows direct infiltration into substrata.	Has standard problems surrounding porous/permeable paving in that it would require maintenance more frequently than conventional paving. Could have potential use off the main carriageway.	https://www.sureset.co.uk/paving-ranges/surecell	2	No	No	Nothing to indicate potential application on high speed roads, but could be used on EABs, and off the main carriageway.	Not reviewed	Not reviewed	Allows for infiltration into substrate, but does not provide water quality treatment.	Installation is relatively easy as cellular plastic grid is laid onto the ground and infilled with gravel.	Does not require any extra land take as the drainage is the natural filtration through the plastic grid.	The product has an 18 year guarantee and an expected lifespan of over 50 years.	£518.40 for 36m2
VortSentry HS	Contech	Hydraulic Separator	SuDS	Treats ss and oil.	The VortSentry HS is a compact stormwater treatment system that uses helical flow technology to enhance gravitational separation of floating and settling pollutants from stormwater. Likely to have similar problems as other separators (expensive and incapable of handling highway catchment areas). Contech is also based in the USA.	http://www.conteches.com/products/stormwater-management/treatment/vortsentry-hs	2	No	No	Used in developments in the US but there is nothing to indicate potential application on high speed roads http://www.conteches.com/products/stormwater-management/treatment/vortsentry-hs#1963290-case-studies	Not reviewed	Not reviewed	Low, frequently occurring storm flows are directed into the treatment chamber through the primary inlet. The tangentially oriented downward pipe induces a swirling motion in the treatment chamber that increases capture and containment abilities.	Data unavailable	Buried below the surface with a grate on top at ground level.	Inspections at least twice a year	Data unavailable