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SUDSnet National Conference

November 14th 2007

Coventry University TechnoCentre.

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SUDSnet National Conference, Nov 14th, Coventry University,

CONFERENCE PROGRAMME

Time	Speaker	Affiliation	Title
8.45 – 9.15	*REGISTRATION*		*Coffee available*
9.15 – 9.25	***Phil Chatfield, EA***		Welcome Address
Session 1: Highways SUDS – in Practice		**Chair: Prof. Chris Jefferies, University of Abertay Dundee**	
9.30 – 9.50	**Mike Whitehead** *(Keynote Speaker)* **and Bob Crabtree**	Highways Agency	'The Highways Agency's Research Programme to Reduce the Environmental Impact from Highway Runoff'
9.50 - 10.10	**Howard Robinson**	Tarmac Ltd.	Asphalt Reservoir Pavements for Surface Water Management
10.10 – 10.30	**Gordon Rowlands**	Carnell Contractors	On-Site Recycling – A Sustainable Approach To Highway Filter Drain Maintenance
10.30 – 10.50	**Fiona Napier, Chris Jefferies and Paul Fogg**	University of Abertay/ ADAS	Traffic-Related Pollutants In Soft-Engineering SUDS: An Experimental and Field Approach
10.50 – 11.00	*Panel Discussion*		
11.00 – 11.30	*Break*		*Poster/Display Session*
Session 2: Highways/Roads – Research		**Chair: John Howe, INTERPAVE**	
11.30 - 11.50	**Martin Mansell and Fabien Rollet**	University of Paisley	The Water Balance Of Paved Surfaces In Urban Areas
11.50 - 12.10	**Stephen Coupe and Ernest O Nnadi**	Hanson Formpave / University of Coventry	Water Recycling And Ground Source Heat Pump Systems Within Permeable Paving– System Installation and on-site Construction Considerations.
12.10 – 12.30	**Piotr Grabowiecki, Miklas Scholz and Stephen Coupe**	University of Edinburgh/ Hanson Formpave	The Next Generation Of Permeable Pavement Systems: Functioning, Biological Safety And Water Quality.
12.30 – 12.40	*Panel Discussion*		
12.30 - 1.30	***The 'INTERPAVE' LUNCH***		*Poster/Display session*
Session 3: Planning and SUDS		**Chair: Alex Stephenson, Hydro International**	
1.30 - 1.50	**Andy Swan and Virginia Stovin**	Sheffield University	A Long-Term Planning-Based Approach To Sustainable Stormwater Management
1.50 – 2.10	**Gaye McKay and Wesley Jones**	MWH/ Environment Agency	The Waterlooville Major Development Area, Hampshire: A Partnership Approach For Addressing The Barriers To Implementation And Adoption Of SUDS.
2.10 - 2.30	**Bob Bray**	Robert Bray Associates Ltd	A Sustainable Drainage Design Strategy For Urban Development: Creating A SUDS Landscape To Replace The Storm Sewer.
2.30 – 3.00	*Coffee Break*		*Poster/Display Session*
Session 4: Water and Environmental Quality		**Chair: Sue Charlesworth, Coventry University**	
3.00 – 3.20	**Adolf Spitzer and Chris Jefferies**	Mouchel Parkman Ewan / University of Abertay Dundee	The Potential Of A Water Quality Index For Analysing SUDS Performance.
3.20 – 3.40	**Miklas Scholz and Xiaohui Wu**	University of Edinburgh	Experimental Constructed Wetlands Treating Urban Runoff Contaminated With Nitrogen.
3.40 – 4.00	**Peter Worrall, Sophie Hine and Derek Bateson**	Penny Anderson Associates Ltd	The Role Of Ecology In SUDS.
4.00 – 4.20	*Panel Discussion*		
4.20 – 4.30	*Sum-up and discussion*		
5.00	*Close of meeting*		*Poster/Display session*

Conference POSTERS

Author(s)	**Poster title**
Sue Charlesworth*, Howard Robinson** and Ernest Nnadi* *Coventry University* and Tarmac Ltd***	The Investigation of pollutant retention by Tarmac Aquifa Pervious Pavements
Hartini Kasmin and Virginia Stovin, *University of Sheffield*	Preliminary Evaluation of the Stormwater Performance of a Green Roof
Alex Stephenson, *Hydro International*	Ecovillage case study: An urban village project using proprietary systems and above ground SUDS to provide a sustainable community.
Justine Jones, *SLR Consulting*	Making SUDS work in Different Environments
Gregor Muirhead, *Dougall Baillie*	SUDS and Biodiversity: A case-study from Gartloch Villages.
Yulia Zakharova and Andrew Wheatley *Loughborough University*	Runoff Quality from the M1

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SUDSnet National Conference, Nov 14th, 2007.
Paper Presentations

Session 1: Highways SUDS – in Practice

Chair: Prof. Chris Jefferies, University of Abertay Dundee

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The Highways Agency's Research Programme to Reduce the Environmental Impact from Highway Runoff

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ABSTRACT

In the UK, the Highways Agency (HA) is responsible for the strategic road network England. It also has a responsibility to ensure that discharges of runoff from these motorways and trunk roads meet the relevant legislative requirements. The implementation of the Water Framework Directive (WFD) has introduced more demanding environmental objectives than ever before. There is however only a limited understanding of the potential environmental impacts of diffuse pollution arising from highway runoff that have implications for highway design. To overcome this the HA is, in partnership with the Environment Agency (EA), undertaking a research programme to develop a better understanding of pollutants in highway runoff and their ecological impact on receiving waters. The long term objective is to provide improved guidance on the circumstances when, and where, highway runoff could have a potential environmental impact and, also, where it is unlikely to. This guidance will help inform the HA of the need for, and the scale of, any drainage treatment solution required in order to optimise environmental performance, make efficient use of resources and deliver more sustainable solutions. The use of Sustainable Drainage Systems (SUDS) is one way the HA could deliver these treatment objectives.

KEYWORDS: highway runoff; diffuse pollution, environmental impact, treatment

INTRODUCTION

In the UK, the Highways Agency is responsible for operating, maintaining and improving the strategic road network (SRN) in England. The network comprises over 4,500 miles (over 7,200km) (1) of road and carries nearly a third of all traffic and two thirds of all freight. The SRN is made up of roads ranging from motorways carrying traffic flows up to 200,000 two-way Annual Average Daily Traffic (AADT), to single carriageway trunk roads carrying fewer than 10,000 AADT. Many thousands of drainage outfalls are located across the SRN that discharge highway runoff into receiving surface waters, or groundwater via soakaways. Under existing legislation highway authorities do not require discharge consents. However, for highway discharges it is their responsibility to ensure that discharges comply with relevant pollution legislation (2).

In order to carry out its duties effectively the HA must have a good understanding of when and where pollution from highway runoff may occur. This is technically difficult and the implementation of the EU Water Framework Directive has presented the HA with a significant new challenge that it has had to address through a programme of research in collaboration with the

Environment Agency. This paper gives a general introduction to: 1) highway runoff and diffuse pollution; 2) the implications of WFD and HA policy; 3) an overview of the research programme and 4) summary results from the ongoing research programme.

Highway Runoff

Pollution from routine highway runoff is often perceived as a single definable entity. In reality though it is a complex matrix of interrelated substances and site characteristics In its most simple terms the potential impact of highway runoff is dependant upon a combination of the pollutant content of routine highway runoff and the characteristics of the receiving environment.

Vehicles, road wear and road maintenance produce a range of contaminants that can originate from a variety of sources. These are well documented (3) but a review of historical data, carried out in the early 1990s, indicated that, in general, pollutant concentrations in highway runoff were low and often close to analytical limits of detection(3). A piecemeal approach to monitoring highway runoff and reporting of research results has limited direct comparisons of observed concentrations and loads between more recent studies(3,4). This has made it very difficult to identify with confidence the significant pollutants in runoff, potential environmental risks and any causative relationships. However, it is recognised that under certain conditions, related to the nature and characteristics of the highway, the rainfall/runoff event and the receiving water, it is possible that the pollutants in highway runoff may exert an acute impact or chronic impact (or a combination of both) on the chemical and ecological status of the receiving water (3,5,6). Traffic flow, climate and antecedent dry weather are considered to be potentially important factors in generating pollutants in highway runoff, as are rainfall event intensity and duration. Those factors thought to be of particular importance for surface waters are: water quality, hardness and flow characteristics. The impact on a groundwater may be modified by the pathways between the point of discharge and the receiving groundwater e.g. depth of unsaturated zone; flow type; grain size of soils and lithology.

Implications of WFD on HA Policy

The EU Water Framework Directive 2000/60/EC (WFD) introduced a new framework for the management of water resources throughout the European Union. Its implementation into UK law in January 2004 has presented the HA with new technical challenges that it must address if it is to manage the risks of pollution from its outfalls effectively and efficiently. The principal objectives set out in WFD Article 4 are:

1. prevent the deterioration of the status of all surface and groundwater bodies; and,
2. protect, enhance and restore all bodies of surface water and groundwater with the aim of achieving good surface water and groundwater status by 2015.

One key feature of the Directive is the introduction of a new water status classification. This new classification will describe a water body's ecological status as well as chemical status. The overall status of a surface water body will then be determined by whichever of these is the poorest. For groundwater the aims are not just to protect groundwater from dangerous substances and over-abstraction, but also to recognise the relationship between surface waters and groundwater and their ecology. The principal objective for the Directive is for all water bodies to achieve 'good status' by 2015. Detailed information on how 'good ecological and chemical status' will be measured and achieved is still being formulated. However, it is quite clear that a broader approach to surface water quality will be adopted by focusing more on ecological status than previously. Ensuring that the HA is able to design highways that comply with these new requirements is problematic because:

1. there is a limited understanding of the complex chemistry of highway runoff; and,
2. the current state of knowledge is not yet sufficient to accurately predict the polluting effects of highway runoff on receiving waters.

The Design Manual for Roads and Bridges (DMRB) Vol. 11, Section 3.10 (2) presents UK guidance on the current assessment methodology for the impact of highway runoff and, whilst updated in 2006, is still based on many of the findings of a study completed in 1994 (3). Although developed from the most up-to-date information available at that time the HA's own research programme(4) has identified that aspects of the guidance and techniques used are largely derived from earlier guidance and based upon data that may not be representative of pollutants and concentrations currently found in highway runoff.

Sustainable Development is at the heart of the Directive which encourages the development of sustainable solutions to water management. DMRB Volume 4 Section 2.1(7, 8) provides guidance on the selection and use of drainage systems for the treatment of highway runoff (some of these systems are described elsewhere as SUDS). Their selection is based upon the predicted pollutant concentrations identified from DMRB 11.3.10 and the associated risks to receiving water. Whilst there is some information regarding the performance efficiency of some types of systems for treating highway runoff, it is limited and can at best only be used as a guide to designers. Better information is required regarding optimum design parameters and environmental performance.

Without a robust environmental risk assessment technique and a means to demonstrate effective mitigation, the HA could be asked to provide unnecessarily complex and expensive treatment systems in order to meet WFD objectives. The HA's long term aim, therefore, is to develop improved advice on the circumstances where, and when, highway runoff is likely to have a significant impact on the receiving water environment, and importantly where it will not. In turn, this will improve decision making with regard to both the need for, and scale of, any capital works for mitigation at any given site, and ultimately deliver more sustainable solutions. As a consequence, the HA has been working in partnership with the EA on a long term integrated R&D programme aimed at addressing the key areas of concern listed in 1) & 2) above.

Highways Agency/Environment Agency R&D Programme

The HA have been working in partnership with the EA since 1997 on a joint research programme to gain a fuller understanding of the possible impacts of non-urban highway runoff on the water environment. The first results of the HA and EA collaborative work were published in 2003 (9) and used to update HA policy guidance in 2006 (2,7,8). The results from the study seemed to differ from earlier studies of runoff quality and receiving water impact. These were largely associated with urban highways, higher traffic densities and different regional climates and receiving water characteristics. As a consequence, the Highways Agency and the EA considered it necessary to undertake further research in support of its policy guidance. In particular, we undertook to:

1. enhance existing data to support the development of a more robust methodology to predict the concentrations of key pollutants in routine highway runoff, for non-urban highways;
2. develop ecologically based receiving water standards to control acute impacts of soluble pollutants in highway runoff; and,
3. develop ecologically based receiving water standards to control the chronic impact of insoluble pollutants in highway runoff.

Points 1-3 represent the core research programme and have been the focus of a triumvirate of integrated research studies that have been developed in partnership with the Environment Agency. These are summarised below;

1. Project: The Improved Determination of Pollutants in Highway Runoff – WRc

Central to this programme of research is a systematic approach to measuring pollutants in highway runoff at locations under a range of site conditions throughout England. The project involved data collection from storm events at 24 locations across the SRN. The aim of these measurements is to identify clearly the key contaminants in routine runoff and the relationships between pollutant concentrations and site characteristics. These data will be used to develop a predictive methodology for highway runoff pollution concentrations, and resulting pollutant loads, discharged to the receiving water. The outputs from this model will be compared against ecological thresholds developed, through the sister projects (detailed below), for determining the risk of acute and chronic impacts in receiving waters.

2. Project: The Effects of Soluble Pollutants on the Ecology of Receiving Waters –WRc, White Young Green & King's College London

The project established, under laboratory conditions, the sensitivity of taxa representative of the main types of rivers and streams in the UK to the principal potential pollutants in road runoff. These data have been used to derive Runoff Specific Thresholds (RSTs) for significant 'soluble' highway pollutants (identified in project 1) that when not exceeded will protect receiving water communities from the 'acute' impacts associated with highway runoff.

3. Project: The Accumulation and Dispersal of Suspended Solids in Watercourses - ECUS and the University of Sheffield

The aim of this project is to determine the fate in watercourses of suspended solids discharged from highways and to understand and quantify the processes involved in the partitioning, mobilisation, and bio-availability and bio-accumulation of metal and hydrocarbon contaminants in accumulated sediments. The main aim of this approach is to determine the ecological significance of contaminated sediments in watercourses and develop Sediment Guideline Values (SGV) for significant insoluble highway pollutants (identified in project 1) that will protect receiving water communities from the potential 'chronic' impacts associated with highway runoff. Tools will also be developed to assess whether or not sediment is likely to accumulate or be dispersed downstream of an outfall and, therefore, present a risk of chronic pollution.

While the research programme is in its final phases the development of RSTs and SGVs is ongoing and remains the subject of further consultation and agreement with the EA. It is only possible at this stage, therefore, to present summary findings from the runoff monitoring programme.

SUMMARY OF RESULTS FOR POLLUTANTS IN HIGHWAY RUNOFF AND FUTURE POLICY DEVEOPMENT

A statistical analysis of all the runoff data collected was carried out on a total of 340 events at 30 sites. Details of the study and wider results are presented elsewhere (9). All sites were monitored for rainfall, runoff and event mean flow weighted (EMC) pollutant concentrations of 56 determinands, including total and dissolved metals and PAHs, MTBE, Cyanide, de-icing salt, Nitrate and Total Suspended Solids (TSS), plus particle size distribution of the TSS. This was then reduced to 36 determinands for the majority of sites on the basis that those were the determinands that had been routinely detected and at concentrations that may present an ecological risk. Overall, the results, with the exception of Total Lead, showed higher concentrations of pollutants than those identified in the previous and current Highways Agency design guidance (2, 10), as shown in Table 1. The values for Total Lead are based on data from the 1980s, whereas the new data are considerably lower and reflect the benefits of removing Lead based additives from petrol.

Table 1 Comparison of Current Design Guidance with Monitoring Data

Pollutant	**HMSO 1998 Median EMC* Range**[(10)]	**HMSO 2006 Median EMC*** **Range**[(2)]	**All Monitoring Data Median EMC* Range** [(9)]
Total Copper (ug/l)	10 - 50	13 - 87	13 - 242
Total Zinc (ug/l)	35 - 85	40 - 317	34 - 903
Total Lead (ug/l)	24 - 272	0.13 – 4.00	0.46 - 114
Total COD (mg/l)	28 - 85	41 - 149	48 - 411
Total Suspended Solids (mg/l)	12 - 135	27 - 201	40 - 612

* value exceeded by 10% - 90% of sites respectively

A number of determinands have been identified and agreed with the EA as being ‘significant’ highway pollutants in relation to their potential risk of ecological impact. These have been taken forward for inclusion in the development of a predictive model that will form the basis of an improved design procedure. Table 2 identifies the summary statistics for these significant pollutants

Table 2 Summary Statistics for Significant Pollutants

Determinand	**Units**	**LOD**	**Average EMC**	**Median EMC**	**Average Event Load/1000m^2**	**Runoff Load Units**
Total Cu	ug/l	0.30	91.22	42.99	0.66	g
Dissolved Cu	ug/l	0.30	31.31	23.30	0.16	g
Total Zn	ug/l	0.60	352.63	140.00	2.44	g
Dissolved Zn	ug/l	0.60	111.09	58.27	0.50	g
Total Cd	ug/l	0.01	0.63	0.29	0.00	g
Total Fluoranthene	ug/l	0.01	1.02	0.30	0.01	g
Total Pyrene	ug/l	0.01	1.03	0.31	0.01	g
Total PAHs (Total)	ug/l	0.01	7.52	3.33	0.04	g
Total Suspended Solids (TSS)	mg/l	2.00	244.00	139.00	1.69	kg

A further objective to support the development of the predictive model was to identify any relationships between pollutants in highway runoff and site and rainfall event characteristics. A number of relationships were identified, however, the results indicated that traffic flow (expressed as the two way AADT) had the greatest influence on the concentrations of the significant pollutants. Figure 2 presents a ‘box plot’ illustrating the increase in dissolved Copper concentrations with AADT.

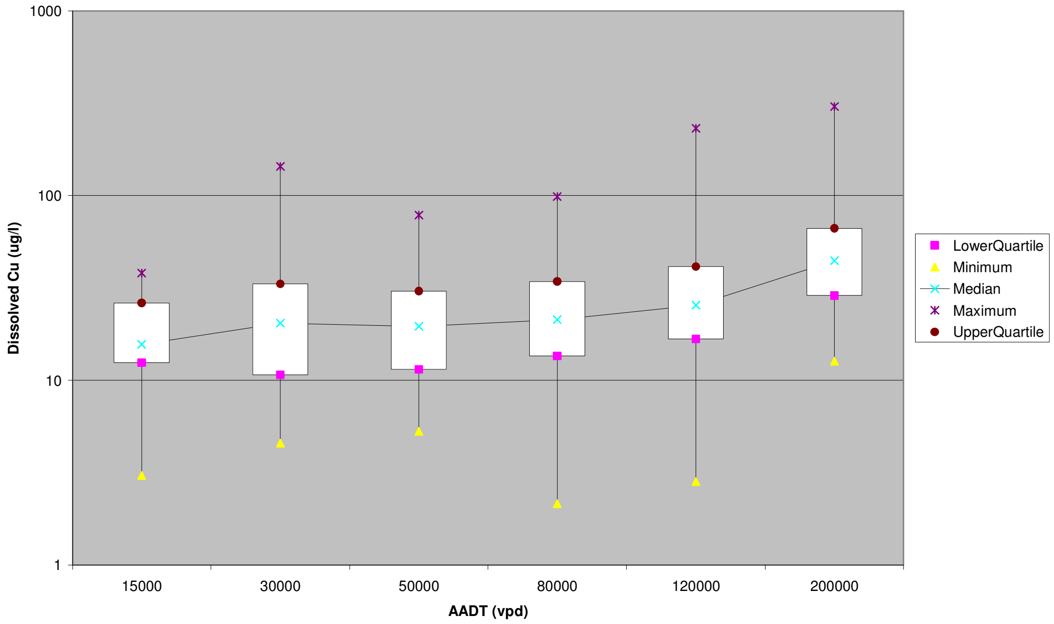

Figure 2 Increasing Dissolved Copper Concentrations with AADT

Work is in progress on the development of a prototype design tool based upon the earlier outputs from the research programme. In concept, this will use the model to predict a 10 year sequence of results for concentrations and loads for the significant pollutants based on a 10 year rainfall time series and the site characteristics. The results will be assessed against the runoff standards (RSTs and SGVs) to identify the risk of ecological impact from acute and chronic pollution in receiving surface waters on a site by site basis.

Better information regarding the degree of environmental risk at a site, and the level of mitigation required to bring highway runoff discharges back to within acceptable environmental standards, will allow more robust decision making with regard to the selection of appropriate drainage treatment systems deployed for mitigation. This will allow resources to be targeted more effectively, and efficiently, in those areas where there is greatest risk of environmental impact. It should also help ensure that the type of mitigation chosen is proportionate with the degree of risk identified although better technical guidance is required regarding the environmental performance of SUDS. This will be the focus of the HA's future research programme.

CONCLUSIONS

For many years the HA has had a wide ranging programme of research and development activities designed to ensure that it's Standards and Technical Advice remain consistent with latest knowledge, best practice; and, promotes innovation. In anticipation of the requirements of the WFD, the Highways Agency has been working in partnership with the Environment Agency on a joint programme of joint research to gain a fuller understanding of the content and potential impacts of highway runoff. A design tool is currently being developed with the EA that on completion will assist highway designers, practitioners and regulators to assess the potential risks of pollution from discharges of highway runoff and, where identified the appropriate measure of mitigation to be applied.

Acknowledgement
This paper has been produced with the permission of the Directors of WRc plc and the Highways Agency and the Environment Agency. The views expressed in the paper are those of the authors and not necessarily of these organisations.

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Asphalt Reservoir Pavements for Surface Water Management

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Abstract

Over recent years there has been increasing media coverage of climate change and related flooding incidents. It is clear industry stakeholders including the Environment Agency, local authorities, designers, planners, material suppliers and the research community need to work together to develop and promote new solutions to alleviate the risk of flooding. Although little used in UK to date, asphalt reservoir pavements can form part of a holistic approach towards meeting the need to mitigate flood damage by enabling flat trafficked areas (roads and footpaths) to act as a sponge and soak up excess rainwater. Asphalt used in this way can also capture and contain rainwater for subsequent reuse as grey water for suitable applications. This paper will report on the development and utilisation in UK of asphalt reservoir pavements over the past 10 years with the aim of increasing public awareness of the benefits this new technology offers.

Background

The effects of climate change, population growth and increasing urbanisation mean that major flooding events are likely to become more frequent in the UK. Recently the UK government announced 3 Million homes are to be built over the next 13 years with a significant number of houses built on land prone to flooding. The hospitals, retail parks and transport amenities required to support this growth simply add to the problem. Increasing heavy rainfall patterns are of concern to water companies and local authorities as high volumes of storm water run off are placing an increased burden on existing drainage systems and urban watercourses. Pollutants settling on impermeable surfaces are swept along and discharged into treatment plants or directly into rivers and streams. Balancing ponds are often used to collect and attenuate the rate of run off from road and footpath surfaces, however whilst effective they often occupy land that could be built on.

Developing sites with hard paved areas and roofs prevents the natural dissipation of rainwater and increases both rate and volume of runoff water. Guidance document PPG25 suggests that Sustainable Urban Drainage Systems (SUDS) enabling recycling of rainwater back to the air and ground should be implemented. The Environment Agency (the agency) advises planning authorities on development and flood risk matters to steer developments away from flood risk areas and to restrict development that would increase risk of flooding. The agency actively encourages local authorities to include porous pavements in supplementary planning guidance on SUDS. House builders are also being encouraged by both the agency and the recently published 'Code for Sustainable Homes' to adopt SUDS porous pavements. The local authorities know there is a presumption in favour of using SUDS and the legislative / regulatory framework is changing to make it more difficult to use conventional drainage design.

Traditionally roads are designed to have dense surfaces and to be fairly impermeable, so rain flows off the road surface into the side drains. However permanent drainage systems are not always able to cope with the severe rainfall we have seen recently. Asphalt reservoir pavements provide a cost effective solution with proven life spans of 20 years or more and at the same time provide storm water management systems that promote infiltration or enable water to be captured for controlled release off site, improve water quality and eliminate the need for balancing ponds. Asphalt reservoir pavements potentially offer significant storage capacity for holding water enabling planners and developers to be better placed to mitigate flood water damage through the provision of alternative drainage systems for capturing and controlling the release of surface water.

The concept

Asphalt reservoir pavements have been used in France for over 20 years around Bordeaux and Paris, the USA and Sweden. Bordeaux is located in a low lying area and is particularly prone to flood water damage so permeable pavements are now required on all new developments. The French focus on water retention and controlled release either into the sub soil or into the outfall drainage system. Cleansing outfall water before it is released back into the natural environment is also a key driver. Reservoir pavements are able to retain and reduce the release of water borne contaminants with bacterial action inside the pavement playing some part in this.

Rainwater percolates rapidly through the asphalt surfacing into a porous sub-base material where it accumulates (reservoir) before dissipating more slowly into the sub-soil or removed through drains into the main surface water drainage system. This process helps to relieve storm water surges and reduces the risk of flooding caused by permanent drainage systems becoming overloaded.

Balancing ponds can be replaced by reservoir pavements located in parking areas, lightly trafficked roads, sporting facilities, housing estates, school playgrounds, footpaths etc. They also help to reduce traffic noise and filter out pollutants in rainwater. Asphalt reservoir pavements are constructed using standard materials, however special polymer modified asphalts can also be used in the surface course to improve toughness and resistance to stresses caused particularly by power steering. The basic concept is to lay 2 or 3 open graded asphalt layers on top of a specially graded granular base layer. The overall pavement thickness is designed to provide the necessary level of structural and hydraulic performance required by each site. The French have experienced consistent performance with pavement design life typically 20 – 30 years. The French have developed pavement design guidelines which offer a full suite of alternative designs to suit particular applications i.e. offering controlled water retention, release, cleansing and noise reduction. Uniformly graded aggregate with 35% voids to store storm water Porous asphalt surfacing Optional filter fabric

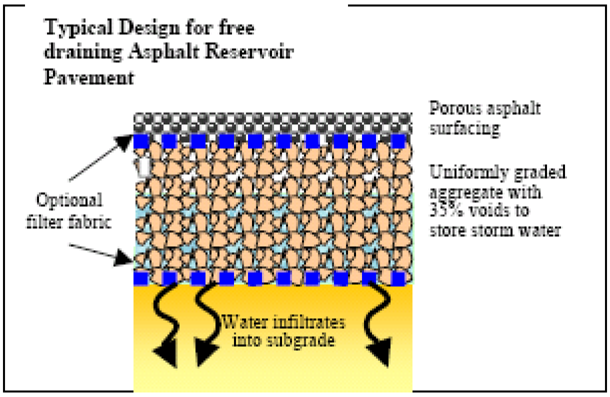

Figure 1. Typical Design for free draining Asphalt Reservoir Pavement. Water infiltrates into subgrade offer a full suite of alternative designs to suit particular applications i.e. offering controlled water retention, release, cleansing and noise reduction.

Market and Drivers

The main markets for asphalt reservoir pavements appear to be lightly trafficked areas i.e. carparks, retails parks, housing estate roads, pedestrian areas, service roads and the like. The French do however also use them on more heavily trafficked urban roads. Poured concrete reservoir pavements, as opposed to block paving, are also available for heavy duty applications. Over the past few years a number of regulatory and environmental issues have emerged which now appear to be driving the need for reservoir pavement solutions. - In 2002 the building regulations were amended to demand the inclusion of ‘mitigating design features’ for new build proposals in areas prone to flood water damage. - PPG 25 ‘Development and Flood Risk’ promotes SUDS for storing surface water e.g. swales, ditches and ponds, however these options sterilise development land. - CIRIA and the agency have issued national guidance to planners, developers and local authorities on SUDS which recognises the need for porous surfaces to capture flood water and thereafter control the outflow rate whilst also ‘cleansing’ and improving the outflow quality before it reaches the natural environment. It is recognised that reservoir pavements optimise land availability for building on.

Experience to date

The first scientific trials of porous pavements were carried out in Pennsylvania and Texas in 1977. This resulted in the production of a design guide which formed a basis for subsequent developments. Since then a growing number of porous pavements have been constructed in the USA resulting in the introduction of a design guide by NAPA in 2003. Developments are more advanced in France where they are known as reservoir pavements by virtue of having a thick granular gap-graded sub-base to temporarily store water. In Bordeaux over 400 reservoir pavement schemes have been implemented since heavy rainfalls in 1982 threatened further development. The proven durability of these pavements in low traffic sites has led to their widespread adoption throughout France.

In the UK, the role of permeable asphalt paving is referred to in the CIRIA SUDS guide. One of the earliest UK trials of an asphalt reservoir pavement took place on a carpark in a Tarmac quarry near Bristol in 1999 and continues to perform well both structurally and hydraulically. Maintenance may be required to ensure the pavement permeability remains functional using water jetting ‘suction’ equipment to unblock the pores. The frequency of cleaning will be site specific, for example Tarmac’s quarry carpark has been cleaned once over the past 8 years in 2005 using a mobile suction plant (see photo below) restoring much of the lost conductivity caused by clogging.

Cleaning Tarmac’s asphalt reservoir pavement

A 20,000m^2 retail carpark was built by Tarmac in Portsmouth (2002) using asphalt reservoir pavement technology (see photo below). The carpark now 5 years old continues to perform well.

The car park was constructed on a flat site a few metres above sea level. This posed difficulties in the provision of an effective run-off gradient for the out-flow drainage system. The designer did not want to use blocks due to the large area involved and was restricted as to the volume of water run off they were allowed to introduce into the existing storm drainage. The infiltration system used avoided difficulties in designing a full capacity out flow drainage system in a very flat, low lying area where water would have to flow a considerable distance before emptying into the sea. This resulted in reduced costs and also ensured the absence of standing water in the car park which is important for a retail outlet where customer safety and comfort are paramount.

The construction used crushed concrete as the granular base and the hydraulic performance of each asphalt layer was tested to assess compliance before laying the next layer. The Transport Research Laboratory assessed the pavement condition using a falling weight deflectograph (FWD) prior to the official opening. The results showed that there was consistency throughout the site in terms of both stiffness and deflection and the structure was considered suitable for the purpose that it was designed for. Because positive drainage was not necessary there was an overall significant cost saving to the main contractor.

Tarmac have been developing asphalt reservoir pavements in the UK since 1997 (patents granted) and are able to offer a bespoke design, build and maintain service backed by guarantees. The use of special polymer modified asphalts and other additives are key to delivering a long life reservoir pavement. Maintenance of hydraulic conductivity is another important aspect which Tarmac are well placed to advise on following extensive research. Tarmac's asphalt reservoir pavement technology has been tested extensively since 1998 in trials and the Transport Research Laboratory have independently validated the systems structural performance. Reservoir pavements can be used on carparks, estate roads, basically anywhere that is lightly trafficked, although the technology is being continuously developed to enable it to be used on heavier trafficked sites.

Benefits

Asphalt reservoir pavements provide a SUDS solution, benefiting the environment and enabling a faster construction technique. As well as reducing or eliminating storm water runoff and flood risks, they help to recharge ground water levels. They also reduce the need for curbing, surface water sewers and balancing ponds. They can be used as soak-a-ways to deal with runoff from roofs and other paved areas. In addition to removing pollutants from runoff water, safety and user comfort is improved by the reduction in noise, spray, glare and standing water. In terms of construction cost they offer significant savings compared to conventional pavements which incorporate positive drainage. Grey water harvesting and reuse is another option and the area available for potential development is maximized. Asphalt surfacings also offer adequate skid resistance for vehicular traffic.

Environmental Considerations

To better understand the risk to the environment from allowing water to drain through the structure into the sub-grade, research at Coventry University has been conducted to measure the cleansing efficiency of Tarmac's asphalt reservoir pavement. This work will be reported fully at a later date however some of the main conclusions are given below:

1. Water containing street dust was applied in measured amounts onto the surface of a number of different asphalt test rigs each having different layer types and thicknesses, the aim being to capture the outflow water at the base of each pavement structure and measure pollutant levels.

2. The heavy metals present in the outflow samples are at concentrations below the WHO drinking water specifications. Because the concentrations detected were very low it proved very difficult to determine any trends.
3. The outflow pollutant concentrations are all well below the applied concentrations apart from Cadmium. Copper is consistently present in the highest concentrations from each rig with mainly Lead second followed by Zinc in line with the concentrations found in the applied pollutants.
4. Suspended sediment concentrations are all mainly below background levels suggesting that it is being trapped within the test rigs.
5. Used engine oil was applied every 4 weeks as a single dose to each test rig at a rate of 25 ml/m^2 until the effluent oil concentration reached 10mg/l. All of the concentrations measured in the outflows from each test rig were below 1 mg/l so the amounts coming out in the effluent are low. Previous work suggests that up to 98% of the oil will be retained in the pavement.
6. Initial results from the Tarmac study indicates that the pollutants which have been applied to the rig surfaces are being held in the test rigs and that applications have yet to reach a threshold beyond which more may be released.

Conclusions

Asphalt reservoir pavements are now available in the UK from Tarmac and have a significant part to play in the UK SUDS strategy for managing surface water in particular for mitigating storm water damage. Considerable economic benefits accrue from using such systems not least build time is significantly reduced through discounting the need to install permanent drainage and captured water can be recycled as required in a cleaner state than when it entered the pavement.

Acknowledgments

Guidance provided by the Coventry University research team: Sue Charlesworth, Professor Chris Pratt, Dr John Davis, Lorna Everall and Phil Chatfield of the Environment Agency is gratefully acknowledged.

On site recycling – a sustainable approach to highway filter drain maintenance

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Introduction

This paper reviews an on-site method for the refurbishment of highway filter drains that enables this important drainage asset to be brought back into full working operation with the minimum use of new stone and a greatly reduced number of HGV movements. The process has been proven in operation over the last 4 years and that experience is used here to focus attention on construction and maintenance issues that are of broad concern to the SUDS community.

Filter drains are recognised as an important SUDS asset, with the advantage that they both attenuate water flow and filter out a major portion of suspended solids, together with significant quantities of hydrocarbons and heavy metals derived from vehicle use of the highway. They have the further advantage of treating the stormwater at source.

In simple terms the filter drain is a trench with a porous carrier pipe at the bottom, back-filled with graded stone. Typically the trench will be 1 m wide with up to a metre depth of stone, with a void porosity of perhaps 25% if Type B angular stone has been used. A three lane carriageway with a hardshoulder is around 13 m wide in total, which means that the drain has a static capacity equivalent to around 19 mm rainfall.

The strategic road network in England is around 7,500 km in length and filter drains are present on around 50% of the network. Hence there is around 7,500 km of filter drain on this network. See Figure 1. The total highway asset in England is valued at £72 Billion, with drainage comprising 9% of this total at £6.48 Billion. Although the English network is only 2% of all roads in Great Britain it carries 31% of all traffic in Great Britain based on total vehicle miles travelled.

Figure 1 is effectively a picture of a stormwater collection and discharge network - around 180 million m^2 of road surface collecting approximately 150 million m^3 rainfall per annum across the network as a whole, using the average rainfall figure for England in 2006. From the point of view of road operators, this 150 million tonnes of stormwater is waste ie. they need to discard it because it is a hazard to road users with respect to braking and visibility and it can weaken the road if in prolonged contact with the substructure.

The challenge of managing highway runoff

All waste producers have a legal duty of care to dispose of their waste in way that does not endanger the public or the environment or cause a public nuisance. Hence stormwater must be discharged without causing flooding and without detriment to water quality, bearing in mind that groundwater may also be polluted if appropriate drainage measures are not in place.

Unlike a factory operator who may create contaminated waste as a by-product, the road operator has no control over how much rain falls, where it falls, or when it fall, or over the number of vehicle movements and the pollution they cause.

The pragmatic approach to this problem is to design drainage systems that can handle intense or extreme storm events and to ensure that steps are taken to protect the most vulnerable outfalls, taking into account the capacity and resilience of the receiving water network.

With respect to water quality, this is currently being tackled by the Highways Authority (HA) by setting and achieving annual targets to deal with the highest priority outfall locations. However, new outfall sites will become priorities as targets are set to improve water quality as well as protect it. Furthermore, given the complexity of the road network, there is incomplete information on outfall locations and where this is the case treatment at source is a more prudent approach.

Turning to the handling of intense or extreme storm events, these cannot be tackled by design alone because the quality of construction and an ongoing commitment to maintenance are essential for achieving sustained drainage performance. As with all SUDS, quality of construction and planned maintenance are essential for sustainability.

Filter drain construction – stone specification

Figure 2 shows the upper and lower limits of the Type B specification for filter drain stone with a typical example for filter drain material. Figure 3 shows typical trial holes (these from the M6). The Type B spec aims to provide a narrow size distribution, with at least 80% between 20 and 40 mm, and the fines content as measured by the amount of material passing a 10 mm sieve should not be greater than 5%. The Type B specification does not refer to particle shape, but it is generally accepted that angular stone is to be preferred because it provides increased void space.

In practice it is not unusual to find 20% or more fines < 10 mm. This is far greater than the amount of material likely to be washed into the drain from the highway and is likely to be due to a poor grade of stone being used in the initial construction or subsequent maintenance. Figure 4 shows the fines content at 400 and 800 mm depth for a North & South bound section of the M25.

It is generally considered that fines washed in from the highway, together with associated pollutants, are more likely to be deposited within the top 300 - 400 mm of the drain. This is supported by chemical analysis which shows that the heavy metal concentration is higher at 400 mm compared to 800mm (Figure 5). A typical particle size distribution of arisings from filter drain refurbishment (see below) is shown in Figure 6.

The implications of this for filter drain refurbishment are that a filter drain may well require attention down to the vicinity of the carrier pipe in order to realise the full hydraulic capacity of the drain. Of equal importance in assessing the performance of a filter drain in a specific location it is necessary to characterise the as-found particle size distribution and the extent to which any maintenance has been previously carried out.

On-site recycling of filter drain media

The stone material used in filter drains is a natural non-renewable resource and hence it makes sense to recycle the stone whilst removing the fines. Dig out and replace with new stone requires large quantities of virgin stone to be brought on site, whilst large quantities off silted stone & fines have to be taken off-site. In addition to the significant number of HGV movements required for this, there is also a large amount of dug-out material destined for landfill if it is not recycled off-site to reclaim the stone.

The patented process developed by Carnell provides mobile plant (StoneMaster) that can physically remove the fines from as dug material without the use of water, returning cleaned stone to the trench at the rear of the operation whilst the fines are conveyed to the front of the operation for removal off-site by tipper vehicles.

Figure 7 shows before and after pictures of refurbishment work carried out on the M4 in Eire. Figure 8 shows the plant in operation on the A82 in Scotland. Around 300m per shift can be undertaken day or night at any time of the year, within the hardshoulder when present, to minimise disruption for road users. Results are typically at least 98% over 10 mm compared to the minimum requirement for Type B of 95% (see Figure 9.).

Refurbishment of the filter drain provides an opportunity for stabilising the drain against vehicle over-run and stone scatter, using the patented StableDrain process. This involves the incorporation of a geogrid into the drain at a depth of 150 mm. See Figure 7 (right). The advantage of this process is that the geogrid does not impede water flow and does not give rise to any concerns about possible water contamination or recycling at a later date.

Waste management

The removal of fines from drainage systems is a cleaning process and having separated those fines they become a controlled waste, their disposal being subject to waste regulations. These regulations cover all aspects of disposal including handling, storage, transport, transfer, treatment, recycling, and landfill and are enforced by the EA in order to protect the natural environment and public health, and prevent public nuisance.

Waste that contains dangerous substances may be referred to as contaminated waste, but there is no legal definition of contaminated waste within the waste regulatory framework, which requires waste to be classified as either hazardous or non-hazardous. Chemical analysis has established that filter drain arisings are non-hazardous.

Waste regulations also classify landfill sites as to whether they can accept hazardous, non-hazardous, or inert waste and EA guidance is provided on the criteria that need to be met in each case. The concept of inert is principally concerned with the protection of groundwater, as inert landfill sites are not lined and there is a danger that leaching of the waste may lead to the subsequent contamination of groundwater.

The option of being able to use non-hazardous or inert landfill is important for both economic reasons and logistics bearing mind that access to landfill sites may require considerable travel times including the return journey. Opening times of landfill sites also have to be taken into account as temporary storage of waste is subject to waste regulation.

Certain wastes are deemed to be inert such as glass and brick, and these require no testing to be accepted at inert landfill sites. However, other non-hazardous wastes need to be leach tested using a prescribed method in order to show that they meet the waste acceptance criteria (WAC) for inert landfill. WAC testing of filter drain arisings has shown that leach rates are low and well within the limits required for disposal at inert landfill. This in part is because the concentration of vehicle pollutants is relatively low, but also because the filter drain by its nature is subject to stormwater leaching over many years.

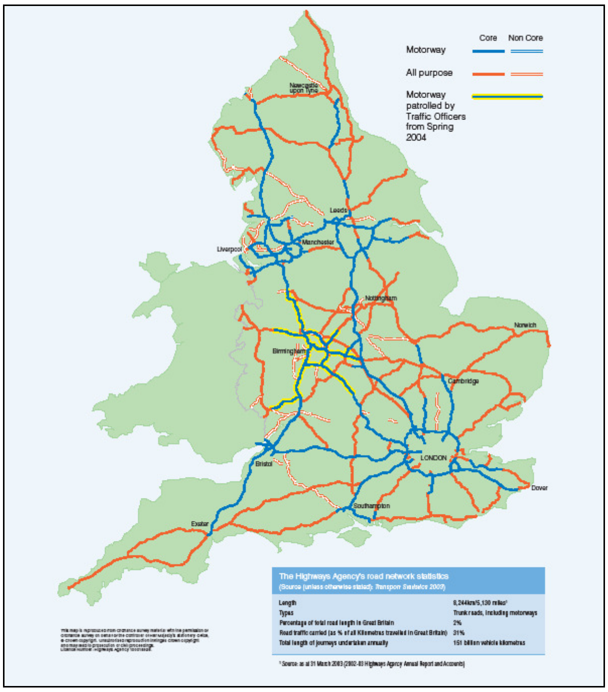
Overall Conclusions

1. Filter drains can be refurbished by on-site recycling to remove a high percentage of the fines, thus improving the hydraulic performance of the drain.

2. The fines content is much higher than expected from stormwater runoff and strongly implies poor construction and / or subsequent maintenance.

3. Fines removed from filter drains are subject to waste regulation and have been found to be non-hazardous.

Figure 1: The Strategic Road Network in England



The Highways Agency's road network statistics
(Source (unless otherwise stated): *Transport Statistics 2003*)

Length	8,244km/5,130 miles¹
Types	Trunk roads, including motorways
Percentage of total road length in Great Britain	2%
Road traffic carried (as % of all Kilometres travelled in Great Britain)	31%
Total length of journeys undertaken annually	151 billion vehicle kilometres

¹ Source: as at 31 March 2003 (2002-03 Highways Agency Annual Report and Accounts)

Figure 2: Type B specification and typical filter drain sample

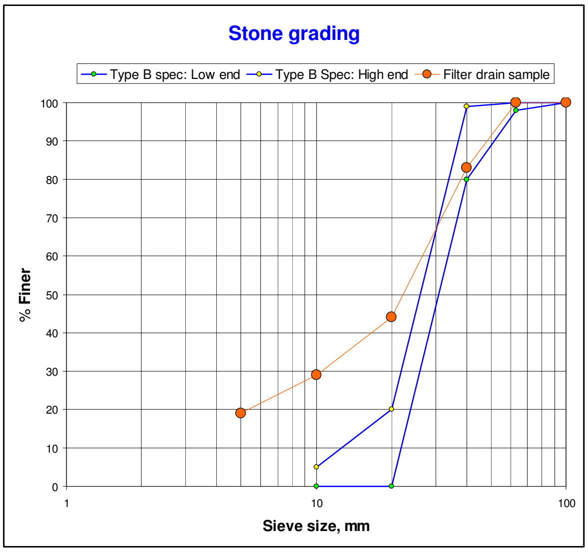


Figure 3: Trial holes on M6

Figure 4: Fines content at depths of 400 mm (samples 1, 3, ...) & 800 mm (samples 2, 4, ...)

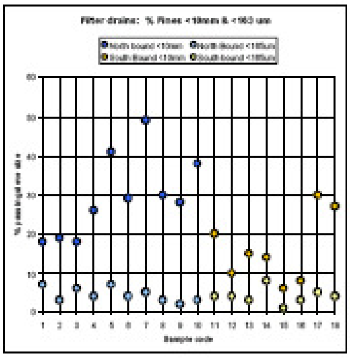
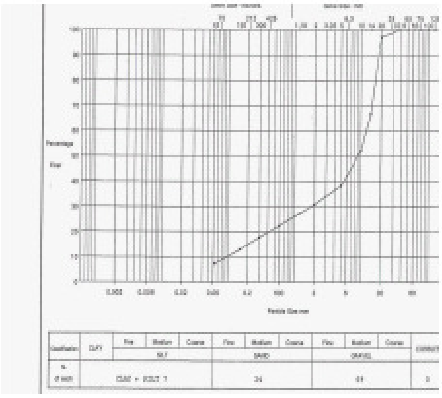


Figure 6: Particle size distribution of arisings from filter drain refurbishment



97% < 20mm
67% < 14mm
52% < 10mm
38% < 5mm
31% < 2mm
27% < 1.2mm
18% < 300um
13% < 150um
7% < 63um

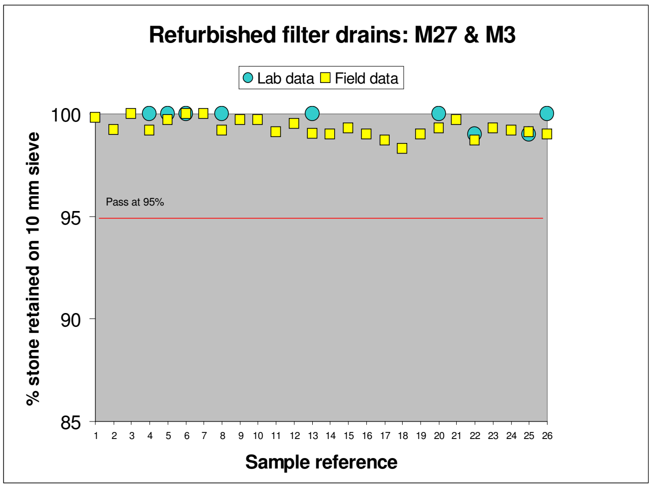
Figure 5: Heavy metal analysis for samples in Fig. 4

	All results	All NV locations		All SV Locations		All locations (NV & SV)	
Depth, mm		Ave 800	Ave 400	Ave 800	Ave 400	Ave 800	Ave 400
Arsenic	5.2	5.7	5.4	4.25	5.3	5.1	5.4
Cadmium	0.5	0.5	0.5	0.5	0.6	0.5	0.5
Chromium	11.5	10.8	11.1	9.9	14.4	10.4	12.6
Copper	28	24	27	23	40	24	33.0
Lead	44	33	39	38	70	35	52.8
Mercury	0.3	0.25	0.25	0.25	0.3	0.3	0.3
Nickel	9.4	12.4	9.1	7.05	8.3	10.0	8.7
Selenium	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Zinc	129	85	126	107	209	95	162.8
						180	276.2

Figure 7: Before & after refurbishment on M4, Eire.

Figure 8: StoneMaster in operation on the A82, Scotland

Figure 9: Field and lab data for recycled filter drains



Traffic related pollutants in soft engineering SUDS: an experimental and field approach

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Abstract

Urban runoff is a potential source for the contamination of groundwater. Sustainable Urban Drainage Systems (SUDS) are increasingly being employed to control urban runoff and have the potential to protect groundwater and surface water quality, yet little is known of the detail of pollutant behaviour within SUDS structures. Vertical movement of contaminants in swales and detention basins will determine potential risks to groundwater. This paper reports on a SNIFFER funded study designed to address the uncertainties surrounding the fate and behaviour of persistent pollutants in soft engineered SUDS.

Keywords

Sustainable Urban Drainage Systems; groundwater; oil; metals; soil

Introduction

The EU Water Framework Directive (2000/60/EC) requires the UK to control diffuse sources of priority pollutants with the goal of protecting water bodies - including groundwater. Sustainable Urban Drainage Systems (SUDS) are being increasingly employed to control urban runoff and have the potential to protect groundwater and surface water quality by minimising the risks of both point and diffuse sources of pollution. While SUDS are effective at retaining sediment-bound pollutants by filtration and sedimentation processes, less is known of the behaviour and fate within SUDS of some of the most important pollutants associated with highway runoff - oils, polycyclic aromatic hydrocarbons (PAHs) and heavy metals. A main area of concern is the vertical movement of contaminants in swales and detention basins which will determine potential risks to groundwater. Environmental conditions will vary between SUDS types. Different pollutants, affected by a variety of physical, chemical and biological processes can be expected to behave in very different ways in the environment. Sediment-bound pollutants in swales and detention basins are exposed to light and air while, in contrast, pollutants bound to aquatic pond sediments are subject to low light levels and anoxic conditions. Consequently there will be differences in pollutant fate. This pollutant fate information is needed to determine the effectiveness of different SUDS types for pollutant attenuation. While guidance is available on how to combine and size SUDS in relation to expected flow volumes, comprehensive data do not yet exist to allow similar decisions to be made regarding pollutant treatment potential. If regulators are to be able to require, rather than advocate the use of specific SUDS technologies, environmental data is required to justify their use. To this end, a co-ordinated programme of controlled studies and field measurements at soft-engineered SUDS in the UK is currently close to completion. The study was commissioned to assess the efficacy of various SUDS designs in managing pollutants, and to gauge any associated any risks to groundwater. This paper discusses results from two of the detention basins sampled as part of the project.

Methodology

The SUDS sampled are extended detention basins, which temporarily retain runoff after storm events. They receive runoff from the M74 motorway in Dumfries and Galloway, a major rural highway with free-flowing traffic. At the locations monitored, the motorway is 6 lanes wide, with an average annual daily traffic (AADT) of 13000. The detention basins vary in various design details, but all consist of an unlined grass basin bisected by a small lined pond (see Figure1). Variables, such as traffic density and composition, driving patterns, and climate, are uniform between the sites, allowing direct comparisons to be made based on SUDS design.

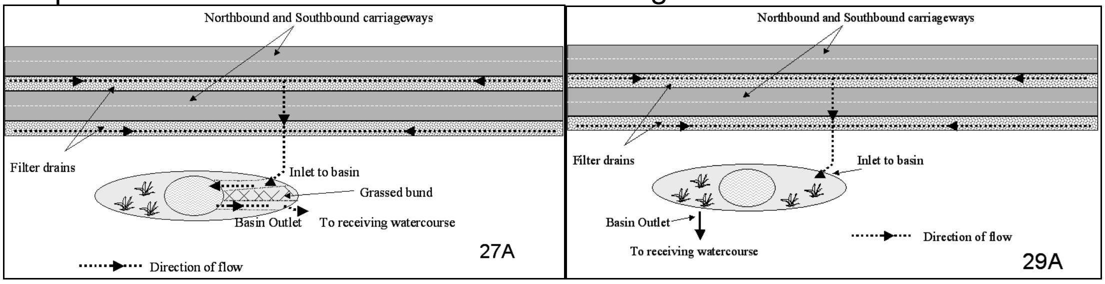


Figure 1 The layout of two detention basins sampled

Table 1 shows the sampling undertaken at each site. The basins are part of a treatment train, with filter drains upstream, and at Basin 29A samples of filter drain sediment were collected. At the same basin, samples of soil pore water were collected using 29 lysimeters porous pot lysimeters installed across the basin at 0.9 m depth.

Table 1. Field site sampling

Location	Nature of sampling
FIELD SITES	
Detention Basin 27A	Soil samples at different locations and 2 depths. Submerged sediment samples.
Filter Drain 29A	Sediment samples from 6 locations and 3 catchpits.
Detention Basin 29A	Soil samples at different locations and 2 depths. Submerged sediment samples from 2 depths. Soil water samples.

Samples of soil from the basins were collected from two depths (0-10cm and 10-20cm) using a hand trowel. The sample locations are shown in Figure 3.

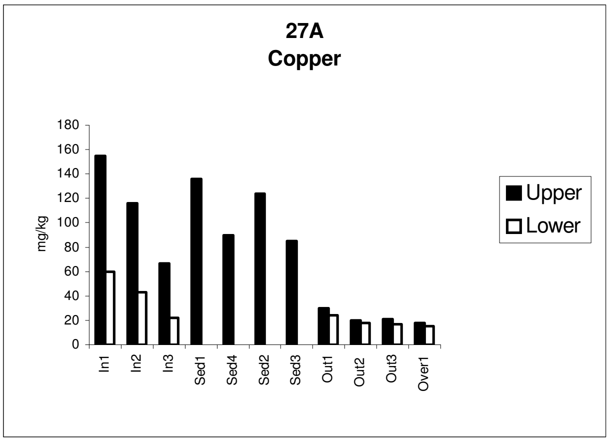
At Basin 29A, samples of pond sediment were collected by boat, using a Wildco® corer attached to a steel extension rod. Multiple cores were collected across the pond and were bulked to give a composite sample from each half of the pond. The sediment at Basin 27A was too loose to collect cores, and a grab sampler was used to collect multiple samples from across the pond, which were bulked to give composite samples.

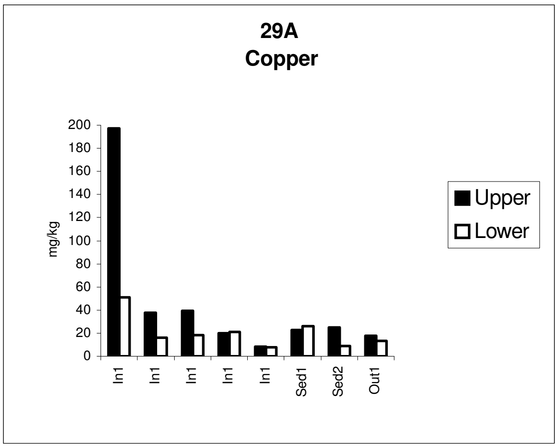
A 200m stretch of the filter drain serving Basin 29A was excavated and samples of sediment were collected from six separate locations along the length.

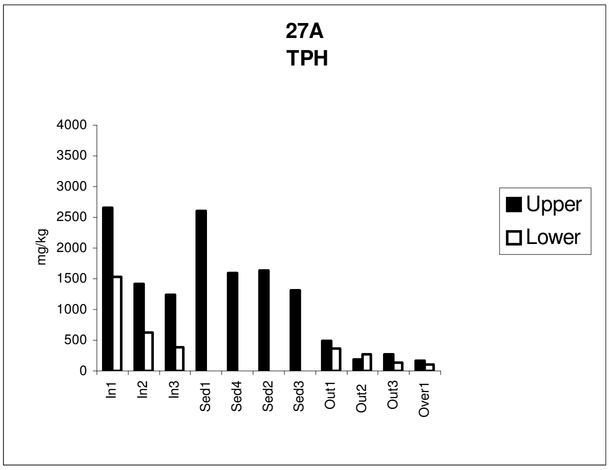
At basin 29A samples of soil water were collected on four occasions from a depth of 0.9m by means of 29 suction cup lysimeters which were installed across the inlet basin.

Results

In general, pollutant concentrations in soil in the basins decrease from the inlet to the outlet, and also with depth, as demonstrated by the values for zinc, copper and TPH shown in Figures 2 and 3. However, the two basins show different spatial patterns of pollutant accumulation. Pollutant concentrations at the inlet to Basin 29A are substantially higher than at the Basin 27A inlet, but concentrations decrease more rapidly across the basin, whilst in Basin 27A concentrations remain relatively high in the inlet channel. A comparison of the calculated average soil pollutant concentrations from the basins, however, show that despite pollutant hotspots, overall soil pollutant concentrations across the basins are very similar (see Table 3).







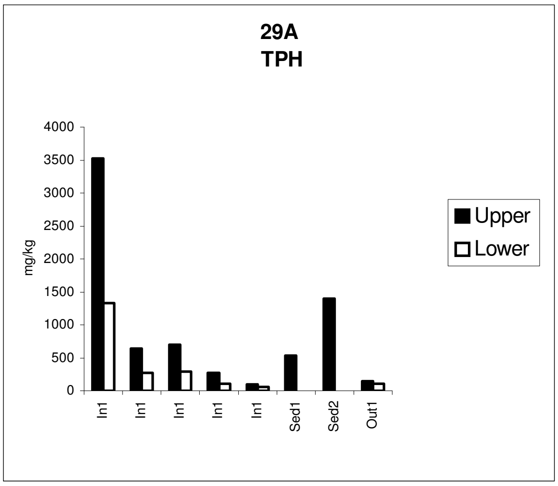


Figure 2. Copper and TPH concentrations at Basin 27A and 29A (previous page)

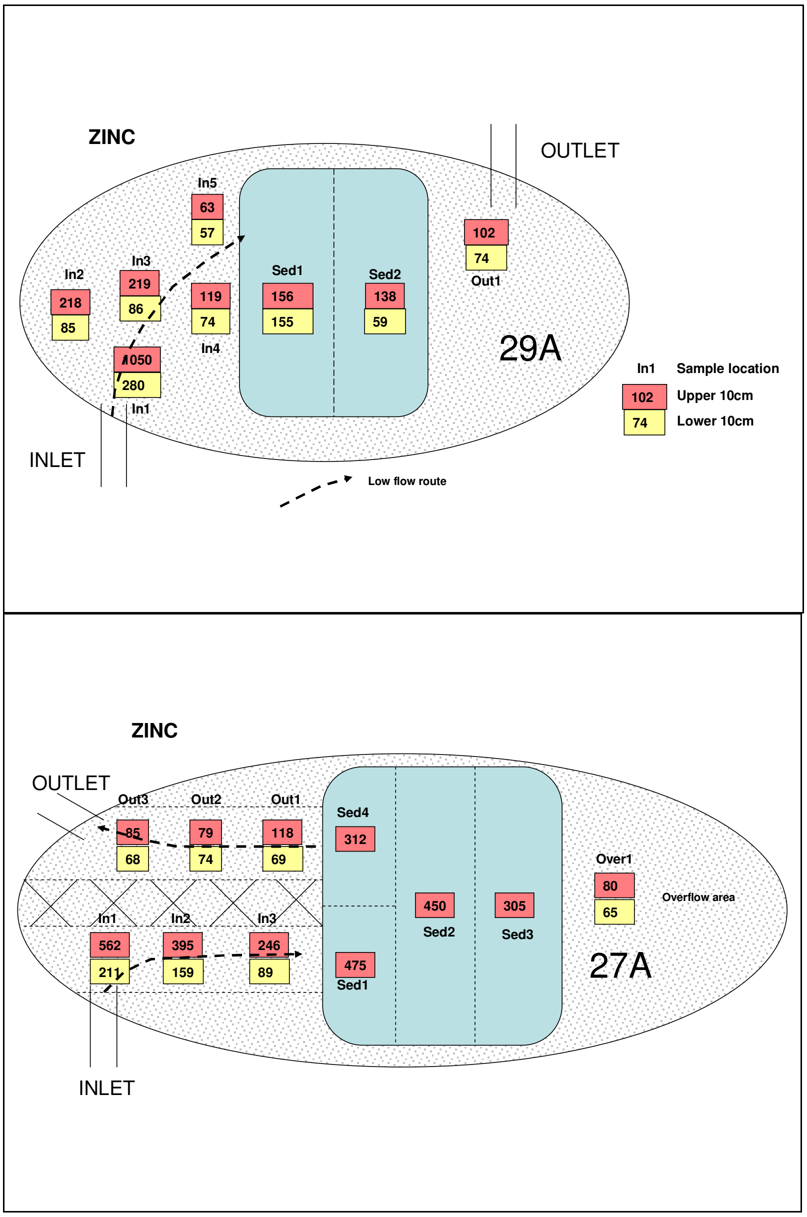


Figure 3. Zinc concentrations at Basin 27A and 29A (previous page)

However, the same is not true for basin pond sediment quality. As seen in Figure 3, at 29A, most pollutant concentrations in the pond sediments are lower than the average soil values (with the exception of TPH). At 27A, pollutant concentrations in the pond sediment were double the calculated soil averages. Comparing both basin sediment qualities, 27A sediments have pollutant concentrations consistently higher than those at 29A - up to 5 times higher in the case of copper.

Average pollutant concentrations found in the filter drain were lower than soil concentrations at the basin inlet, implying accumulation over time in basin soil. However, when comparing averages, the filter drain sediments were generally more contaminated than the basin soil.

Measured pollutant concentrations in the soil pore water are shown in Table 2. These are generally low and, with the exception of a single nickel value of 0.2mg/l, are comparable with surface water EQSs.

Table 2. Pollutant concentrations in Basin 29A soil water sampled on four occasions.

Date of sampling	Cadmium mg/l	Copper mg/l	Lead mg/l	Nickel mg/l	Zinc mg/l	pH	TPH mg/l	Total PAHs µg/l
23/03/2007	<0.0001	0.001	<0.001	0.003	<0.002	No result	<0.1	0.333
31/03/2007	<0.0001	0.009	0.002	0.003	0.010	7.6	0.2	0.991
11/05/2007	<0.0001	0.013	0.001	0.003	0.010	7.7	<0.1	0.160
29/06/2007	<0.0001	0.009	0.002	0.211	0.020	8.2	0.1	No result

Discussion

Efficacy of SUDS design

As the basins receive similar loadings, and both have filter drains upstream, it can be assumed that the differences observed must be a result of varying basin design. Flow at 27A is channelled along the narrow inlet channel ($30m^2$) directly into the pond, whereas flow at 29A spreads across the whole basin ($250m^2$) before reaching the pond. Contaminated sediments at Basin 29A will be deposited close to the inlet as the inflow velocity quickly dissipates, resulting in the high pollutant concentrations measured at the inlet. The velocity of flow entering 27A is slower to reduce because of the narrow inlet channel, and sediments will be transported further. It follows that flow entering the pond at 27A will have received less treatment en route than at 29A, and the higher pollutant concentrations in the pond sediments at 27A would seem to confirm this hypothesis.

Table 3. Comparison of average pollutant concentrations in basin soil, basin pond and filter drain sediments

	Cd	Cu	Pb	Ni	Zn	TPH	PAH
29A Filter drain	0.3	66	43	44	388	**2100**	9.7
27A Inlet and outlet soil	0.2	44	28	48	160	**695**	3.2
29A Inlet basin soil	0.2	40	32	35	218	**698**	3.6
27A Pond	0.4	**109**	60	43	386	**1785**	4.7
29A Pond	0.2	21	25	32	127	**965**	1.6
Standards for aquaitic sediments[1]	10	110	250	75	820	1500	
ICRCL lower threshold concentrations		130			300	1000	50.00
Permitted soil limits following application of sewage sludge to agricultural land*	3	135	300	75	200		
Soil guidance values (SGVs)[2]	30		450	75			
[1]severe effect level, Ontario Ministry of Environment (1993)		*pH 6-7					

Submerged sediment vs exposed soil

Results show that the TPH and PAH concentrations in the submerged sediments in the ponds which are part of the M74 basins are significantly more contaminated than the soil in the adjacent basins which dry out between rainfall events. Sediment at both basins exceed one or more quality standards given in Table 3. At 27A, pollutant concentrations in the pond sediment were double the calculated soil averages. This is contrary to expectations for a SUDS treatment train, where pollutant concentrations are expected to be sequentially reduced. At both basins, concentrations of the organic pollutants reduce from the filter drain to the basin, but then increase again in the ponds. Further evidence of increased concentrations in submerged sediments is seen in the filter drain. The highest TPH and PAH concentrations across the entire study -5340mg/kg and 20.23mg/kg respectively - were measured in submerged sediment from the filter drain catchpits. These values are more than double the average concentrations measured in the dry filter drain sediment.

Risk to groundwater

Basin soil was collected at two depths to investigate pollutant migration through the soil profile All samples show higher concentrations in the upper 10cm than in the layer below for metals and organic pollutants. In general, the magnitude of the vertical change in soil concentration measured at the basins decreases with distance from inlet.

Traffic-related metals are strongly correlated in the upper and lower soil layers in the basin inlet (R^2 values from 0.92 to 1.00), and these correlations decrease in strength with distance from inlet, evidence that the lower concentrations in the 10-20cm layers are not simply a measurement of background levels. One explanation for the observed change in concentration is sediment accumulation over time, with later deposits being more contaminated than earlier deposits. However, it is extremely unlikely that 20cm of soil has accumulated in the basins in the 7 years since their construction, especially with a filter drain upstream. This implies that downward migration of pollutants through the soil. It would appear that over the 7 years that the basins have been receiving runoff, there has been a very slow downward movement of pollutants through the soil.

Soil data would indicate, however, that infiltration based SUDS represent a low risk to groundwater as even in the most contaminated soil (at the inlets) 64-84% of the total pollutant loading was found in the in the top 0.1m. Concentrations of the pollutants under investigation in the soil pore water from basin 29A were however very low, confirming the negligible risk to groundwater. These field data are supported by experimental data from a controlled leaching study carried out as part of the overall project (results to be reported in future publications). Soil core lysimeters (three soil types) were dosed with metals, oil and PAH, irrigated and samples of leachate collected and analysed. The results showed <0.45% of the applied metals and <0.07% of the organic pollutants leaching through the 0.5m soil cores over the 3-month study duration. The minimal leaching that did occur was found in the clay soil, and was attributed to preferential movement. The physically disruptive SUDS construction process interrupts the connectivity of macropores and cracks in soil, and reduces the speed at which water can move to depth. Therefore even in the presence of occasional preferential movement which may allow pollutants to move to depth, there would be significant potential for further attenuation when considered the sub-catchment and catchment scale.

Conclusions

- The study shows metals and organic pollutants accumulating in basin soil.
- There is evidence of the vertical movement of pollutants through the top 0.2m of soil. However, concentrations of pollutants measured in soil water 0.7m below the basin were low.
- The breakdown of organic pollutants is much reduced in submerged sediments compared to soil-based systems.

Session 2: Highways/Roads – Research

Chair: John Howe, INTERPAVE

Martin Mansell and Fabien Rollet	University of Paisley	The Water Balance Of Paved Surfaces In Urban Areas
Stephen Coupe and Ernest O Nnadi	Hanson Formpave / University of Coventry	Water Recycling And Ground Source Heat Pump Systems Within Permeable Paving–System Installation and on-site Construction Considerations.
Piotr Grabowiecki, Miklas Scholz and Stephen Coupe	University of Edinburgh/ Hanson Formpave	The Next Generation Of Permeable Pavement Systems: Functioning, Biological Safety And Water Quality.

The Water Balance of Paved Surfaces in Urban Areas

Dr Martin Mansell and Fabien Rollet, School of Engineering and Science, University of Paisley

Introduction

This paper concerns an investigation into the water balance of various paved surfaces using a three layer numerical model which was calibrated under field conditions using 500mmx500mm slabs.

The water balance relationship can be expressed as

$$\textit{Precipitation} = \textit{Evaporation} + \textit{Infiltration} + \textit{Runoff} \qquad (1)$$

Conventionally, the water balance of urban areas has focussed on estimating the volume of runoff from short duration rainfall. In such cases evaporation is normally neglected and infiltration is allowed for using a constant runoff coefficient and an initial depression storage which is usually estimated from a simple regression equation, such as used in the Wallingford Method (Hydraulics Research (1983)). These methods will tend to overestimate runoff and underestimate the recharge to groundwater (Ragab, Rosier et al. (2003)) and do not reflect the complex pattern of urban water balance in the long term. Rodriguez, Morena et al. (2005), for example, have shown that there is a considerable variation in the runoff coefficient with different rainfall conditions while Davies and Hollis (1981) showed that infiltration and losses due to depression storage are more important than runoff.

Evaporation and infiltration depend on a dynamic interaction between the microclimate above the surface (particularly temperature, energy flux, wind speed and relative humidity) and the distribution of moisture within and on the surface. The moisture distribution itself is a function of the material properties, the surface texture and the microtopography of the surface in terms of surface depressions which lead to detention storage.

Infiltration

Infiltration into paved surfaces, although generally less than into non-paved surfaces may still be significant. Moisture movement into and within a paved surface material occurs as a result of either permeable flow, diffusion or flows through macro cracks or joints in the pavement

There are very few field measurements of infiltration through paved surfaces. Rollet and Mansell (2006) found infiltration to be less than 2% of rainfall based on 300mm samples of concrete and bituminous macadam. Ragab, Rosier et al. (2003) investigated the infiltration through various car park and road surfaces and found values of 6 – 9% of rainfall. The difference between these sets of data probably represents the flow through macro cracks.

Evaporation

Under saturated conditions, evaporation is mainly controlled by the prevailing wind speed, humidity and other climatological variables. However, where the surface is dry, evaporation is largely limited by the rate of diffusion of moisture upwards in the pavement material.

Evaporation from urban areas has been assumed to be considerably less than that from rural areas. However, urban areas include many vegetated areas and also contain areas of depression storage which is later evaporated. Although evaporation losses during storm conditions are often neglected, tests described later in this paper suggest that some evaporation does occur during rainfall events. Certainly, over the long term, evapotranspiration is often the largest output in the urban water balance (Mitchell, Mein et al. (2001)). In one study Davies (1981), evaporation from roof surfaces accounted for 19% of rainfall and infiltration through road surfaces accounted for 36% of rainfall (more than twice the runoff). Grimmond and Oke (1991) showed that evaporation constituted 38% of the annual water balance in Vancouver, Canada and 81% of the summer water balance.

Proposed Numerical Model

The proposed numerical model consists of three notional storage tanks (Figure 1). The upper tank represents surface depression storage and the second and third tanks represent the moisture stored in the surface and bottom layers of the paved surface respectively.

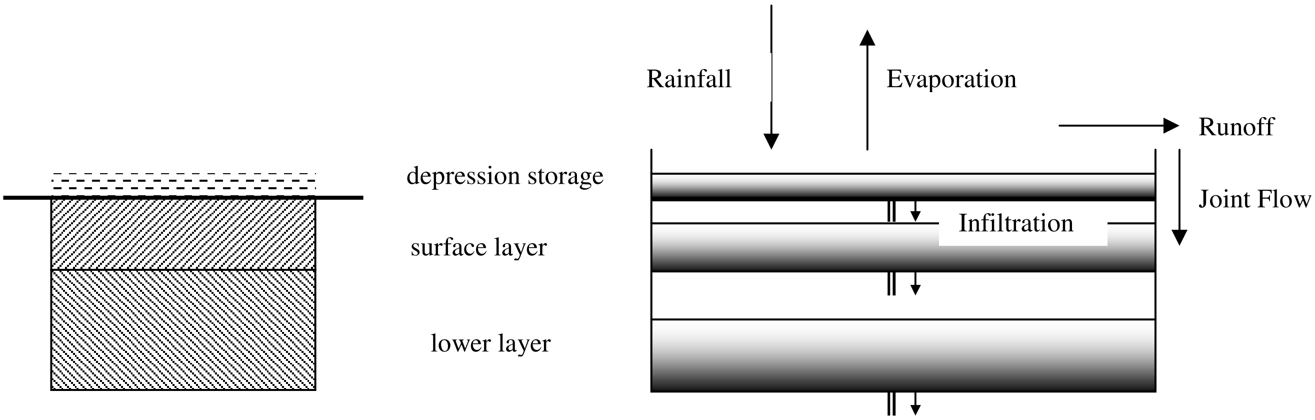


Figure 1 Structure of Numerical Model

The water balance on the surface depends on whether there is rainfall and/or depression storage. During a rain event the depression storage fills to a maximum storage. Infiltration into the second tank is a function of the depth of depression storage and the relative moisture content of the surface layer. Evaporation is taken as a constant function of rainfall. Runoff occurs when the depression storage exceeds the maximum but surface runoff only occurs when runoff exceeds a certain threshold (which may be zero): the balance is assumed to pass through joints and cracks in the surface.

Where there is no rainfall but there is depression storage, water is lost from the depression store at a rate proportional to the potential evaporation, as well as through infiltration to the second tank. The potential evaporation is based on the grass reference evapotranspiration (E_0) calculated from the Penman Monteith formula adapted for an hourly time step (Allen, Pereira et al. (1998)).

Where there is no rainfall and no depression storage, the evaporation from the surface is assumed to be a function of the potential evaporation together with the relative moisture content of the surface layer.

The second tank drains into the lower tank, at a rate which is a function of the relative moisture contents of the surface and lower layers and the lower tank drains to the subsoil at a rate dependant on the moisture content of the lower layer. The storage in the tanks is calculated from the difference between the average inflow and outflow over a time period.

The above analysis leads to six simultaneous equations which are solved simultaneously for each hourly time step.

Experimental Results

Tests on Slabs

The model was also calibrated using observed values of runoff and moisture content from 500mm x 500mm slabs of five different paving materials. The samples were exposed to normal atmospheric conditions for a period of approximately 8 weeks. The materials used were

(a) concrete (horizontal)
(b) concrete (inclined at 1 in 6)
(c) dense bituminous macadam (good condition)
(d) dense bituminous macadam (poor condition)
(e) brick paving

Rainfall was measured by a tipping bucket rain gauge and other meteorological parameters such as wind speed, temperature and relative humidity were also recorded by an adjacent weather station. The samples were placed in plastic trays which were used to collect the runoff which was also measured by tipping bucket rain gauges (Figure 2). In the case of the brickwork paving, the amount of infiltration through the joints was also recorded using a tipping bucket rain gauge. A 100mm cube of the same material was located next to each slab and was weighed periodically to measure the change in moisture content in the material.

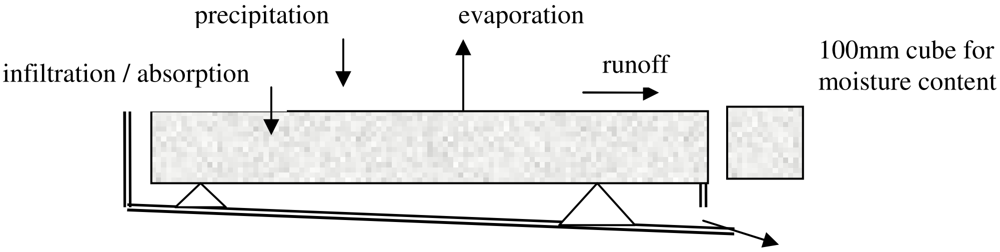


Figure 2 Arrangement of Experimental Slabs

Figure 3 shows a comparison of the simulated cumulative runoff with the observed values for the flat slab.

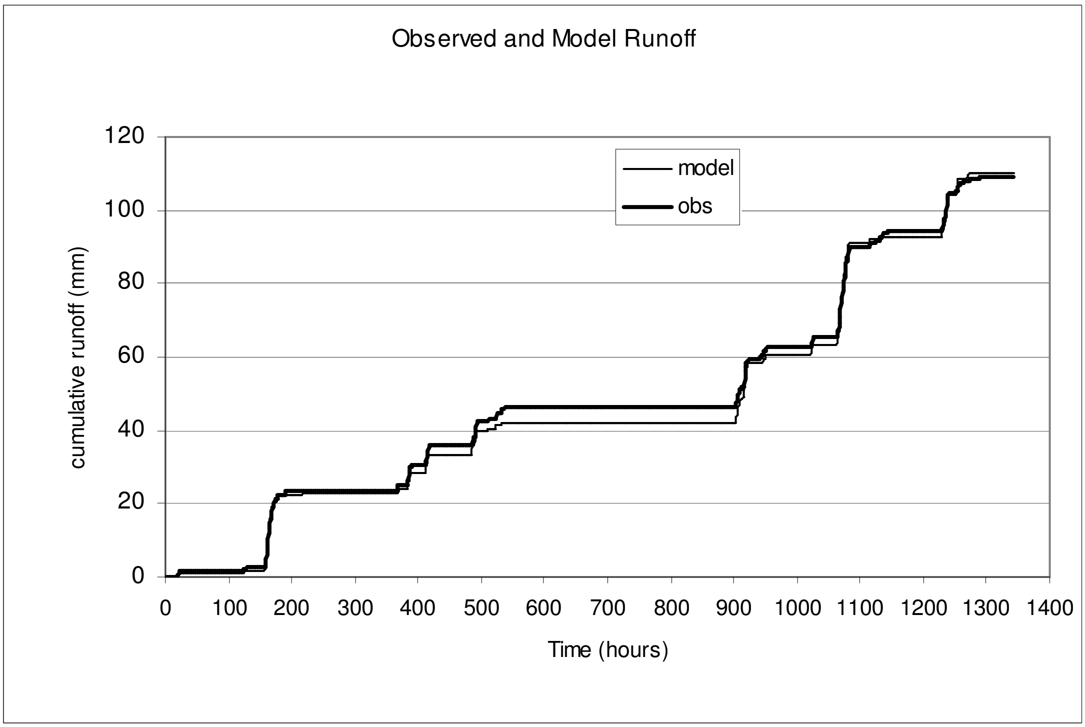


Figure 3 Comparison of Cumulative Runoff

The absorption/detention properties of the various materials were compared by calculating the cumulative initial excess rainfall. This was defined as the sum of the difference between rainfall and observed runoff at the start of a rain event (until runoff >= rainfall) i.e.

$$\textit{initial excess rainfall} = \Sigma(R_i - Ro_i) \qquad (2)$$
$$\text{for } R_i > Ro_i \text{ and } Ro_{i-1} \ldots Ro_{i-5} = 0$$

Table 1 Initial Excess Rainfall (mm)

Flat Concrete	66.0
Sloping Concrete	61.9
Bitumen (1)	96.2
Bitumen (2)	153.7
Brick Paving	119.5

The high value for the bitumen sample was due to the presence of large surface cracks.

The overall water balance for a typical rain event is shown for the flat concrete surface in Figure 4 based on the model simulation. It can be seen that depression storage is a significant component at the start of the rainfall and also during a temporary ceasing of the rainfall in hour 174 and 180 when the depression storage is evaporated. The importance of evaporation is highlighted but infiltration is a relatively small component.

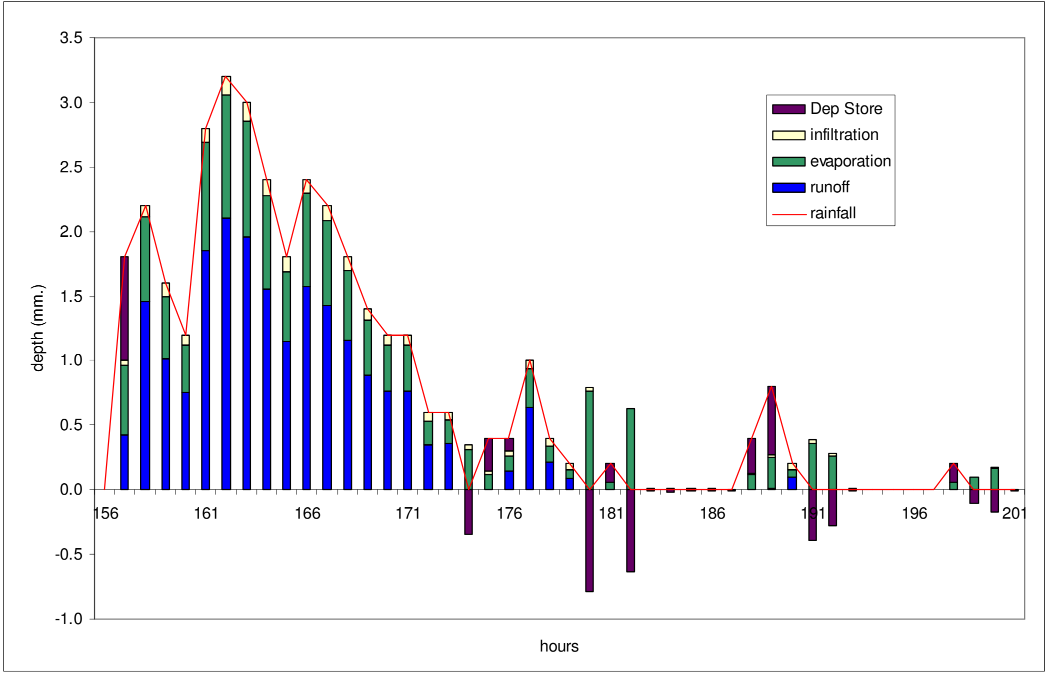


Figure 4 Water Balance for a Flat Concrete Surface

The overall water balance for the five materials are compared in Figure 5, which is also based on the simulation using observed rainfall and runoff data.

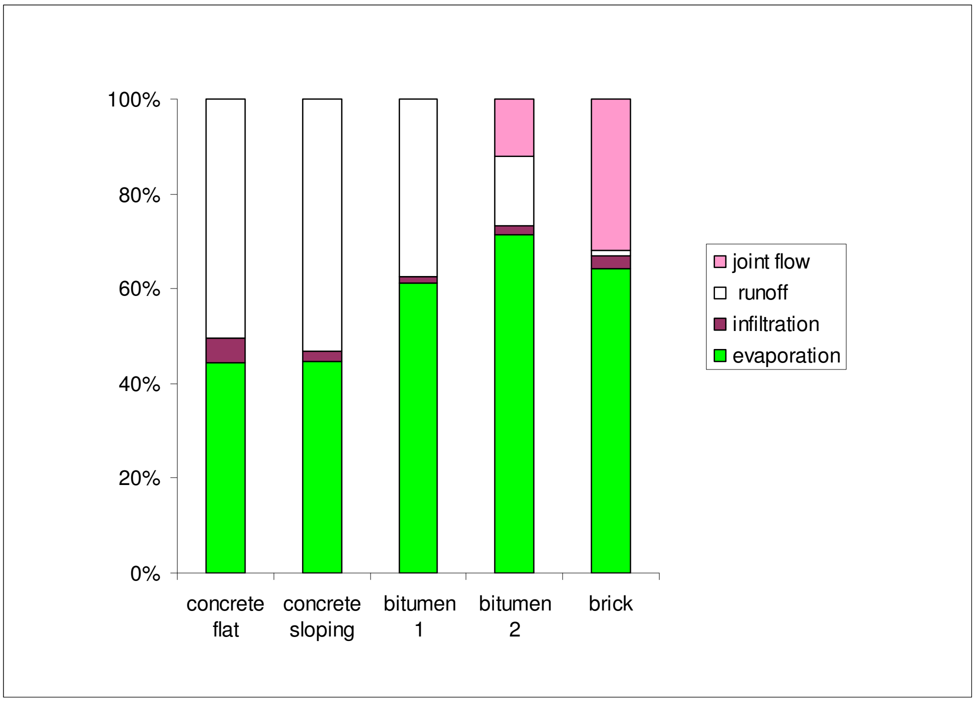


Figure 5 Comparison of Water Balance for Different Materials

The evaporation component refers to evaporation from water in depression storage only. In the long term, most of the water which infiltrates will also evaporate as the paving material dries out.

Conclusions

The proposed simple three-layer tank model shows good agreement in simulating the runoff from samples of various paved surfaces under field conditions.

The model results indicate that evaporation, both directly from surface depression storage and from moisture which has infiltrated into the material, is a significant component of the water balance. The amount of infiltration is generally quite small except where there are surface cracks.

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Water recycling and ground source heat pump systems within permeable paving- system installation and on-site construction considerations

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Abstract

The recycling and reuse of rainwater, using permeable paving as the reservoir for storage, shows great potential in the reduction of mains water use for low grade uses. Water for toilet flushing, landscaping and car washing can be stored in the pavement structure and pumped out for reuse. Hanson-Formpave have constructed a field site at BRE Watford, UK that incorporates not only the Aquaflow system to replace traditional drainage infrastructure but rainwater recycling and a ground source heat pump (GSHP) system.

Linked to the Hanson EcoHouse, the paving system will provide over 50 % of the mains water for non-potable uses and when full could provide a family of 4 with 30 days water without any extra rainfall.

The GSHP is linked to underfloor heating and cooling technology this and can provide 6kW for these purposes. Up to 80 % of the costs incurred for annual heating and cooling can be removed by the use of this technology and the typical period payback on the up-front investment is 3-6 years.

Multiple benefit SUDS solutions

Sustainable drainage infrastructure has the potential to function as more than a tool for water quantity attenuation and water quality improvement. It is important that SUDS systems are seen as multifunctional and if possible, particularly where market forces exert a particularly strong influence such as in the domestic arena, that additional benefits are provided to the consumer. These benefits are very useful in justifying the real or perceived high up-front costs of installing sometimes unfamiliar technology such as SUDS. The onsite use of rainwater in non-potable purposes for both domestic and industrial settings shows great promise in reducing the need for highly purified mains water. In a domestic setting at certain times of the year, over 50 % of water could be provided by the use of rainwater, certainly when feeding sprinkler systems in dry weather. Commercially available water butts rarely hold more than 200 litres and in the UK it would be expensive and contrary to planning regulations to install large water holding structures such as water towers or tanks above ground in residential areas. Below ground rainwater storage tanks may be effective in providing sufficient storage volume, but a significant investment in time, excavation and installation costs may make this strategy unattractive to many end users.

A more holistic view of on site water management would therefore improve the chances of rainwater use in a wider variety of locations. This could be done by providing an attractive combined onsite rainwater use package based on multiple environmental and end-user benefits within one site, whilst minimising any additional costs for installation. Feasibility studies on water efficiency and water recycling and reuse are already underway in parts of the UK. A joint EA/WS Atkins study in Kent has analysed water consumption in 50 houses using water saving devices such as aerating shower heads and flow restriction devices in addition to water awareness advice. These were compared with 50 houses containing no water saving devices and with the residents receiving no water awareness training. The results showed that the reduction in mains water use was masked by the variable demand for water during the study period. However a nearby school was shown to have achieved payback on its water efficiency scheme within 1 year (Reed, 2007).

Permeable pavements and water storage

Installing permeable paving, is currently accepted as good practice within urban drainage, primarily from the quantity and quality improvements provided relative to piped systems (e.g. Newman *et al*, 2005). If a permeable pavement was specified on a particular scheme, it would seem logical to use the water storage capacity of the system in place of a separate water tank. Aquaflow permeable paving has a storage capacity of approximately 1000 litres per 10 m^2 of paving, yielding a possible 5 m^3 of water in a medium to large sized driveway. If the paving system was bound by an impermeable liner and connected via an overflow to a soakaway or was part of a treatment train, then a pervious, attractive and durable surface could reduce runoff, clean the water and provide a huge storage volume all within the hypothetical 50 m^2. Roof water could also be diverted to the tank to increase the disconnected area and potentially double the source for rainwater collection.

The OFFSITE 2007 exhibition

During late 2006 and June 2007 Hanson Building Products constructed their version of a sustainable home at the Building Research Establishment (BRE) in Watford. Alongside many examples of good practice in sustainable building including state of the art insulation and offsite construction, water resource considerations were very much the focus of attention.

As the offsite exhibition was intended to last for a minimum of 2 years, an incentive was provided to go beyond current good practice and utilise new methods to improve sustainability. The Hanson Formpave innovation included both rainwater use for flushing WC’s, providing water for car washing and applying to soft landscaping and also used the Aquaflow paving as the source area for heating and cooling harnessed by ground source heat pumps (GSHP).

GSHP and renewable energy schemes

Several EU and UK commitments are in place to encourage more sustainable construction, with a major focus on carbon dioxide emissions. Gordon Brown announced at the recent Labour party conference that all existing homes are to be low carbon by the year 2016 (King, 2007). In line with EU council commitments, 20 % of all EU energy must be from renewable sources by 2020 (Wolfe, 2007). In order to achieve this figure, the contribution from onsite renewable energy must increase significantly. Onsite renewables (meaning local sources of non-grid derived power) could contribute to the 20 %

renewables target alongside greater energy efficiency and investment in other renewable energy sources. GSHP as onsite renewable technology are seen as appropriate for a new development situation and only applicable to retrofit in circumstances where there is sufficient space and resources necessary for the relatively complex installation and commissioning when compared with solar water heaters or wind turbines (Wolfe et al, 2007).

GSHP technology and ground heat

The temperature of subsoil at 500 mm below ground is typically around 10 °C. In a GSHP system this heat is harnessed in a similar way as a refrigerator keeps the interior chamber cool by removing the warm air inside using a coolant and then dispersing it at an exhaust point. In a GSHP, coolant is circulated around a piped system buried in the soil which draws in heat from the surrounding soil water. This heat is then moved via a heat pump into the building and may be terminated in underfloor heating or a radiator system. As long as the heat extraction pipes buried in the soil are wet, a good efficiency of removal of the ground heat is experienced. Up to 6 KW of heating or cooling energy can be produced from the 65 m^2 Aquaflow paving installed at BRE and this is more than enough power to maintain a comfortable year round temperature. Up to 80 % of domestic heating and cooling costs can be removed by the use of GSHP technology and payback on the system is usually achieved after 3-6 years (Geothermal International Ltd, 2007). These data demonstrate that GSHP are clearly a viable technology for the minimisation of fossil fuels within newly built properties and that Aquaflow permeable paving may be an excellent vehicle for the GSHP system, reducing installation costs and delivering multiple benefits.

The operational efficiency of GSHP technology that is buried within a permeable pavement is expected to be more efficient than when buried in soil water for two main reasons: (i) the large water holding capacity of the pavement system, when full and subject to the installation of a properly sealed tank system, ensures that the heat extraction pipes will constantly be buried in water, unlike in soil water where fluctuations of the water table or soil drying could dramatically reduce heat transfer efficiency and (ii) the termination of downpipes in the paving system is likely to lead to a replenishment of local heat in the stored water by mixing and the introduction of kinetic energy from flow. It is clear that from an *a priori* perspective, the combination of SUDS technology, and particularly permeable paving, with extra environmental benefits such as water recycling and GSHP is feasible. The following section of the paper will feature an account of the installation of this technology in May-June 2007 at the UK test site, BRE Watford.

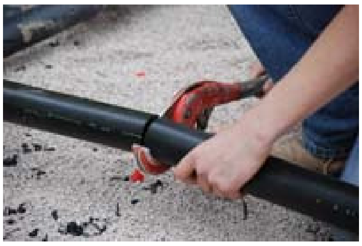
Construction of the Hanson Formpave combined SUDS at BRE Watford

In order to keep the rainwater harvesting and GSHP tanks separate, two discrete paved areas were constructed. This was done in order to prevent depletion of water in the GSHP system, to better monitor the water use in the rainwater harvesting system and to screen the water quality in the separate system. Excavation was made to a depth of 500 mm as usual in Aquaflow construction and a protective fleece put over the excavated area to prevent puncturing of the liner. A heavy duty impermeable membrane was lapped over both sites.

The stone sub base was added and vibrated flat to better accommodate the Inbitex geotextile membrane.

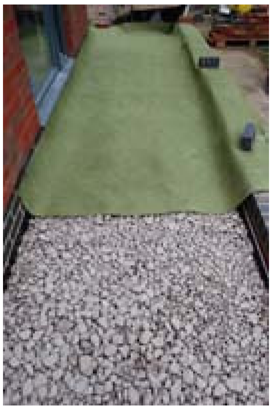
For the GSHP apparatus, the heat capture pipes were installed at the bottom of the sub base and backfilled with the aggregate. It was necessary to put a shallow layer of gravel beneath the pipes in order to minimise the risk of any deterioration of the membrane by the temperature fluctuations from the ground heat capture process.

The pipes were fused together and filled with coolant in order to extract the ground heat from the pavement water.

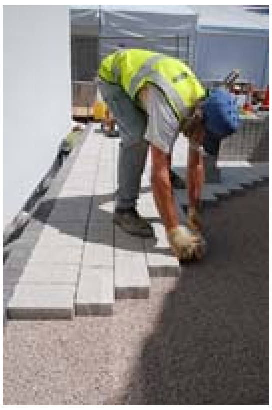


For the rainfall harvesting pavement, a series of concrete rings were placed within the sub base area in order to provide a ‘well’ in which to place an electric pump to top up the two Ecohouse WC’s with rainwater. A gross filter was installed in the system to clean any debris from the water before adding to the WC cisterns. On both sides of the system, Inbitex geotextile was placed on top of the sub base before the gravel bedding layer.





Formpave Ecogranite blocks were placed on top of the construction and 3 mm grit brushed in to aid surface stability.



Monitoring and analysis

In collaboration with Coventry University, Hanson Formpave will monitor the BRE site for at least the next two years. Funding has been found for a PhD studentship to determine the effectiveness of the combined SUDS/GSHP in meeting the needs of a domestic user.
Some of the variables to be analysed will include:

- Temperatures inside and outside the Ecohouse
- Rainfall characteristics onsite and the effect of these on stored rainwater, including evaporation and seasonal demands
- The temperature around the heat capture pipes –to determine the risk of the growth of any dangerous microbiological agents
- The water quality discharged from both halves of the site, with particular reference to WFD considerations
- A subjective measurement of the effect of living in a 'sustainable dwelling' by operating the features as a consumer would.

It is hoped that the analysis phase will provide clear guidance as to whether it is feasible to combine SUDS elements in the way described in this paper. If it can be shown that a SUDS system can also provide water and heating, the profile and level of general acceptance should increase.

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The Next Generation of Permeable Pavement Systems: Functioning, Biological Safety and Water Quality

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Abstract

This paper assesses the functioning of the 'next generation' of permeable pavement systems (PPS). The overall concept is to combine traditional PPS with ground source heat pump systems. The variability of temperature has an important impact on the microbial biodiversity and allows potentially for the survival of pathogenic organisms within the sub-base of some PPS, which may release them into the effluent. The research enables decision-makers to assess public health risks, treatment requirements and efficiencies, and the potential for runoff recycling. Findings indicate 99% and 95% biochemical oxygen demand and ammonia-nitrogen removal, respectively. The great system stability of the innovation and minor water quality data variability between individual experimental PPS provide good evidence for the controlled engineered application of this novel technology. Anaerobic processes are concentrated in the space within and close to geotextiles, where carbon dioxide concentrations reached up to 2000 ppm.

Keywords: permeable pavement; ground source heat pump; geotextile; water quality; ammonia-nitrogen; biochemical oxygen demand; microbiology; carbon dioxide

1. INTRODUCTION

Permeable pavement systems (PPS) are suitable for a wide variety of residential, commercial and industrial applications. Where there is any concern about the possible migration of pollutants into the groundwater, PPS should be constructed with an impermeable membrane, and the treated storm water should subsequently be discharged into sustainable drainage systems (Wilson, 2003; Scholz, 2006a,b).

The general principle of PPS is simply to collect, treat and infiltrate freely any surface runoff to support urban groundwater recharge. In comparison to traditional urban drainage systems, storm water retention and infiltration is a sustainable and cost effective process, which is suitable for urban and rural areas (Dierkes, 2000a; Scholz, 2006a; Scholz et al., 2006). Moreover, PPS have many potential benefits such as reduction of runoff, recharging of groundwater, saving water by recycling and prevention of pollution (Pratt et al., 1999). A detailed review of PPS has been published by Scholz and Grabowiecki (2007).

Ground source heat pumps (GSHP) or Geo Exchange systems are commonly used in North America and some European countries. According to US EPA (Bose, 2005), GSHP are using refrigerant to move energy (i.e. heat) out of buildings during summer and into them during winter. They use constant temperatures of surrounding grounds, which are lower than the corresponding air temperatures during warm seasons (heat sinks) and higher during cold seasons (heat sources). There is no need for burning fossil fuels to transfer energy either side; therefore, this is an 'environmentally friendly' and sustainable technology, which also reduces carbon dioxide (CO_2) emissions (Geothermal Heat Pump Consortium, 1998).

Applying GSHP can lead to 54% CO_2 emission reductions in comparison to air-source heating pumps (Genchi et al., 2002). Moreover, energy bills for domestic applications can be reduced between 30 and 70% during the heating mode and between 20 and 50% during the cooling mode (Bose, 2005).

The aim is to assess two experimental rigs comprising six different setups each, and to compare them with each other in terms of their treatment efficiencies and designs for the different PPS types. The objectives are as follows:

(1) To assess the combined PPS and GSHP performance;
(2) To characterize microbial activities under different temperature patterns;
(3) To assess the water quality at the bottom of tanked PPS systems; and
(4) To describe the mobility of potentially pathogenic organisms.

RIG SET-UP AND OPERATION

Table 1 indicates the experimental set-up of the overall experiment. Two rigs were operated under controlled and uncontrolled environmental conditions. Aquarium heaters (VISI-THERM, Aquarium Systems NEWA, Loughborough, UK) were used to achieve temperature increases. In-line aquarium coolers (Titan 500, Aqua Medic, Bissendorf, Germany) were applied to decrease the temperatures within coils. No direct contact between heat transferring water and water stored within the PPS sub-base was allowed during the experiment.

Table 1. Schematic layout of the experimental rigs.

	Inside rig						*Outside rig*					
Feature	1	2	3	4	5	6	1	2	3	4	5	6
Inbitex composite	√	√	√				√	√	√			
Inbitex geotextile				√	√	√				√	√	√
Cooling or heating	√	√		√	√		√	√		√	√	
Animal feaces	√			√			√			√		
Air thermometers	√				√	√	√				√	√
Thermometers	√				√		√				√	
Carbon dioxide sampling	√				√		√				√	

Typical 240-litre wheelie-bins (Isoplastic, Warwickshire, UK) have been used as basic construction devices. The indoor PPS was placed in a temperature-controlled room with a mean ambient temperature of 16°C. The outdoor rig was submerged within the ground and located outside the local laboratory building where atmospheric temperature conditions prevailed. All bins were partly filled with the inflow water, and operated in batch flow mode.

During cold periods of the first year of research, heat was provided to the sub-base, resulting in a relative increase of the temperature within the sub-base. This arrangement simulated 'real' site conditions of the out-flowing water for the inside rig, and increased relative temperature differences for the outside rig. During warm periods, the opposite arrangement was made, and the sub-base subsequently became relatively cold.

The biologically contaminated influent samples were prepared by collecting gully pot liquor and fresh dog faeces on the same day of analysis. Gully pot liquor (one part) was mixed with dechlorinated tap water (ten parts) in a plastic beaker. Approximately 3.1 g of dog faeces were subsequently added and mixed properly to obtain a homogenous mixture. American standard methods (Clesceri et al., 1998) were used for water analysis.

RESULTS AND DISCUSSION

Tables 2 to 5 indicate the inflow and outflow water quality. The main contaminant in this experiment was dog faeces, which is the second (after oils) most critical pollutant in car parks and driveways, and one the most frequent reason of complain concerning avoidable health and safety risks by the public to local authorities. It is estimated that the UK's dog population produces 1000 tonnes of faeces every day (Environmental Campaigns, 2003). Faeces are the most serious pollutants to human health, and their potential presence in PPS is often hampering their domestic installation particularly in warm countries such as Spain and Australia.

Table 2. Summary statistics of the water quality for the inflow (IN) without and with additional pollutants (dog faeces, P) for the permeable pavement systems (n=55)

	IN	IN+P	IN	IN + P
Variable	*Mean*		*Standard deviation*	
Five-day @ 20°C biochemical oxygen demand (mg/l)	7.5	92.7	8.49	78.59
Suspended solids (mg/l)	227.5	133.3	411.37	180.76
Total dissolved solids (mg/l)	62.8	98.0	34.74	29.86
Dissolved oxygen (mg/l)	9.8	9.4	0.86	1.09
pH (-)	7.0	7.1	0.42	0.44
Conductivity (μS)	126.6	196.7	69.83	59.91
Ammonia-nitrogen (mg/l)	14.7	39.3	63.63	117.60
Nitrate-nitrogen (mg/l)	1.1	1.1	0.84	0.56
Ortho-phosphate-phosphorus (mg/l)	1.9	26.2	6.46	81.45

Temperature fluctuations had a major impact on the performance of the PPS and the associated microbial community compositions within the sub-bases. During the heating period, temperatures in the bins were between 20 and 25°C. During the cooling period, the temperature was approximately 5°C. These temperature recordings contrast air temperatures between 11 and 20°C during summer, and between 3 and 13°C during winter. The settings for all equipment were the same in the indoor and outdoor rigs, and the mean temperature for the temperature-controlled room was 14.7°C throughout the year. The temperature of the inflow water and the temperature of the outflow water differed between 0.3°C and 1.3°C during cooling.

Table 3. Summary statistics of the outflow water quality for the rig located indoors (n= 55).

Variable	*Statistics*	*Bin numbers*					
		1	*2*	*3*	*4*	*5*	*6*
BOD (mg/l)	Mean	0.7	1.0	1.2	1.2	1.1	1.1
	SD	0.30	0.67	0.70	0.67	0.32	0.30
SS (mg/l)	Mean	166.7	199.0	260.0	131.1	138.2	174.2
	SD	179.98	269.09	256.73	136.42	166.32	179.77
TDS (mg/l)	Mean	202	213	187	217	201	202
	SD	19.0	20.1	29.9	12.8	17.5	29.8
DO (mg/l)	Mean	5.0	5.3	6.5	5.4	4.6	5.6
	SD	1.52	1.71	2.20	1.34	1.38	2.08
pH (-)	Mean	7.4	7.5	7.5	7.5	7.4	7.5
	SD	0.26	0.21	0.26	0.28	0.21	0.22
Cond (μS)	Mean	403	428	374	435	403	416
	SD	38.4	40.7	59.5	25.4	35.1	80.4
AN (mg/l)	Mean	0.15	0.11	0.11	0.13	0.10	0.11
	SD	0.219	0.146	0.123	0.154	0.102	0.114
NN (mg/l)	Mean	3.2	1.0	2.7	1.4	0.4	2.2
	SD	3.69	1.35	3.10	1.35	0.49	2.78
OPP (mg/l)	Mean	0.89	0.48	0.47	0.82	0.43	0.47
	SD	0.460	0.481	0.491	0.559	0.549	0.502

BOD = five-days @ 20°C biochemical oxygen demand; SS, suspended solids; TDS = total dissolved solids; DO = dissolved oxygen; Cond = conductivity; AN = ammonia-nitrogen; NN = nitrate-nitrogen; OPP = ortho-phosphate-phosphorus; SD = standard deviation.

CONCLUSIONS

The combined permeable pavement system (PPS) and ground source heat pump (GSHP) system performances for the inside and outside rigs were satisfactory. The water quality at the bottom of the tanked systems was below common secondary wastewater treatment standards for the biological oxygen demand (<25 mg/l) and well above the threshold of 35 mg/l for suspended solids.

The ortho-phosphate-phosphorus and ammonia-nitrogen removal rates were very high (up to 95%), and the corresponding absolute concentrations fulfilled European urban wastewater treatment standards. Although an increase of nitrate-nitrogen has been observed, the concentrations were well within European standards.

Table 4. Summary statistics of the outflow water quality for the rig located outdoors (n = 30)

Variable	*Statistics*	*Bin numbers*					
		1	*2*	*3*	*4*	*5*	*6*
BOD (mg/l)	Mean	1.2	0.1	0.3	0.1	0.3	0.4
	SD	1.72	0.30	0.65	0.30	0.65	0.67
SS (mg/l)	Mean	90.0	77.3	130.0	71.3	96.0	42.0
	SD	112.03	146.70	275.56	97.02	208.44	78.00
TDS (mg/l)	Mean	202	213	187	217	201	202
	SD	19.0	20.1	29.9	12.8	17.5	29.8
DO (mg/l)	Mean	5.1	6.1	6.8	5.5	6.4	7.3
	SD	1.15	0.90	1.17	0.87	0.81	1.41
pH (-)	Mean	7.2	7.4	7.5	7.4	7.5	7.5
	SD	0.28	0.14	0.15	0.16	0.12	0.15
Cond (μS)	Mean	403	428	374	435	403	416
	SD	38.4	40.7	59.5	25.4	35.1	80.4
AN (mg/l)	Mean	0.14	0.03	0.03	0.04	0.03	0.03
	SD	0.103	0.027	0.022	0.036	0.020	0.027
NN (mg/l)	Mean	1.7	0.3	2.6	1.0	0.7	1.8
	SD	2.27	0.25	1.26	1.56	0.72	0.99
OPP (mg/l)	Mean	0.35	0.22	0.22	0.60	0.14	0.23
	SD	0.428	0.336	0.253	0.298	0.120	0.236

BOD = five-days @ 20°C biochemical oxygen demand; SS, suspended solids; TDS = total dissolved solids; DO = dissolved oxygen; Cond = conductivity; AN = ammonia-nitrogen; NN = nitrate-nitrogen; OPP = ortho-phosphate-phosphorus; SD = standard deviation.

Table 5. Mean colony forming units (CFU) for the inside and outside bins, raw inflow, and inflow contaminated with dog faeces (P) between November 2006 and April 2007 (inside system: n = 288; outside system: n=192).

Rig location	CFU per 100 ml	Bin number						Inflow	
		1	2	3	4	5	6	- P	+ P
Inside	*Shigellae; Salmonellae*	498	441	260	195	198	68	636	920
	Enterococci	173	215	68	578	59	185	883	3900
	Total Heterotrophs	121000	56750	38500	74000	63500	78750	101250	7605000
Outside	*Shigellae; Salmonellae*	8931	368	598	371	708	485	160	78
	Enterococci	704	251	370	198	95	98	178	598
	Total Heterotrophs	51500	100833	180000	129800	77667	76833	171750	378250

Microbial activities during high temperature durations led to enhanced treatment performances. The elevated carbon dioxide concentrations and corresponding reductions in biochemical oxygen demand are evidence for the increased microbial activity within the sub-base, especially on the geotextile.

The strong microbial community may increase the risk of potential transfer of pathogens to humans, although this requires additional assessments of large-scale systems, as the experimental rigs were intentionally overloaded with biological pollutants.

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Session 3: Planning and SUDS

Chair: Alex Stephenson, Hydro International

Andy Swan and Virginia Stovin	Sheffield University	A Long-Term Planning-Based Approach To Sustainable Stormwater Management
Gaye McKay and Wesley Jones	MWH/ Environment Agency	The Waterlooville Major Development Area, Hampshire: A Partnership Approach For Addressing The Barriers To Implementation And Adoption Of SUDS.
Bob Bray	Robert Bray Associates Ltd	A Sustainable Drainage Design Strategy For Urban Development: Creating A SUDS Landscape To Replace The Storm Sewer.

A long-term planning-based approach to sustainable stormwater management

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Introduction

Many of the UK's urban areas experience problems with excessive Combined Sewer Overflow (CSO) discharges and/or sewer flooding, with consequent aesthetic and water quality impacts. In many cases these problems have been induced or exacerbated by the progressive urbanisation of the local catchment. This process leads to higher levels of catchment runoff and subsequent peak storm flows in the sewer systems.

Sewer-related problems in England and Wales can be reported by any of the key stakeholders (e.g. the general public, local authorities, industrial users, and the Environment Agency (EA)); these problems are generally then prioritised for remedial action by the water companies in conjunction with their regulators (OFWAT (Office of Water Services) and the EA). Remedial action is then undertaken by the local water company, or one of their contract partners.

The English and Welsh water companies are required to maintain a register of local properties considered to be at risk of internal sewer flooding on average every five years. The information is provided to the regulatory body – OFWAT – and is used as one of the factors driving their capital programme. The register is known as the DG5 register.

Improving problematic CSO discharges and addressing DG5 flooding problems are key elements of the present and forthcoming five year asset management programmes (AMP 4 and 5) in England and Wales; and the Quality and Standards 3/4 programmes in Scotland. The EU's Water Framework Directive (WFD, 2000/60/EC) provides supporting legislation aimed at delivering water quality improvements.

CSO and flooding problems are typically resolved using engineered solutions that are implemented within the sewer network. For example, in-sewer storage (e.g. a storage chamber or oversized sewer pipes) is widely used to resolve catchment problems by storing excess flows, and releasing them back into the sewer once peak storm flows have subsided.

The design, construction, operation and maintenance issues associated with in-sewer storage solutions are well understood; and these approaches are widely implemented within the UK[i]. However, this approach is not necessarily optimal. Such schemes miss opportunities to utilise water as a resource, and cannot deliver amenity or water quality benefits beyond those associated with volumetric attenuation. In-sewer storage may lead to increased energy requirements if the stored stormwater needs to be pumped and/or passes through a treatment works further downstream. This contravenes the anticipated regulatory requirements on water companies to reduce their carbon footprint.

For these reasons the EA and the Scottish Environment Protection Agency (SEPA) actively promote the use of Sustainable Drainage Systems (SUDS)[ii] for the management of surface water runoff. SUDS include, amongst others, green roofs, soakaways, swales, infiltration basins and ponds. Because of their reliance on natural catchment processes (i.e. infiltration, attenuation, conveyance, storage and biological treatment) these techniques are seen to constitute a 'more sustainable' approach to stormwater management.

Although SUDS usage is being actively promoted for new developments in the UK, the potential to make use of SUDS within existing urbanised areas has received only limited attention. The term retrofit is employed when SUDS-type approaches are intended to replace and/or augment an existing (combined or separate) drainage system in a developed catchment. One example of a retrofit SUDS would be the disconnection of roof runoff from a combined sewer and its diversion into a garden pond or soakaway. Retrofit SUDS approaches seek to remove the stormwater component from the piped drainage system, thereby eliminating treatment/pumping costs and energy requirements. They may also make positive contributions to water quality, habitat and amenity. Desk-based feasibility studies have suggested that retrofit SUDS could provide cost-effective components of catchment rehabilitation strategies[iii,iv]. Decision-support tools aimed at identifying opportunities and approaches to SUDS retrofitting have also been proposed[v,vi].

There are several international examples of this type of approach being successfully implemented, including the Portland (Oregon, USA) downspout disconnection programme[vii] and the extensive SUDS retrofit undertaken in Malmo (Sweden)[viii]. Some smaller UK examples include work undertaken to retrofit SUDS within the Bourne Stream[ix] catchment, and at Matchborough School[x].

However, recent work aimed at designing and implementing retrofit SUDS at a larger, catchment scale[xi,vi] has suggested that retrofit SUDS are difficult to implement within the current UK regulatory environment. Present legislation appears to promote the use of 'quick fix' solutions to sewer problems, and incentives for any of the key stakeholders (e.g. water utilities or local authorities) to adopt and maintain SUDS are almost non-existent. In this context, the construction of retrofit SUDS will frequently appear to be more disruptive, risky and expensive than conventional solutions. To date there are no medium or large-scale examples of a UK water company retrofitting SUDS to address a CSO or DG5 problem.

This paper will present a new case study comparison between conventional in-sewer storage and retrofit SUDS as alternative options for addressing a DG5 problem. Some of the barriers to retrofitting SUDS within the current legislative context will be described and an alternative, planning-based, approach will also be proposed. This alternative approach may be seen as a reversal of the incremental way in which stormwater management problems tend to develop over time.

Cromer case study – Catchment characteristics

Work on the Cromer catchment was undertaken by the University of Sheffield in collaboration with Anglian Water. The project was funded by the EA and the BOC Foundation[xi].

The Cromer catchment has verified DG5 surface flooding, largely attributable to stormwater drainage problems. The DG5 problem had been earmarked for remediation during Anglian Water's AMP4 programme of measures. The mechanisms of flooding are well understood and a relevant catchment model exists.

Cromer is situated on the North Norfolk coast, approximately 25 miles north of Norwich. The catchment area is approximately 23 ha, of which 46% is impermeable surface that drains into the surface water system (14% roofs; 32% roads). The catchment topography drains towards the North East and converges at the highlighted flooding location (See Figure 1), with a typical slope of 1 in 22. The land-use is dominated by a business park and an industrial estate, with associated high levels of impermeable area and positive stormwater drainage. The catchment also includes a residential area, council offices, a petrol station and a derelict old coal yard site.

Surface water flooding (DG5 flooding) at Barclay Close affects a number of residential properties on a relatively frequent basis (in the region of once per year). The flooding problem is largely due to high levels of surface runoff emanating from the upstream catchment which exceed the capacity of the surface water sewer during storm conditions. The topography of Holt Road also promotes the conveyance of storm water runoff into the affected area.

Cromer case study – Historical evolution of the flooding problems

The progressive urbanisation of the Cromer catchment over the last 50 years is shown by historical maps (See Figure 1). The current flooding problems occur in a topographic depression at the downstream end of the catchment. With hindsight, it is worth questioning the initial decision to construct housing in this locality. The 1957 historical map shows very little development (with the exception of a small number of buildings at the northern end of the catchment) within the contributory catchment of the current flood site. By 1973, there had been significant development of the northern part of the catchment (including an industrial estate to the south of Sandy Lane); the southern part of the catchment was largely un-urbanised. By 2006 a residential estate had been constructed in the north of the catchment; and further industrial developments and council buildings (North Norfolk District Council) built within the southern end of the catchment.

Preliminary survey work suggested that the Cromer catchment has good ground infiltration characteristics – which would indicate that the levels of runoff conveyed from the catchment's surface in its natural state would be relatively low – and that ponding at the flooding site may have been negligible prior to urbanisation. It also suggested that the use of infiltration devices would have been a technically feasible stormwater management strategy within many of these developments.

Anecdotal evidence collected from interviews with local residents indicated that the catchment's flooding problems were a direct consequence of the urbanisation of the upper extents of the contributory catchment (e.g. the council site) which was thought to have occurred in the late 1980s.

The local residents' claims were investigated using a crude InfoWorks modelling exercise, in which an 'existing case' catchment model was used to generated a benchmark level of catchment flooding (both in the immediate vincity of the DG5 properties and the overall upstream catchment) for the critical M30 design storm. This 'existing-case' performance was then compared with simulations generated for two 'historical' catchment scenarios. The 1957 and 1973 historical maps were used to develop ‘historical’ catchment models that represented the level of urbanisation within the Cromer catchment at those points in time.

Modelling simulations undertaken for the critical M30 design storm and the ‘existing case’ catchment model predict that the flood volume in the immediate vincity of the DG5 properties would be 63 m^3; and 872 m^3 within the entire catchment. The historical 1973 catchment model simulated flood volumes of 5 m^3 and 157 m^3 in the corresponding locations, whilst the 1957 scenario generated no flooding from either location.

This simple modelling exercise supports the claims of local residents that the current DG5 flooding problem has been introduced and exacerbated (over a period of 50 years) with progressive urbanisation of the catchment.

The Cromer case study is considered to be representative of many other catchments throughout the UK. Many of the UK’s urban drainage problems can be attributed to the impacts of increased urbanisation on drainage systems that were designed several decades ago; and which now have insufficient capacity for their current levels of operational service.

Intervention options

This section highlights the three main design strategies that were considered for resolving Cromer’s flooding problems as part of the combined study by Anglian Water and the University of Sheffield. The ‘preferred’ solution, and the reasons for its selection are also outlined.

Conventional in-sewer storage A typical conventional solution to the Cromer flooding would involve the installation of on-line storage within the sewer network (e.g. in the form of a concrete storage chamber or oversized sewer pipes) to store excess storm flows, releasing them back into the sewer later for subsequent conveyance down to treatment or disposal. There are a number of sites where this storage could be potentially installed (including the old coal yard site in Holt Road, or the pavement adjacent to the flooding site).

Retrofit SUDS The most straightforward retrofit SUDS option in this context would involve the disconnection of large individual properties from the storm sewer, using SUDS devices to deal with their storm drainage instead. The most effective SUDS from a water quality perspective would consist of a number of SUDS units (referred to as a ‘treatment train’). Ground conditions at Cromer make it possible to consider both infiltration and storage-based SUDS devices. Visible, above-ground SUDS have greater potential amenity and habitat benefits compared with sub-surface (infiltration-based) SUDS. A second possibility would be the connection of (larger-scale) SUDS devices via overflow weirs to receive high flows from the storm sewer. A single large infiltration-based below-ground SUDS would offer comparable levels of construction activity and disruption to the in-sewer storage approach; whilst still offering many of the benefits associated with source control highlighted earlier.

There are three locations that seem appropriate for retrofitting SUDS treatment trains to the Cromer catchment: Site 1 – the Council offices; Site 2 – the road-side verge facing the end of Sandy Lane; and Site 3 – the old coal yard site (see the 2006 map in Figure 1). It is envisaged that schemes in these locations could combine the use of infiltration swales, wetland areas and infiltration basins (or ponds) to treat and dispose of the surface runoff. Preliminary design work on these proposed retrofit SUDS schemes has indicated that they could provide comparable levels of hydraulic protection to the engineered storage system.

Preferred solution Anglian Water's preferred solution comprised a conventional in-sewer storage option made up of twin plastic storage tunnels located in the road verge between Holt Road and the Old Coal Yard site. The stormwater will flow under gravity out to sea, where water quality issues are not *currently* of concern.

The main reasons for rejecting the retrofit SUDS options focused on unresolved SUDS adoption issues and concerns about the level of disruption that might be associated with the SUDS construction and maintenance. This 'point' location intervention was considered to entail limited disruption when compared with the multi-site treatment train-based retrofit SUDS option, though levels of disruption would have been minimal for the single large infiltration device-based retrofit SUDS option. Implementation of work to the council site would have entailed significant loss of car-parking space on a short-term basis and some loss of space on a permanent basis. Although it should have been possible to negotiate one-off arrangements for compensation and/or altered water pricing, these considerations, along with the longer-term arrangements for maintenance, represent sizable steps away from 'business as usual'. The design team were relatively inexperienced with respect to the development of SUDS solutions compared with conventional in-sewer solutions. The (property) flooding in the Cromer catchment had become a fairly high profile problem within the locality (with local press and politicians involved) and as such the design team were reluctant to risk the use of a novel/untried solution within this context due to the fear of it failing. Under these circumstances, tight deadlines were imposed upon the project delivery, which severely limited the design team's flexibility to accommodate the 'learning curve' required by this novel approach.

If SUDS do not comply with the definition of a sewer (i.e. having a proper outfall) as stated in Sewers for Adoption (5th edition)[xii] then these cannot be included as part of a water company's asset base. There is currently no real financial incentive for either the water company or the council to opt in to the retrofit SUDS option, and both perceived the approach to present certain risks that they were wary of taking on.

Ironically, all of the stakeholders could see the broader longer-term benefits that the retrofit SUDS solution might have provided. Although retrofit SUDS implementation was not achieved in the Cromer case, Anglian Water feel that they gained valuable experience through their involvement on the project. They are considering retrofitting SUDS in other catchments, and – as with many other stakeholders in the industry – working to address issues relating to adoption and maintenance.

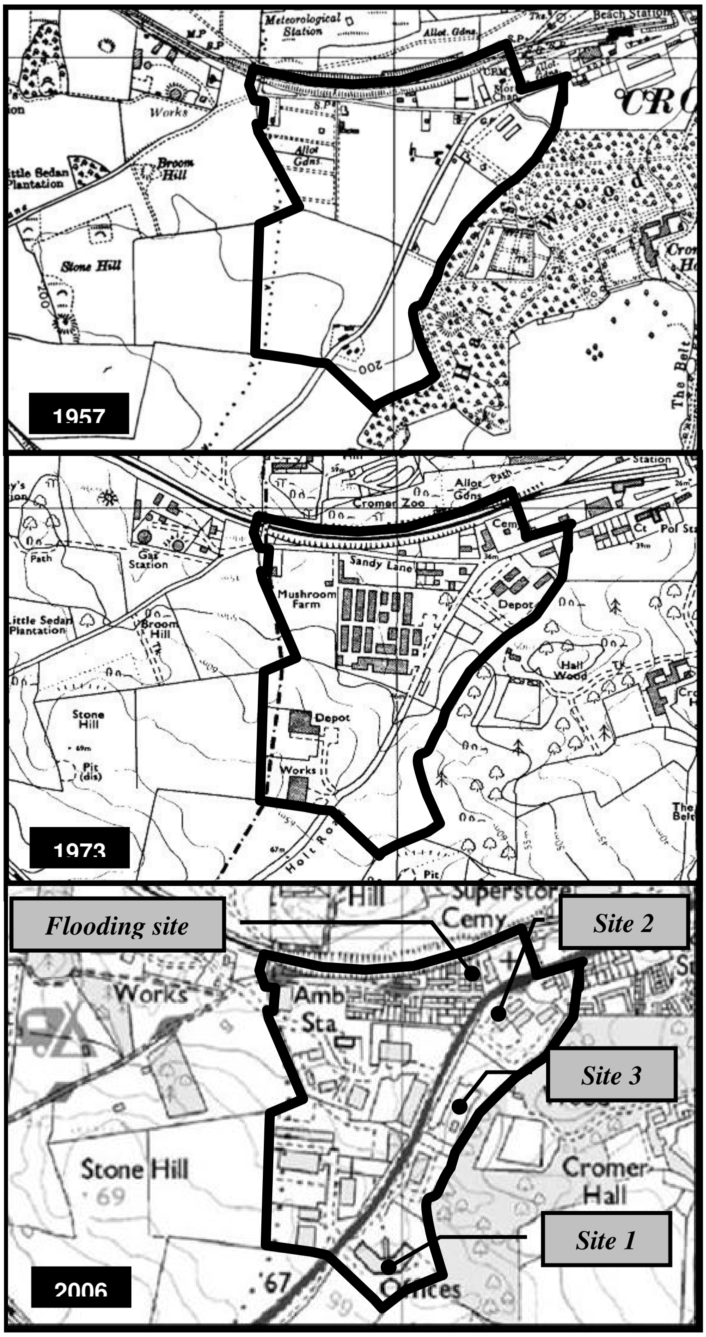

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Figure 1: Historical maps showing progressive urbanisation of Cromer catchment

This is a relatively standard planning requirement, but it may be observed that several opportunities have been missed here. These include the option to place more stringent (i.e. better than existing) runoff controls to the site, or to insist on some additional provision to deal with runoff from areas outside of the site, and/or to use SUDS/infiltration rather than storage-based attenuation. The planned development will be implementing a controlled runoff solution involving sub-surface storage immediately adjacent to the planned Anglian Water storage pipes; this in a location where it appears feasible to have designed one infiltration-based system to serve both purposes.

This may – in the longer term – suggest a 'more sustainable' approach than either the conventional in-sewer storage option or the 'quick-fix' retrofit SUDS option, reliant on the use of planning controls to incrementally better a catchment's stormwater management characteristics.

The use of SUDS technologies within a 'planning-based' approach, involving the progressive imposition of 'green-field', or stricter, runoff restrictions to all new planning proposals (both new-build and brown-field redevelopment) submitted within a problem urban catchment may represent a more sustainable way for water companies to reduce the stormwater runoff entering the system, and the associated problems, over the longer term. This approach would also transfer some of the cost to developers. Within Cromer, the redevelopment of the old coal yard site demonstrated the potential of using the urban planning process to enforce stringent (better than existing) runoff controls and to subsequently offset some of the capacity problems within the local sewer system. In this instance, this opportunity was missed, but it highlights the importance of all stakeholders working together to address urban drainage problems. Steps are now being taken within DEFRA to recognise and promote the need for such an integrated approach[xiii]. The value of this is underlined by the fact that, in England, the percent of new dwellings built on brownfield land has risen from 51% in 1994 up to 70% in 2005[14].

Large-scale (master) planning provides better opportunities to ensure SUDS are implemented when compared with the approvals process for planning applications associated with small developments. SUDS can be considered at the same time as building and street layouts are being developed, and options to integrate SUDS with amenity space can be considered. Local Development Frameworks (LDFs) should provide a forum for affected stakeholders (Councils/EA/Water Companies) to understand specific urban drainage problem zones (i.e. the contributing areas upstream of significant sewerage capacity problems), and drive for disconnections, SUDS retrofits and/or better than 'existing' runoff performance for brown-field regeneration projects. Many local authorities already recognise that waterside locations and green infrastructure can add to the value of development land, and that these are important considerations in strategic urban regeneration proposals.

In line with this positive role for planning, the authors would also support reviews of both Section 106 of the Water Resources Act 1991 (the 'right to connect') and 'permitted development rights'. It would also seem logical to utilise drainage charging mechanisms to provide consumers with some incentive to disconnect.

Conclusions

Examination of a typical urban catchment affected by a DG5 flooding problem has revealed that the problem reflects a lack of consideration for stormwater management as urbanisation progressed. Significant increases in impermeable area, without reference to the catchment's naturally-good infiltration characteristics have lead to the current flooding problem. Although retrofit SUDS appear to be a technically-feasible option for this catchment, and the potential longer-term benefits of this option were recognised by all stakeholders, implementation of this approach in practice is extremely difficult. The current UK regulatory/funding environment promotes 'quick fix' solutions to urban drainage problems. Retrofit SUDS have rarely been explored as remedial solutions; when they have been explored, their merits have generally been assessed against those of conventional solutions using reasonably ‘short-term’ considerations – a factor that often renders them apparently more expensive and disruptive, and hence less preferable. The longer-term benefits associated with retrofitting SUDS into developed urban catchments need to be formally recognised by OFWAT before the water companies will give serious consideration to their wider-scale implementation.

Many of the UK’s cities have experienced significant levels of urban regeneration over the last 10 years. Much of this regeneration has been the construction of residential/business developments in, and around, heavily urbanised city centres, where the levels of imperviousness are already comparatively high. Other significant redevelopments have related to out of town industrial/retail parks, which inherently contain large roofs and car-parks. In hindsight much of this redevelopment represented significant opportunities to rectify – or at least not add to – existing sewer capacity problems. Instead these developments may more often have exacerbated drainage systems already stretched beyond their design capacities. However, further urban regeneration will take place in the UK over the next ten years, and urban planning systems have a key role to play in delivering more integrated and sustainable urban drainage.

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The Waterlooville Major Development Area, Hampshire: A partnership approach for addressing the barriers to implementation and adoption of Sustainable Drainage Systems (SUDS)

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Abstract

Waterlooville has been identified for a major residential and commercial development. This is to be a phased expansion where SUDS have been identified as critical infrastructure. This paper focuses on the practicalities of a partnership approach between developers, local planning authorities and the Environment Agency to ensure that an appropriate storm water masterplan was designed and implemented. It reports on how design, adoption and maintenance issues were addressed through the formation of a steering group, to ensure best practices were adopted and potential barriers removed.

This paper briefly describes the structure of the SUDS monitoring project. The investigation is at an early stage, with no SUDS constructed on site. However, pre-construction monitoring has been carried out in the watercourses to determine baseline conditions.

Introduction

SUDS provide an integrated multidisciplinary approach toward urban runoff management. SUDS allow integrated land use planning, providing surface water drainage methods that take account of quantity, quality, amenity and habitat enhancement. They minimise the impact of urban runoff by capturing surface water as close to the source as possible and releasing it back at the greenfield runoff rates.

In England, Planning Policy Statements 1 (1) and 25 (2) and Building Regulations(3) state that regional planning bodies and local authorities should promote the use of SUDS. However, in practice there is still resistance, mainly due to uncertainties over their adoption and maintenance. Measuring the degree of success of these systems has been difficult, as there have been few opportunities to monitor their performance right through from pre-development to the post construction phase.

The west of Waterlooville is proposed for a 405 hectare major development area, which is to be located on a greenfield site on the border between Winchester City Council and Havant Borough Council in Hampshire. The development lies within the Partnership for Urban South Hampshire (PUSH), which will accommodate 80,000 new homes by 2026. Thus knowledge from the Waterlooville project can be used in developing surface water drainage strategies for these extensive development areas.

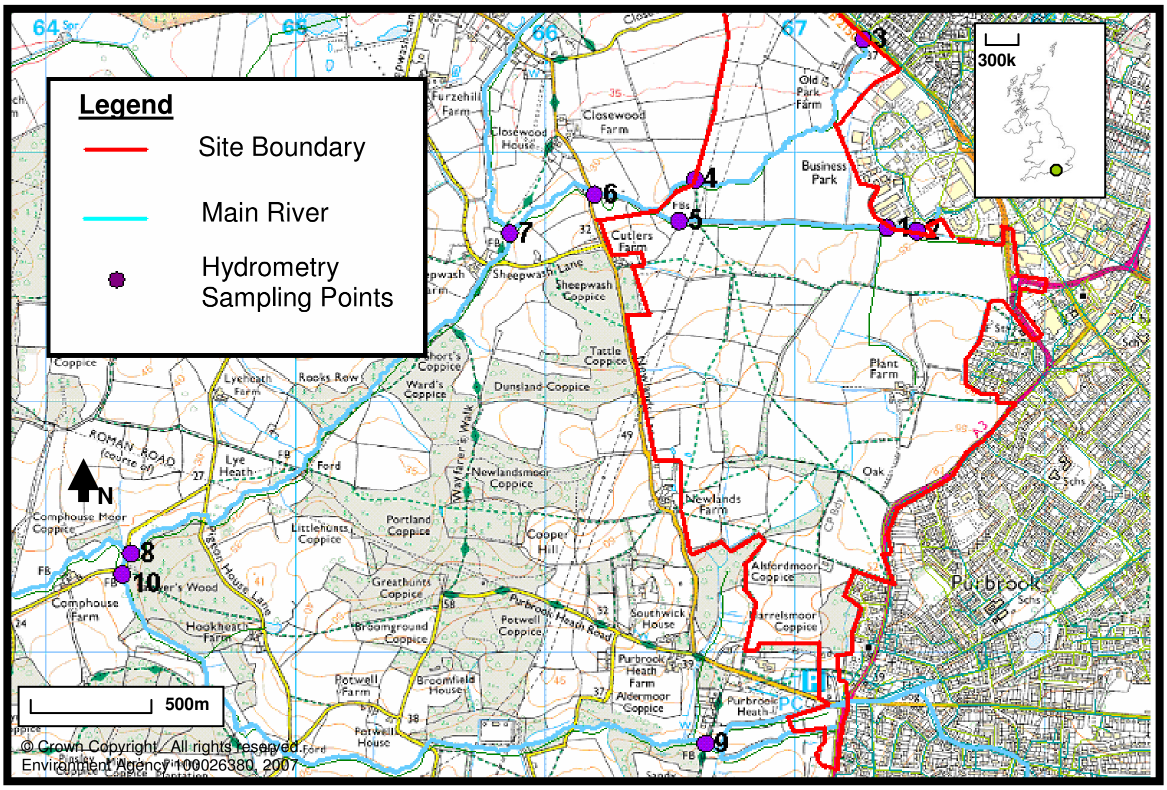

Fig. 1. The Waterlooville Major Development Area and main rivers with hydrometric network

The site was identified in 2002 by the Environment Agency, as one that could benefit from the integration of SUDS from an early stage, and with the developers, Graingers and George Wimpey, on board the SUDS research project was set up and led by the Environment Agency.

The aim of the monitoring project is to support and promote the future use of SUDS by generating an improved understanding of how these systems operate. The project aims to determine how effective SUDS are in controlling the runoff before it enters the existing watercourses preventing an increased risk of flooding or a deterioration of water quality or ecology, which is consistent with the objectives of sustainable development. This project is considered to be a showcase site for SUDS in the region and of national importance for SUDS research.

Practicalities of Developing a SUDS Masterplan

The Environment Agency were instrumental with the implementation of SUDS by forming steering groups and working closely with interested parties to ensure that contentious issues with adoption and maintenance were addressed at the earliest opportunity.

It was acknowledged at an early stage that close liaison was required between relevant parties to address maintenance and adoption of SUDS, in the absence of legislation. A steering group was formed to ensure that these issues did not become a barrier to the implementation of SUDS on this site.

The first SUDS adoption meeting was organised by the Environment Agency in March 2003. Present were representatives from the two local authorities, Highways Agency, Southern Water, the developers, Mayer Brown and WSP (consultants for the respective developers), and representatives from the Environment Agency. A separate technical group was then formed to discuss the detailed design and technical aspects of the SUDS. As with many developments in England and Wales there were a number of issues which required addressing to ensure SUDS could be implemented effectively:

Land Take: Land take was quoted as a barrier for the use of SUDS, as the developers were under pressure to accommodate as many dwellings as possible. The Environment Agency was therefore keen to promote the management train concept, therefore, reducing the size of the SUDS required downstream.

The decision making process involved considering a wide range of sustainability issues besides residential density. The amount of land set aside to accommodate SUDS was agreed at an early stage. This land was identified as essential infrastructure and importantly was not included within housing density calculations. The agreed masterplan assumed an average residential density of 40 dwellings per hectare across the site.

Adoption: A steering group was formed with the specific task of resolving the SUDS adoption issue. From the outset there were concerns raised, over responsibility and cost of future SUDS maintenance and discussions took place over commuted sums. Originally, the solution suggested was to reduce the amount of private ownership and maximise public ownership, to increase confidence of continued maintenance in future years. Another suggestion was forming a management company, which would have commercial ownership of any SUDS.

Both local authorities were supportive of SUDS in principle but were reluctant to commit to adoption. It was suggested that SUDS could be adopted within the public open spaces costs and sit within existing functions, such as the parks department. However they felt they were neither equipped nor had the financial resource to carry out this maintenance. Through a steering group approach, the local authorities were persuaded that by designing systems appropriately, such as incorporating gentle side slopes on swales, they would have the experience and the machinery available to carry out this work.

Agreement was reached on maintenance rates per m^2 for systems including swales, wetlands, and detention basins. Ponds would be examined individually. The exercise demonstrated that the cost for the local authorities to carry out routine works for public open spaces was similar to that identified for SUDS maintenance. A commuted sum was then agreed between the developers and the local authority and SUDS maintenance costs were then written into a draft Section 106 agreement.

The project progressed in line with this agreement, until it was realised that a phased approach to development would be adopted, which could potentially continue over a 10 year period. It was then up to the parties involved to decide what would happen in the interim period, between the SUDS being built and the council adopting the overall drainage infrastructure. An interim phase handover plan was suggested, which allowed the local authority to observe the overall SUDS scheme for a one year period prior to adoption, to monitor their performance and to allow any necessary adjustments.

In light of these uncertainties over the interim period, it was agreed that the southern section of the site would be maintained, which included the SUDS and public open spaces, through a private maintenance agreement. This would avoid conflict over the interim period.

To ensure that SUDS were effectively maintained in the light of the private company folding, measures such as legal agreements and bankruptcy bonds were agreed upon. The northern section of the site, being developed by George Wimpey, is hoped to be adopted and maintained by Havant Borough Council.

Water Authority Concerns: One contentious issue which needed to be overcome was centered around the Water Industry Act 1991 Section 106(1) and the 'right to connect'. Southern Water were supportive of the concept of SUDS but had concerns that under current legislation the householder had the right to connect the drainage from within their curtilage into the nearest sewer. Concerns were raised that if only one foul sewer was present, (as the surface water would be draining into the SUDS) and if the SUDS were to fail or the householder were to connect into the sewer system then these additional flows would lead to the capacity of the foul network being exceeded.

Southern Water was also in the position where they could not adopt public open spaces, due to OFWAT constraints. The group therefore agreed a strategy where conventional surface water drainage systems were deployed within individual housing plots, which then discharged into SUDS features downstream, when the water entered public ownership. Limited amounts of source control devices could be employed, including permeable paving, which were the responsibility of the developers.

SUDS Technical Steering Group

All of the SUDS devices were designed in accordance with CIRIA guidance C697(4), with consideration for quantity control, water quality and amenity/biodiversity. The Environment Agency specified that that the developers had to demonstrate, for the range of annual flow rate probabilities up to and including the 1% annual probability (1 in 100-year event), the developed rate of runoff was no greater than the undeveloped rate of runoff for the same event. Volumes of runoff had also to be reduced where possible.

Discussions also took place over the most appropriate types of SUDS to employ, due to the perceived constraints using certain types of systems:

Permeable Pavements : Initially Hampshire Highways were against employing permeable paving, due to uncertainties over structural integrity and envisaged maintenance problems. However, as the group evolved and permeable paving technologies developed, Hampshire Highways accepted that such devices would be considered on a site by site basis. This was on the condition that the structural integrity of the highways was guaranteed and an acceptable level of access for maintenance was agreed. They also had to be designed in accordance with guidance provided by Interpave, 'Permeable Pavements – guide to the design construction and maintenance of concrete block permeable pavements.'

Therefore permeable paving was to be utilised for some non adoptable roads, car parking areas and driveways.

Swales: Hampshire Highways advised that swales could be constructed adjacent to roads, providing the road substrate was constructed appropriately. The same systems could then be used to accommodate both the highway runoff and the runoff generated by other urban areas. For the majority of swales the preference was for enhanced dry swale type design with an underdrain or a permeable bed, draining into a perforated pipe system.

Grass cutting was a particularly contentious issue, as the local authority parks department was reluctant to collect grass cuttings created within swales. The group consensus was that different types of grasses should be explored with a 'natural meadow mix' being considered as the most appropriate. Strategic tree planting incorporated into designs would avoid leaf litter problems.

Detention basin / ponds: The group struggled with developing a strategy for future dredging due to conflicting reports on dredging regularity and toxic content of sediment. The costs for wet and dry sediment disposal and classification of waste are still to be determined. Many of the SUDS systems will incorporate sediment forebays, to ensure sediment and the associated pollutants are trapped at the inlet of the devices, to minimise the amount of dredging required elsewhere. The toxicity of the sediment will dictate if it will have to be disposed off site or close to source.

The frequency of sediment removal will be based on intermittent inspections to be carried out as part of the maintenance requirements and will only be removed when it is assessed to be to be impairing their performance.

Health and Safety: The group identified safety concerns that are associated around all water bodies. Solutions included ponds designed with shallow slopes, strategic barrier planting and toddler proof fencing. All safety aspects of the pond designs are to be audited by The Royal Society for the Prevention of Accidents (ROSPA).

SUDS Monitoring Project Aims and Objectives

The aim of the monitoring will be to support and promote the future use of SUDS through creating a better understanding of how these systems operate. The project will endeavor to demonstrate that the development will not increase flood risk, worsen water quality or impact on the ecology of local watercourses, which is consistent with the objectives of sustainable development.

The objectives include:

- To establish a research programme, which will monitor the changes in the physical characteristics of the catchment in relation to the development and the use of SUDS and therefore determine the effectiveness of SUDS.
- To provide long term monitoring information pre, during and post construction.
- To educate and promote SUDS implementation.
- To encourage habitat enhancement by influencing the design detail.
- To provide a local and national showcase site.

Hydrometery: Monitoring is being carried out at 13 locations, in main rivers across the site. Continuous stage data, spot flow gauging and rain gauges have been used to record the hydrology of the catchment.

Water Quality: The Environment Agency has been collecting monthly spot samples since winter 2003. Samples are collected from seven sampling points, with a number of parameters being recorded.

First flush samplers have been employed to collect information on runoff from the upper reaches of the catchment. This information will be supplemented by the use of auto-samplers to record variations in pollutant concentrations throughout the duration of a storm event.

Ecological Monitoring: The impact of the development on the ecology will be assessed, along with the impact of the SUDS in terms of habitat creation. To date, ecological monitoring has been carried out to assess the baseline conditions in the watercourses.

Conclusion

The Waterlooville steering group provides a framework in which to implement SUDS for a major development areas. The success of this project demonstrates that a partnership approach enables barriers to be overcome through discussion and compromise.

Adoption of SUDS in England continues to be problematic, particularly for phased developments. It is essential that this issue is addressed at a national level to ensure SUDS are widely implemented and function correctly.

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A Sustainable Drainage Design Strategy For Urban Development: Creating A Suds Landscape To Replace The Storm Sewer

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Introduction

It is more than 10 years since a new approach to drainage was introduced at Coventry University in 1996 and promoted as ‘best practice’. Sustainable Drainage Systems or SUDS as it became known, promised improvements in quality, quantity and amenity but has been resisted by the development industry and drainage consultants in many ways. Although many of the ‘barriers’ have been demolished, there are still issues that continue to marginalise the SUDS approach in practice.

This presentation considers the often stated ‘myth’ that SUDS cannot be applied to high density development and offers a model to create an urban SUDS landscape.

‘A design compromise creates the myth’

Guidance such as CIRIA C521 – C522, the SUDS design manuals published in 2000, and The SUDS Manual - CIRIA 695 in 2007, clearly state that SUDS should mimic natural drainage and include the ‘management train’ concept, beginning with prevention and ‘source control’ before moving to ‘site controls’ and finally ‘regional controls’. However most SUDS schemes, whether single development sites or planned SUDS infrastructure, have relied on conventional runoff collection methods using gully and pipe mechanisms rather than source controls, and have directed the onward conveyance of runoff in pipes and sewers to regional controls or watercourses. This has been particularly true where development pressures have increased due to urban density or the problems of SUDS in housing.

A review of two examples of SUDS planning

There have been few attempts to create SUDS regional infrastructure but two major SUDS planning exercises demonstrate how the absence of the ‘source control’ element in the ‘management train’ and the use of piped conveyance have inhibited the creation of a SUDS model that can be replicated in dense urban development.

The DEX Development

The first planned SUDS infrastructure in Great Britain was DEX (Dunfermline Eastern Expansion) in eastern Scotland. It is important not to underestimate how important this project has been in developing SUDS ‘best practice’, but as the first expression of the SUDS philosophy in the UK it might be expected that there are both strengths and weaknesses in how it was delivered. Apart from one or two exceptions, the housing areas at DEX are drained using gully and pipe collection systems and conveyed to detention basins and ponds within the housing landscape. These detention basins and ponds generally receive untreated, silty and polluted runoff and are the first part of the 'treatment train'. They usually discharge directly, through a pipe, into a 'regional control' pond and wetland for final treatment and volume control before discharge to watercourses.

Critical elements at DEX that prevent a repeatable model for urban sites are:
- Low to medium density housing with generous open space and dedicated areas for SUDS
- Visible silt and oil pollution in open structures due to gully and pipe collection of runoff
- High inlet flows to basins and swales at single point inlets due to pipe and gully collection
- Reliance on regional wetland pond features for storage and cleaning runoff
- Management issues due to single function features in addition to public open space

Clearly, with no significant precedent in Great Britain, DEX is the starting point for all subsequent SUDS design, but it does however demonstrate how difficult it has been to force a re-appraisal of detail layout design and integrate source control into new development. It also demonstrates the dependence of drainage designers on the pipe as a default solution for conveyance of water.

Upton, Northamptonshire

The original Upton Design Code, published in May 2003 (revised 2005 Version 2) stated the project aimed 'to create an urban extension that would promote best practice in sustainable urban growth…'. The code describes four 'character areas', the Urban Boulevard, the Neighbourhood Spine, Neighbourhood General and Neighbourhood Edge. Most of Upton falls within the Neighbourhood General character area with the Neighbourhood Edge links to the Upton County Park to the south.

The street hierarchy comprises:
- Urban Boulevard (Western Road)
- Main Street (High Street)
- Streets
- Streets with SUDS
- Lanes
- Mews and
- Central Courtyards

The use of SUDS is introduced in the fourth street category, 'Streets with SUDS', and interestingly 'The driving factor governing the layout and design of streets with SUDS is the requirement to optimise sunlight onto the SUDS ……' resulting in either:

- SUDS located in the middle of the street – N-S alignment or
- SUDS located at the side of the street – E-W alignment

The SUDS technique used in the Streets with SUDS model is a 1M deep swale 7-11M wide within a street width of 25-30M. Although permeable pavement is referred to for small un-adopted courtyards, it is not clear how these small areas integrate with the SUDS infrastructure. The SUDS, Parks and Open Spaces chapter describes a limited SUDS infrastructure based on the ‘Streets with SUDS’ and it is assumed that the remaining parts of development are drained conventionally leading either directly to the wetlands in Upton County Park or to the conveyance swales in the ‘Streets with SUDS’. Clearly there is insufficient storage within the urban extension for attenuating all runoff. This is confirmed in the code, ‘The SUDS will primarily consist of linked swales which will have a storage and infiltration function which will mainly convey runoff to shallow storage wetlands around the playing fields’. It seems that a large part of Upton is drained conventionally using gullies and pipes with the main storage relying on extensive open space beyond the urban development boundary.

Again there are a number of elements at Upton, similar to DEX, that prevent this being a SUDS model for urban development:

- Medium density housing with generous open space and dedicated areas for SUDS
- A partial SUDS solution within the urban development relying on conventional drainage for the remaining hard surfaces
- Reliance on regional wetland features for storage and final cleaning
- 1M deep swales with limited multifunction or social use and significant Health & Safety concerns
- Conveyance swales that deal with polluted runoff and unrestricted flows
- Lack of source control due to pipe and gully collection creates visible silt and pollution in the SUDS features
- The detailing and planting character of the SUDS features will need high maintenance input

This general hybrid SUDS arrangement is set out in Figure 1. CURRENT SUDS PRACTICE

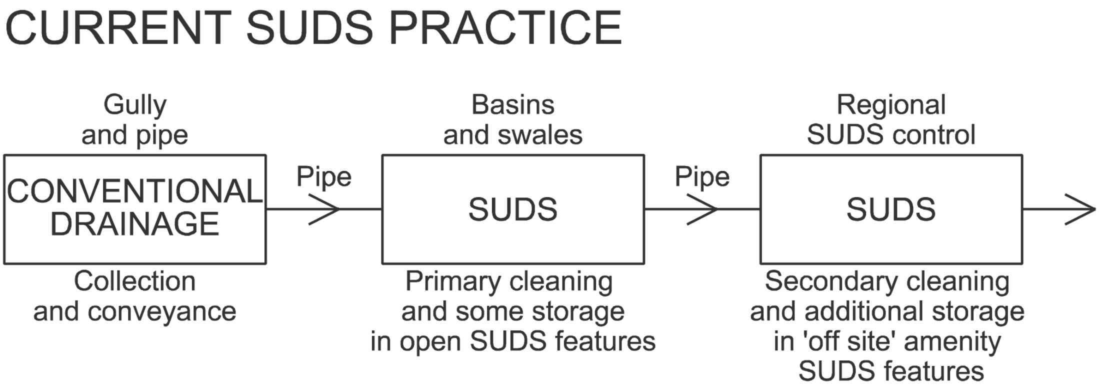


Figure 1

The SUDS philosophy provides the key to creating a repeatable model

‘The philosophy of SUDS is to replicate, as closely as possible, the natural drainage from a site before development’ – The SUDS Manual CIRIA C697 p 1-1

The space constraints in urban areas, together with restricted conveyance routes, confirm that collection, cleaning and storage should be located where rain falls with onward controlled conveyance to reduce both the impact of pollution and unregulated flow. The SUDS selection process points to permeable surfaces as the optimum technique in constrained urban space although other techniques may contribute where space is available for drainage design. Permeable surfaces, including green roofs, permeable block paving, permeable asphalt, bio-remediation features and under-drained swales, all provide effective primary treatment in the ‘management train’. The SUDS footprint can be almost zero and the construction of the permeable structure provides both cleaning and storage ‘at source’.

The next element in the first part of the model is the use of the sub-catchment principle to ensure that only a clean and controlled flow of water leaves any convenient small drainage area. In natural drainage, rainfall either percolates into the ground or collects locally before slowly moving to ground water or a watercourse. Pipes do not occur in natural drainage systems and therefore they should be used sparingly in urban drainage and not as the main conveyance mechanism to act as a sewer. Onward conveyance of un-attenuated water in urban areas will generally require space.

In order to provide amenity to the urban landscape, allow ease of maintenance and prevent cross connections, the conveyance route should be predominantly on the surface and follow urban green space wherever possible. The principle of the urban watercourse provides a convenient conveyance mechanism with occasional landscape nodes allowing flow control checks, occasional storage, and urban water features at convenient stages along a route to the natural drainage system.

Final urban wetland fringes providing ‘polishing’ treatment rather than large storage features and can be located where development pressure reduces, urban biodiversity is required or generally at the edge of settlements.

In summary, the model comprises:

- Source control – collection, cleaning, storage within the development footprint
- Sub-catchment control – managing pollution and flow control at source in a small area
- Urban watercourses – providing manageable conveyance of clean stormwater
- Landscape nodes – urban public open space providing a multiuse drainage function
- Peripheral urban wetland – a final ‘polish’ before runoff goes to groundwater or a watercourse

The Urban SUDS Model is set out in Figure 2 below:

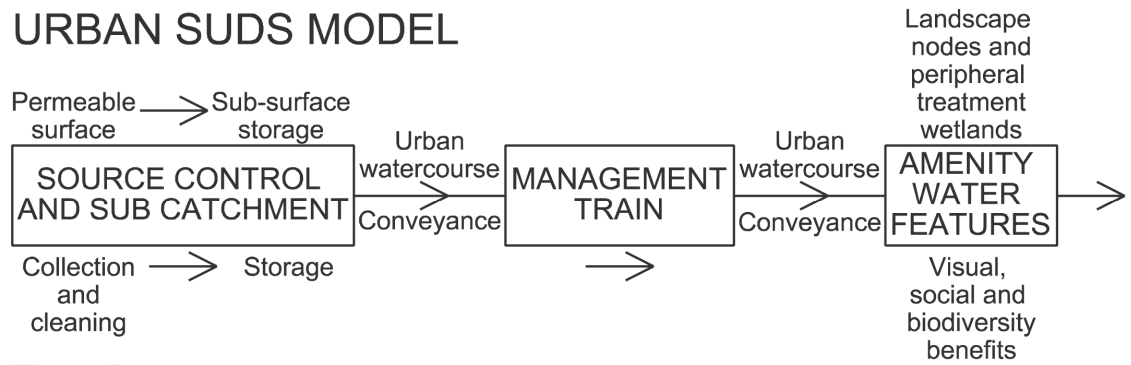


Figure 2

The Design Model sub-catchment in practice

Two recent urban SUDS projects have contributed to the idea of the self-contained urban SUDS model demonstrating minimal land take, permeable surfaces, below ground storage and visible conveyance mechanisms with amenity to the community.

Uplands Co-housing, Stroud – now Springhill

The Springhill housing development is on a steeply sloping site with flats and parking at the top and a pedestrian street below separated by a 3-5m high crib-block or gabion retaining wall. The site includes 28 housing units and a community house representing a housing density of about 55 units/hectare. This is well within current PPS 3 recommendations for urban development.

The SUDS system comprises two sub-catchments:

The upper car park terrace

- Access road and parking runoff flows to permeable block paving with voided stone sub-base storage enhanced with geocellular boxes.
- The permeable surface also receives roof water from studio flats above covered car parking.
- A control chamber regulates flow from this sub-catchment to a T-piece outfall in tile hanging on the retaining wall, dropping to a short swale and onwards to an ornamental pool.
- Roof water from some upper level houses flows directly to one of the 2 T-piece outfalls providing a dramatic cascade down the tile hung panel on the retaining wall when it rains.

The lower pedestrian street

- Roof water either enters rills on each side of the street or flows directly from the community building into an on-line ornamental pool which acts as a silt trap.
- Street runoff flows across a tarmac surface into a rill on the lower side of the street.

- Increasing flows are directed through T-piece inlets from the rills into geocellular storage boxes underneath the street.
- Volumes in excess of the 1 in 2 year storm can overflow into the detention basin play area
- Flow controls operate at the end of the two geocellular storage boxes, the ornamental pool and the detention basin before discharge through a road culvert into the Slad Brook.

The rills, tile cascade, open swale and final stone channel represent the urban watercourse with the ornamental pool and detention basin the landscape nodes.

In the recent floods in July 2007, when Slad Road was flooded to more than 2m deep, the detention basin at Springhill only retained about 150mm of water, indicating the robustness of the system, particularly since it is designed to a 1 in 25 year return period.

Blashfields Place – Stamford

The development accommodates some ground floor houses, apartments and maisonettes on a redeveloped and prestigious site next to the River Welland in Stamford.

The SUDS system comprises an access road with 2 linked courtyards that can be considered as 3 small linked sub-catchments.

- All road, courtyard and some car parking spaces are in permeable block paving
- All other paved surfaces flow to the permeable surfaces
- Some roofwater flows through filter chambers into diffuser boxes in the voided stone below the pavement
- Remaining roofwater is discharged directly into the canals and rills
- The main courtyard releases water into a canal feature through a control chamber which leads to a rill onward across the road to a second canal
- Access road runoff and the second courtyard flow directly through 2 control chambers to the second canal
- The second canal overflows through a slot weir down a stepped channel outfall to the River Welland

This development illustrates the model in a simple form with water released through sub-catchment controls into the start of an ‘urban watercourse’. The urban watercourses can be any surface conveyance structure including rills, channels, canals, pools and basins or softer wetland features like wooded streams or ornamental brooks. Even short pipe runs or grille covered channels can be used to bring water to the urban landscape.

The Integrated Urban SUDS Model

A proposed sustainable development at North Harlow, designed to provide up to 30,000 new homes and associated infrastructure, was the main driver to develop this SUDS model. The development has a high ‘sustainability’ ethos and the client and engineer were prepared to consider a radical SUDS approach to stormwater management. The urban designer was initially concerned that SUDS would require swales and wetland systems and be difficult to reconcile with the ‘urbanism’ philosophy of the development.

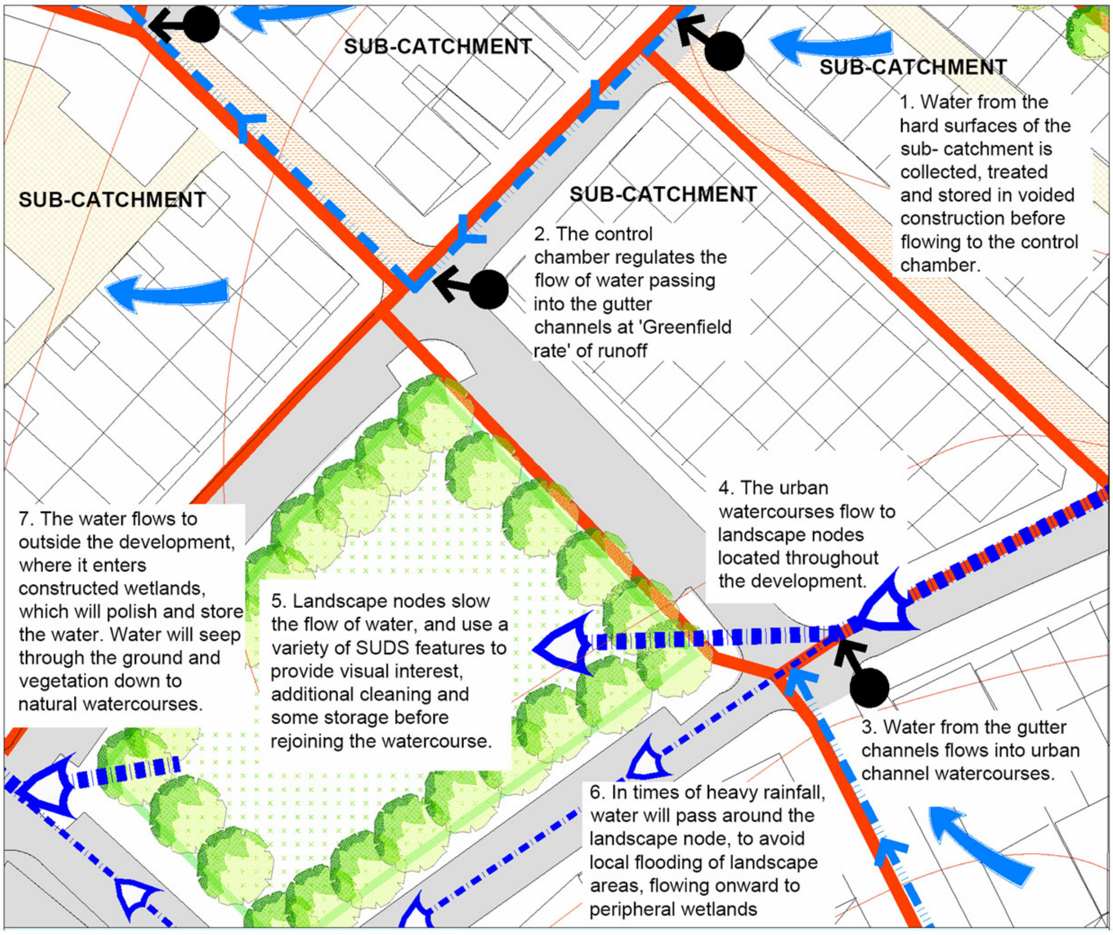
The first radical decision was to replace the storm sewer with a series of interconnected sub-catchments that managed rainfall ‘at source’. This action generated some discussion as the ‘storm sewer’ has become an automatic requirement in most new development. Once the concept of the self-contained sub-catchment was accepted then the idea of the urban watercourse as the conveyance method was considered by the team.

The ‘urbanism’ character of the development actively avoided linked ‘green corridors’ which would have been the natural routes for urban watercourses. Instead, the idea of the enhanced gutter or channel, so common on the continent and in older British cities, was proposed as the first conveyance mechanism. Instead of road gutters running only during rainfall, the new gutter may run for hours until the sub-catchment storage is discharged.

At some point gutters join to form a more substantial rill or channel feature carrying water to landscape nodes or green spaces. Simple weir structures allow a ‘greenfield rate’ of flow to pass onwards delivering any excess to surface or below ground storage. Eventually the urban watercourse delivers reasonably clean water to peripheral linear wetlands for final cleaning before release to groundwater or watercourses. The defects in recent models for urban development are addressed in this approach by applying the SUDS philosophy to high density ‘urbanism’.
The model requires all hard surfaces to be considered as both collectors of rainwater and storage structures for urban runoff. This requirement is critical if current required storage volumes are to be accommodated within urban development.

The model depends on integrated planning in the first instance to ensure that existing watercourses are retained and gravity flow routes are retained or created.

The model then requires a holistic approach to drainage with many disciplines becoming players in the design of a Sustainable Drainage solution for urban landscapes.



1. Water from the hard surfaces of the sub- catchment is collected, treated and stored in voided construction before flowing to the control chamber.

2. The control chamber regulates the flow of water passing into the gutter channels at 'Greenfield rate' of runoff

3. Water from the gutter channels flows into urban channel watercourses.

4. The urban watercourses flow to landscape nodes located throughout the development.

5. Landscape nodes slow the flow of water, and use a variety of SUDS features to provide visual interest, additional cleaning and some storage before rejoining the watercourse.

6. In times of heavy rainfall, water will pass around the landscape node, to avoid local flooding of landscape areas, flowing onward to peripheral wetlands

7. The water flows to outside the development, where it enters constructed wetlands, which will polish and store the water. Water will seep through the ground and vegetation down to natural watercourses.

The Integrated Urban SUDS MODEL – Sub-catchment Planning

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Upton Design Codes March 2005 Version 2

Session 4: Water and Environmental Quality

Chair: Sue Charlesworth, Coventry University

Adolf Spitzer and Chris Jefferies	Mouchel Parkman Ewan / University of Abertay Dundee	The Potential Of A Water Quality Index For Analysing SUDS Performance.
Miklas Scholz and Xiaohui Wu	University of Edinburgh	Experimental Constructed Wetlands Treating Urban Runoff Contaminated With Nitrogen.
Peter Worrall, Sophie Hine and Derek Bateson	Penny Anderson Associates Ltd	The Role Of Ecology In SUDS.

The Potential Of A Water Quality Index For Analysing SUDS Performance

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Abstract

The paper aims to initiate discussion on the implementation of a water quality index (WQI) for SUDS. A WQI for SUDS is outlined and the case for using such an index for measuring SUDS performance is set out. The index presented is based on a modified index developed for Scottish watercourses by the Scottish Development Department (SDD, 1976). The index of the SDD (1976) has been modified to reflect the key parameters of urban runoff quality and SUDS performance. The sensitivity of the SUDS WQI to variations in parameter quality is analysed and two options for compiling the overall WQ results are briefly discussed. The use of the SUDS WQI for practitioners is demonstrated by comparing conventional presentation of WQ results with results presented through the WQI. The paper concludes by highlighting the potential advantages of a WQI for analysing and reporting the WQ performance of SUDS.

Key Words

SUDS WQI, SDD WQI, measuring SUDS performance.

Introduction

Communicating the WQ performance of SUDS is challenging. The practice to date has been to produce reports outlining inflow and outflow concentrations and the removal efficiencies of a SUDS facility or system on a variable by variable basis. Although this approach provides detailed information on each WQ parameter and system behaviour it contains several major drawbacks. Firstly, it is difficult to convey the overall WQ, resulting from the combined impact of several measured variables, to groups of stakeholders with greatly differing expertise in WQ. Secondly, judging system performance solely on the degree of improvement of each measured parameter can be misleading, as the pollutant concentrations in runoff may often be too low for the systems to achieve significant improvement. One possible solution for conveying SUDS WQ performance is to reduce the multivariate nature of WQ data by employing an index that will combine all WQ measures and provide a general and readily understood description of the overall WQ. This paper proposes the use of a WQI for measuring and reporting the performance of SUDS.

Issues Associated With Reporting Water Quality

Table 1 shows a summary of results obtained during a water quality monitoring programme. From these results it is obvious that only people with a good understanding of water quality issues are able to judge the general performance of the SUDS facility under investigation.

Table 1: Example of typical sampling results summary

Samples of 2002 event sampling		**pH**	**Conductivity** (micro S/cm)	**TSS** (mg/l)	**Turbidity** (NTUs)	**NH3** (mg/l)	**PO4+** (mg/l)	**Chloride** (mg/l)	**DO** (%sat)	**Temperature** (deg C)
Sample size	**Inlet**	129	129	129	129	107	115	129	57	57
	Outlet	171	169	170	170	84	81	171	126	126
Maximum value	**Inlet**	7.85	81,100	568	610	1.08	0.52	21,000	91	7.8
	Outlet	7.80	2,620	33	31	0.23	0.31	597	86	6.6
Minimum value	**Inlet**	5.89	182	44	31	0.00	0.00	26	66	5.2
	Outlet	5.71	1,155	0	4	0.00	0.00	128	61	2.6
Arithmetic Mean	**Inlet**	6.99	6,590	148	201	0.11	0.05	2,431	84	5.9
	Outlet	6.85	1,547	7	14	0.04	0.03	304	73	4.8
Standard deviation	**Inlet**	0.42	11,064	91	140.6	0.18	0.07	4,352	7.08	0.65
	Outlet	0.45	268	5	5.68	0.05	0.07	105	4.66	0.94

Using another example, Figure 1 shows the performance of several WQ parameters at the inflow and the outflow of a pond. Figure 1 illustrates the main difficulties when SUDS performance should be judged from these graphs. Concentration units between different WQ parameters can vary by factors of 1,000. Variations of similar magnitude are also common between in- and outflow concentrations of certain parameters. The large differences in pollutant concentrations make it difficult to plot all the investigated parameters on the same scale and, for certain parameters, scaling is also an issue when in- and outflow concentrations are shown on the same graph.

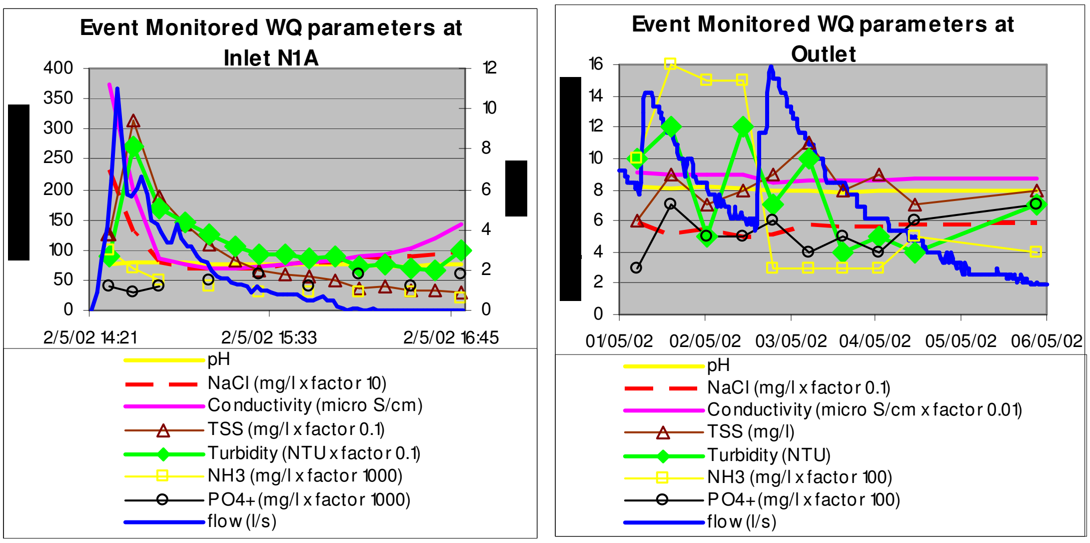

Figure 1: Example of typical SUDS inflow and outflow water quality graphs

Describing SUDS WQ performance through percentage removal of pollutants is also problematic and can be misleading when system inflow has low pollutant concentrations. In these cases, percentage removal figures can indicate poor system performance even when outflows are of high quality.

The Scottish Development Department WQI Applied To SUDS Data

Research into reporting WQ through more readily understood methods has been ongoing for several decades (Brown *et al*, 1970 and 1972; Horton, 1965; SDD, 1976), although until recently no efforts have been taken to develop a WQI for SUDS (Spitzer & Jefferies, 2005; Spitzer, 2007). In 1976, the SDD adapted a WQI concept developed by the US National Sanitation Foundation (Brown et al, 1970) for reporting quality of Scottish Waters. The index is based on WQ ratings curves, developed by a panel of WQ experts. These WQ rating curves were translated into a WQ ratings table that includes ten parameters (DO, BOD_5, NH_3, E-Coli, pH, TON, PO^{4+}, TSS, Temperature and Conductivity). The maximum possible score of each parameter was made dependent on its significance to WQ. An extract of the SDD WQ table is shown in Table 2.

Table 2: Extract of the SDD WQI (SDD, 1976)

Weighted Water Quality Rating (q_i x w_i)	**DO** (% sat)		**pH**		**Conductivity** (micro S/cm)
18	93-109				
17	88-92	110-119			
16	85-87	120-129			
15	81-84	130-134			
14	78-80	135-139			
13	75-77	140-144			
12	72-74	145-154			
11	69-71	155-164			
10	66-68	165-179			
9	63-65	180+	6.5-7.9		
8	59-62		6-6.4	8-8.4	
7	55-58		5.8-5.9	8.5-8.7	
6	50-54		5.6-5.7	8.8-8.9	50-189
5	45-49		5.4-5.5	9-9.1	0-49; 190-
4	40-44		5.2-5.3	9.2-9.4	240-289
3	35-39		5-5.1	9.5-9.9	290-379
2	25-34		4.5-4.9	10-10.4	380-539
1	10-24		3.5-4.4	10.5-11.4	540-839
0	0-9		0-3.4	11.5-14	840+

Note: q_i = parameter quality index (range 0 – 1); w_i = parameter weight index (dependent on relative importance in overall water quality index; 0 – 18 in SDD (1976) index).

For computing the overall WQ score of a water sample, the scores from all parameters analysed are combined by using Equation 1 (SDD, 1976).

$$WQI = \frac{\sum (wqr)^2}{100}$$ **Equation 1**

Where:

WQI = water quality index
wqr = water quality ratings

The calculation of the overall WQ score can be adapted, in case any of the ten parameters included in the index is missing. Equation 2 shows the SDD (1976) method for allowing for missing WQ parameters.

$$\eta = \frac{1}{\sum rwp}$$ **Equation 2**

Where:

rwp = remaining water parameters
η = correction factor

For example, if all of the ten parameters of the WQI apart from DO are available, and DO has a maximum WQ score of 18 points, the correction factor to be applied is 1/0.82, as shown in Equation 3.

$$WQI = \frac{\left(\sum wqr \times \left(\frac{1}{0.82}\right)\right)^2}{100}$$ **Equation 3**

The SDD (1976) WQI was applied to provide a WQ summary for the field data shown in Table 1 and the overall WQ for the data in Figure 1. The computed results are shown in Table 3 and Figure 2. Figure 2 also shows the sensitivity of the WQI to each of the included parameters.

Table 3: Summary of typical result analysis summary

Analysis of 2002 event sampling		**pH** (WQI/100)	**Conductivity** (WQI/100)	**TSS** (WQI/100)	**Turbidity** (WQI/100)	**NH3** (WQI/100)	**PO4+** (WQI/100)	**Chloride** (WQI/100)	**DO** (WQI/100)	**Temperature** (WQI/100)	**Overall WQI** (WQI/100)
Sample size	**Inlet**	129	129	129	129	107	115	n/a	57	129	129
	Outlet	171	169	170	170	84	81	n/a	126	126	170
Maximum value	**Inlet**	100	100	100	71	100	100	n/a	94	100	72
	Outlet	100	0	100	100	100	100	n/a	78	100	80
Minimum value	**Inlet**	78	0	0	0	25	62	n/a	56	100	31
	Outlet	67	0	43	57	75	13	n/a	44	100	44
Arithmetic Mean	**Inlet**	99	11	11	14	92	98	n/a	85	100	54
	Outlet	98	0	94	84	98	92	n/a	66	100	66
Standard deviation	**Inlet**	3.84	19	13	19.11	17.99	6.66	n/a	11.23	0	8.91
	Outlet	5.15	0	10	13.94	5.07	20.90	n/a	8.14	0	7.25

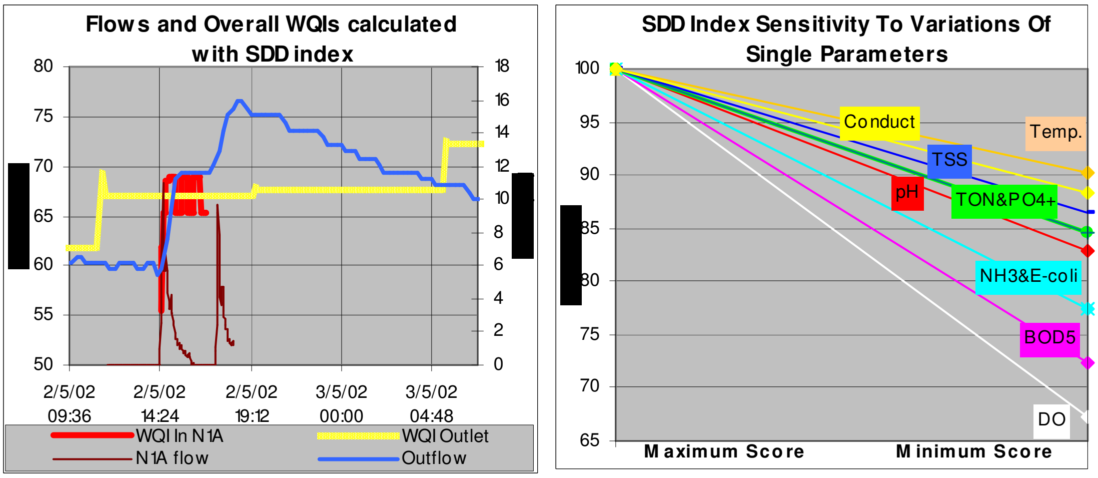

Figure 2: SDD index applied to field data and its sensitivity to variations in its water quality parameters

Comparing the result graphs in Figure 1 with the results for the overall WQ shown in Figure 2, it is obvious that Figure 2 provides the more easy to understand method of reporting and comparing WQ behaviour.

Independent investigations whether the SDD (1976) WQI can reflect overall WQ appropriately showed that the method reflects WQ well at the upper end of the scale (Anglian Water Authority, 1978; Yorkshire Water Authority, 1978; House and Ellis, 1980). However, the same researchers found that this method was less reliable for reporting WQ at the lower end of the WQ scale. Under certain conditions, the WQI may mask parameter qualities that are potentially harmful for aquatic life. This is an issue needing to be addressed, for example by applying a ‘penalty’ factor to the overall score when a parameter exceeds a potentially harmful threshold.

Alternative to the arithmetic weighting method, used by the SDD (1976), geometric weighting can be used for calculating the overall WQI score. In this method, the overall WQ score is computed by taking the nth root of the product of all WQ results, as shown in Equation 4. Compared to the arithmetically weighted index, the geometrically weighted index is generally accepted as being very accurate when recording poor WQ (House and Ellis, 1980). However, this method is insensitive to the impact of a single poor parameter score as long as this score is not zero.

$$\boldsymbol{WQI} = \left(\prod_{i=1}^{n} qi\right)^{\frac{1}{n}} \qquad \textbf{Equation 4}$$

Where:
WQI = water quality index
q = water quality rating
n = number of parameters included in the index

The results of arithmetic and geometric indices will be similar if the ratings of all WQ parameters included in the indices are similar. The two methods may return significantly different results if parameters vary considerably from each other. On balance, the arithmetic index appears more user friendly as it is more straightforward to compute.

The Scottish Development Department WQI Modified And Applied To SUDS Data

The SDD (1976) WQI, outlined in Section 5, is a suitable method for analysing WQ and presenting the results in a ready to understand way. However, the graphs of inlet and outlet WQ of a SUDS facility in Figure 2 show that the SDD (1976) index needs modification to make it suitable for performance analysis of SUDS. The SDD (1976) index is composed to best represent the WQ of freshwater systems. It includes parameters that are not essential, or may even be misleading, when analysing the performance of SUDS. Some of these non essential parameters have a relatively high weighting assigned. On the other hand, the index assigns relatively low weightings to good SUDS performance indicators. To construct a WQI suitable for the specific requirements of SUDS performance analysis, the SDD (1976) index was modified (Spitzer, 2007). Several parameters were removed from the index and the weighting of the remaining parameters was changed, as shown in Table 4.

Table 4: Modified Index Parameters For Analysis Of SUDS Facilities

Parameter	Original score	New score	Comment
NH_3	12	30	--
pH	9	18	--
PO^{4+}	8	20	--
TSS	7	21	--
Conductivity	6	11	--
DO	18	--	removed
BOD_5	15	--	removed
E-Coli	12	--	removed
TON	8	--	removed
Temperature	5	--	removed
Total	**100**	**100**	

The removal of certain parameters and new weighting of the remaining ones is justified.

SUDS DO values are often higher at inflows than at outflows, as inflows are often more turbulent which enhances oxygenation. DO is of major importance for river WQ (Harremoes, 1982; Rauch and Harremoes, 1997), but its inclusion into a SUDS WQI can be misleading.

E-coli and BOD_5 as SUDS performance indicators can also be misleading. Several scientists reported higher SUDS outflow than inflow E-coli counts (e.g. Bavor et al, 2001) and, amongst other factors, it appears that wildlife fouling can contribute significantly to the outflow E-coli counts (Atlanta RC, 2001; House et al, 1993). Ponds that offer good wildlife habitat are therefore particularly prone to higher outflow than inflow E-coli counts. It can be assumed that these issues also apply to BOD_5.

It was assumed that water temperature variations at SUDS outflows are of no significant impact on receiving waters under the UK's prevailing meteorological conditions.

TON, also an indicator of a waterbody's ability to support algae bloom, was removed from the index as PO^{4+} is generally the limiting nutrient for that organism.

The weightings proposed for the remaining parameters are based on their relative importance as SUDS WQ performance indicators and potential impacts on the receiving water. Following this logic, the highest importance was assigned to NH_3, as this substance is toxic to most aquatic species. The second highest weighting was assigned to TSS, as this is probably the most important indicator of SUDS performance. There is a widely held opinion that many pollutants in urban runoff form strong bonds with small sized suspended particulates (Bavor et al, 2001; Krishnappan and Marsalek, 2002; Vaze and Chiew, 2002), making TSS a good indicator for heavy metals, pesticides and pathogens removal. PO^{4+} is typically the limiting nutrient for algae bloom and therefore only slightly lower weighted than TSS. In comparison, pH and conductivity are of lesser importance as SUDS performance indicators. However, extreme pH values have the potential to destroy most aquatic life in the downstream vicinity of a discharge and many chemical processes are dependent on pH (Reddy, *et al*, 1999). Conductivity is a good indicator for salts and ions, and high concentrations influence the chemical state of metals (Bewers and Yeats, 1989; Revitt, *et al*, 2003).

The weightings proposed in Table 4 serve for demonstration and merit further discussion. The modified WQI was applied to calculate the overall WQ for the field data shown in Figure 1 and the result is shown in Figure 3. Figure 3 also shows the sensitivity of the WQI to each of the included parameters.

Comparison of the water quality index graphs, in Figure 2 (SDD WQI) and Figure 3 (modified SUDS WQI) provides clear evidence that the modified SUDS WQI reflects WQ in a way more relevant to urban drainage issues. For example, Figure 3 better reflects, compared to the outflow, the higher inflow TSS load than Figure 2 does. This is reflected in the significantly lower inflow WQ score calculated with the modified SUDS WQI. The modified SUDS WQI also reflects the good TSS removal in the SUDS facility better than the SDD (1976) WQI, shown in a significantly better outflow WQ score.

The comparison of the sensitivity analysis in Figure 2 to Figure 3 shows that the relative influence of each in the WQI included parameter on the overall WQ result is much more pronounced in the modified SUDS WQI than in the SDD (1976) index.

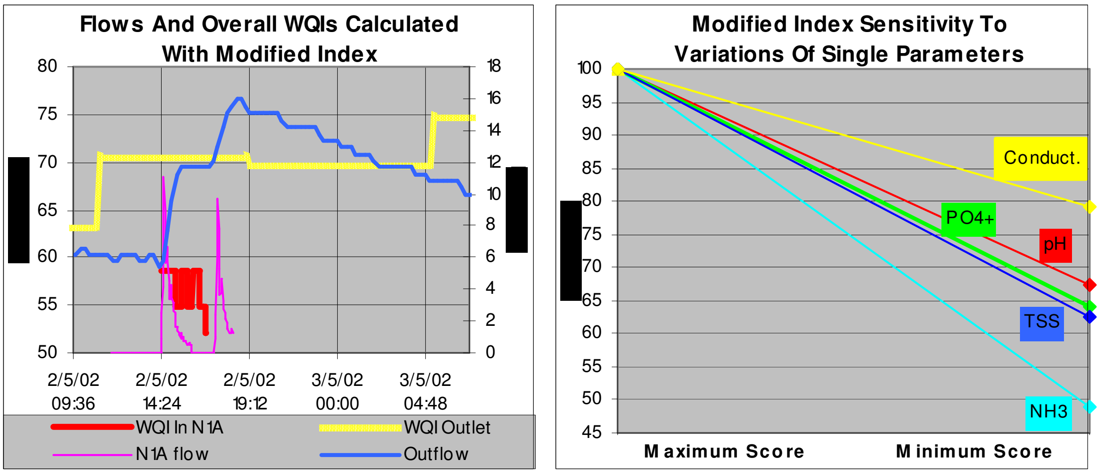

Figure 3: Modified SUDS index applied to field data and its sensitivity to variations in its water quality parameters

Conclusions

The work presented in this paper promotes the use of a WQI for analysing and reporting the performance of SUDS. A WQI system is proposed and evidence is provided that a WQI is an excellent tool for reporting the complicated interactions between several water quality parameters in a robust and readily understood way. The proposed index achieves its clarity in WQ reporting by assembling data from each of the parameters included in the same multivariate index formulation. Its metric of interest is the comparison of the measured data relative to its objective. It can also be concluded, in terms of SUDS performance analysis, that the index is superior to the commonly used method of calculating the percentage removal of certain pollutants, as it unambiguously states the quality of discharge which is a key SUDS performance parameter.

The proposed index is parameter weighted as experience from field observations (e.g. Duloch Park; Spitzer, 2007) suggests that certain water quality parameters reflect SUDS performance better than others. Parameter weighting also offers the most transparent and convenient way in case adjustments to the significance of certain WQ parameters need to be made, should thinking on their relative importance to WQ change.

It was found that several of the WQ parameters included in the SDD (1976) WQI are not essential and may be misleading as SUDS performance indicators. These parameters were screened out, resulting in a SUDS WQI consisting of five water quality parameters. The five selected parameters are deemed to appropriately express the overall WQ performance of SUDS. The reduction in the number of parameters also reduces resource requirements for analysis.

WQ indices bear the risk that the performance of poorly performing WQ parameters remains hidden underneath the index score and potentially hazardous pollution concentrations could remain undetected. This can be avoided with a simple ‘penalty’ system, where the overall WQ score is reduced by a certain percentage if one of the parameters exceeds a certain threshold.

It is likely that the use of the proposed WQI will result in better reporting of WQ performance of SUDS, as the index provides a comprehensible method to condense the complex interactions of several WQ parameters into a readily understood index number.

It is proposed to invest further work in enhancing the method proposed in this paper to create a WQI that is valid for the whole of the UK.

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Experimental Constructed Wetlands Treating Urban Runoff Contaminated with Nitrogen

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Abstract:

The aim of this research project was to assess the role of the macrophyte *Phragmites australis* (Cav.) Trin. ex Steud. in experimental, mature and temporarily flooded vertical-flow wetland filters treating simulated urban runoff. During the experiment, ammonium chloride was added to sieved concentrated road runoff (i.e. gully pot liquor) to simulate primary treated urban runoff contaminated with organic matter. The five days @ 20ºC biochemical oxygen demand (BOD) and chemical oxygen demand removal efficiencies were lower in planted filters in comparison to those of unplanted filters. The nitrogen removal performance of planted filters was more efficient and stable throughout the seasons compared to that of unplanted filters. A substantial load of nitrogen was removed by harvesting *P. australis*. Plant uptake was the main removal mechanism for nitrogen during high concentrations of ammonia-nitrogen in the urban runoff.

Keywords: Phragmites australis, urban runoff, wetland filter, nitrogen, biochemical oxygen demand.

1. INTRODUCTION

Macrophysics of vegetation plays a critical role in constructed wetlands (CW) through enhancing bacterial activity and taking up nutrients [1,2]. The macrophytes transport approximately 90% of the oxygen available in the rhizosphere. This stimulates both aerobic decomposition of organic matter and the growth of nitrifying bacteria [3-5]. Between 6 and 48% of nitrogen can be retained by macrophytes planted in gravel-bed sub-surface-flow wetlands [6]. The uptake capacity of macrophytes is roughly between 30 and 150 kg P/ha×a and 200 and 2500 kg N/ha×a [7].

The aim of this study was to assess the mechanisms of nitrogen removal, especially the role of *Phragmites australis* (Cav.) Trin. ex Steud. in experimental vertical-flow wetland filters treating urban runoff. The objectives were

- to analyze the pollutant removal performances for various filter designs;
- to assess their effects on the nitrogen removal efficiencies under high concentrations of ammonia-nitrogen; and
- to assess the effect on the five days @ 20ºC biochemical oxygen demand (BOD) removal efficiency under different environmental conditions.

2. EXPERIMENTS, MATERIALS AND METHODS

Since 9 September 2002, six different mature wetland filters treating pretreated gully pot liquor were located and operated outdoors at The King's Buildings campus (The University of Edinburgh, Scotland) as described previously [2]. Filter 1 was similar to a wastewater stabilization pond or gully pot (extended storage) without a significant amount of aggregates. In comparison, Filters 2 and 4 were similar to gravel and slow sand filters, and Filters 3, 5 and 6 were typical reed bed filters (Table 1). The reed bed filters contained gravel and *P. australis*, all of similar total biomass weight during planting. In comparison, Filters 4, 5 and 6 also contained adsorption media (Filtralite, light expanded clay product, and Frogmat, a barley straw product). The filters were used to assess the filtration performance under high concentrations of ammonia-nitrogen in an additional experiment (01/05-04/12/06).

The filters were designed to operate in batch flow mode to reduce pumping and computer control costs. All filters were periodically inundated (100%) with pretreated inflow gully pot liquor, and partially drained (50%) or entirely drained (0%) to encourage air penetration through aggregates [4,8]. Raw gully pot liquor was sieved (pore size of 2.5 mm) to stimulate preliminary and primary treatment effluent.

On 1 May 2006, the ammonia-nitrogen concentration of the inflow was artificially raised by addition of ammonium chloride (NH_4Cl) to the sieved gully pot liquor. As a consequence, the inflow ammonia-nitrogen concentration increased up to approximately 10 mg/L.

Phragmites australis was harvested at the end of fall and was taken from points at least 83 cm above the bottom of the planted filters. It follows that the stems were cut approximately 20 cm above the top of the layer of debris. Plants in each filter were collected, dried at 80ºC for 24 hours and finally weighted. Randomly selected plant samples were divided into stems and leaves, and were prepared for subsequent analysis of total nitrogen (TN) and total phosphorus (TP) concentrations after digestion. All variables were determined according to standard methods [9].

3. RESULTS AND DISCUSSION

3.1. Effect of *Phragmites australis* on biochemical oxygen demand and chemical oxygen demand removals

The mean reduction rates of unplanted Filters 2 and 4 were mostly higher than those of the corresponding planted Filters 3 and 5 (Table 1). However, there was no statistically significant difference between the unplanted and planted filters. These findings suggest that *Phragmites australis* did not significantly affect the removal performance of organic matter as reported elsewhere [10].

In contrast to previous researchers, who reported the worst seasonal performance for BOD removal during cold periods [11], all filters with the exception of Filter 1 (44%; extended storage) and Filter 5 (59%) showed high mean BOD removal efficiencies (>85%). The corresponding water temperature was <10ºC. This suggests that microbes have the capacity to effectively decompose organic matter during cold periods, at least as long as the water is not frozen.

Table 1. Comparison of the five days @ 20ºC biochemical oxygen demand (BOD), chemical oxygen demand (COD), total inorganic nitrogen (TIN) and ortho-phosphate (PO_4^{3-}) reduction rates of unplanted (Filters 1 , 2 and 4) and planted (Filters 3, 5 and 6) filters.

Filter	BOD			COD		
	Loading (g/m^2 day)	Removal (g/m^2 day)	Reduction rate (%)	Loading (g/m^2 day)	Removal (g/m^2 day)	Reduction rate (%)
1	12.67	6.77	53.4	22.15	8.51	38.4
2	8.06	7.04	87.3	14.10	9.85	69.9
3	8.58	7.48	87.2	15.00	9.97	66.4
4	8.52	7.58	88.9	14.90	10.42	69.9
5	8.81	7.45	84.5	15.41	9.20	59.7
6	8.29	7.70	92.8	14.50	10.35	71.4

Filter	TIN			PO_4^{3-}		
	Loading (g/m^2 day)	Removal (g/m^2 day)	Reduction rate (%)	Loading (g/m^2 day)	Removal (g/m^2 day)	Reduction rate (%)
1	1.39	0.21	15.1	0.55	0.07	12.7
2	0.88	0.40	45.4	0.35	0.14	40.0
3	0.94	0.89	94.6	0.37	0.29	78.4
4	0.93	0.47	50.5	0.37	0.24	64.8
5	0.96	0.90	93.8	0.38	0.28	73.6
6	0.91	0.89	97.8	0.36	0.30	83.3

Compared to the unplanted filters, the chemical oxygen demand (COD) in the effluent of planted filters increased sharply between the beginning of September and the end of October 2006. A possible explanation for the relatively low BOD and COD concentrations in the unplanted filters was the absence of detritus from vegetation. However, macrophytes are responsible for additional aeration and subsequent oxidation of the organic load [5].

The BOD removal rates observed in the planted and unplanted filters in the presence of sulfate (concentrations ranged between 8 and 79 mg/L; mean of 15 mg/L) were not significantly different. With respect to Filter 3, the mean BOD removal ratio was 0.823 when sulfate concentrations exceeded 60 mg/L, while the mean BOD removal ratio was 0.841 when sulfate concentrations ranged between 8 and 19 mg/L, which was the case during most of the operation time.

This finding contrasts recent research regarding the sulfate reduction achieved with surface-flow constructed wetlands [12]; it was reported that when influent concentrations were above 75 mg/L sulfate, the organic matter removal decreased by 20%. It follows that this may be related to sulfide toxicity, which has been observed to affect both sulfate-reducing and methanogenic bacteria in anaerobic reactors [13,14].

This observation was confirmed elsewhere [15] with the help of similar experiments; the COD removal efficiency was approximately 85% in the presence of sulfate and around 95% in its absence. This finding is rather unexpected, because sulfate-reducing bacteria can compete well with methanogenic bacteria, and are therefore more efficient in removal organic matter [1].

3.2. Effect of *Phragmites australis* on suspended solids removal

Insignificant differences in the suspended solids (SS) removal performances between wetland filters with and without *P. australis* indicated that the contribution of this macrophyte to the physical removal processes of SS was not high in the temporarily flooded vertical-flow wetland filters [16]. The SS removal performance was not affected by *P. australis*, contradicting previous results [11] indicating that the vegetated systems exhibit nearly twice as high removal efficiencies if compared to a comparable unplanted system. Higher SS removal performances in planted systems are attributed to larger surface areas, reduced water velocities, and reinforced settling and filtration by *P. australis* [2].

3.3. Effect of *Phragmites australis* on nutrient removal

As presented in Table 1, total inorganic nitrogen (TIN) reduction efficiencies for the planted Filters 3, 5 and 6 were always higher than for the corresponding unplanted Filters 1, 2 and 4. Findings indicated that the TIN removal ratio for planted filters did not seasonally fluctuate between May and December 2006. A linear relationship between the loading and removal rates of TIN in vegetated filters was observed. In comparison to Filter 2, high TIN removal rates and more consistent removal performances were observed in Filter 3 predominantly due to the uptake of nitrogen by *P. australis*.

Early (i.e. in October rather than December) harvesting of nutrients in The Netherlands resulted in higher removal rates [17]. Therefore, the total nitrogen removal by harvesting *P. australis* was estimated on 4 October 2006. Loadings were calculated based on the concentration of the total nitrogen and the corresponding weight of harvested *P. australis.* A substantial amount of total nitrogen (between 473 and 532 mg in 2006) was removed by harvesting *P. australis.* Total nitrogen concentrations in the leaves were always higher than those in the stems within all planted filters.

The major problem for nitrogen removal in CW is the availability of oxygen for nitrification and subsequent availability of a carbon source for biological denitrification [18]. In general, nitrification is more efficient in free water surface CW than in sub-surface flow CW [19]. Corresponding findings indicate that the oxygen concentration within wetlands slowly decreased with respect to the distance from the inlet. However, the dissolved oxygen (DO) concentration at the 40 cm distance mark (measured from the inlet point) in Filter 3 increased slightly, because *P australis* supplied some oxygen to the rhizosphere [20].

In particular, the DO concentration was sufficient for nitrification within all filters, so that the nitrate-nitrogen concentration increased through the treatment process in unplanted filters with the exception of Filter 1 (extended storage only). However, denitrification was insufficient for planted and unplanted filters, possibly due to relatively high DO concentrations (sometimes even higher than 0.5 mg/L in summer) within these systems [18].

3.4. Nitrogen removal mechanisms regarding planted filters

Findings confirm reports in the literature that CW can be used as nutrient sinks and/or transformers [5,17,21]; particularly, nitrogen can be removed through wetlands by several pathways including nitrification followed by denitrification, assimilation into biomass, mineralization of organic nitrogen, ammonia volatilization and adsorption of ammonia onto substrate. Denitrification is the main mechanism for nitrate removal in free surface-flow CW [22].

Ammonia volatilization depends on the wind velocity and water temperature, but predominantly on pH. However, in this experiment, the pH of the influent was always less than 8, so the ammonia volatilization's contribution to the nitrogen removal was limited. This result confirmed findings discussed elsewhere [23].

Concerning nitrogen assimilation onto biomass [24], the amount of nitrogen immobilized by biomass was 15% of the added nitrogen during the first year of operation. However, wetlands should achieve nitrogen transfer equilibriums when they are operated in a stable mode after the startup period. Thus, the contribution of biomass assimilation can be negligible. So the nitrogen assimilation onto microbial biomass was not taken into account.

4. CONCLUSIONS

Phragmites australis (Cav.) Trin. ex Steud. has a negative impact on the organic matter removal processes. However, this macrophyte provided good filtration conditions by preventing the filters from becoming clogged. The biochemical oxygen demand removal performances of all filters were not significantly different in the presence of different concentrations of sulfate. Compared to the unplanted filters, *P. australis* was found to contribute significantly to the nitrogen removal process as plant uptake was the main pathway for nitrogen removal.

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The Role of Ecology in SUDS

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(Thanks go to Potteric Carr Nature Reserve, Yorkshire Wildlife Trust, for supporting the survey work on their wetland SUDS)

Abstract

The development of SUDS in the UK has been guided largely by engineering principals and the need to urgently address water quality and flood management issues within our urban areas. Where a SUDS requires a habitat component, the role of ecology has been confined to the final detailing in the design of the scheme. It is proposed here that ecology should play an integral and early part in the SUDS design, implementation and management process in order to fully capitalise on the various environmental and ecological services they have the potential to support. This paper outlines the roles ecology should play in SUDS development and investigates issues relating to ecological potential of habitats polluted with urban runoff.

Only two days after the unprecedented and devastating floods in South Yorkshire, Liberal Democrat peer, Baroness Miller, raised a question in the House of Lords as to whether the Government could bring forward its planned investment in sustainable drainage systems in response to the growing problems associated with urban flooding[1]. The 2007 floods have given a profile to SUDS the likes of which has not been seen before, and as much as this is welcomed, the rush to design and install SUDS, especially those that involve habitats of some kind or other, needs to be done with careful planning to ensure that all the opportunities SUDS can offer are realised.

There is little doubt that the momentum for SUDS has been initially generated over concerns for two of the three SUDS drivers, those of water quantity and water quality. The third driver, biodiversity and amenity has yet to take its full place in the process. However, if we are to capitalise fully on SUDS then ecology has to play an early and deterministic role in SUDS design, construction and management. Ecology should not be seen as an adjunct to or artefact of landscape design but as a critical input to facilitate the sustainability of the environmental services that SUDS are capable of delivering.

For many SUDS schemes the role of the ecologist would be to specify the plants to be used in the system. This may seem a straightforward process; if it is a wetland SUDS, then specify wetland plants. What could be simpler? However, this task is more critical to the success of the SUDS than many seem to think. In Australia and the USA concerns have been expressed about the

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[1] Hansard House of Lords Debates Wednesday 27th June 2007

‘failure’ of wetland SUDS because of the use of inappropriate plants which are not able to sustainably tolerate the “dynamic nature of urban hydrology”[2].

The critical role of ecology is therefore to define the species and habitat structures that address the essential prerequisite of such systems, i.e. to be sustainable. To embark on this process there are three basic questions to be asked:

1. Which plants would be viable in response to the hydrometric and water quality character of the site?
2. Which species and assemblages of plants are ecological appropriate within the nature conservation context of the site in which the SUDS is to be built?
3. How can the selection of plants, assemblies of plants and habitat structures provide strategic wildlife and nature conservation services?

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Selecting the plants.

Most SUDS are scaled on the basis of their capacity to retain the design flood event. This often means constructing a wetland basin, a large proportion of which only acts as a wetland infrequently. Some parts of the basin may be wet all year round whilst others will have varying degrees of wetness. In order to create a list of appropriate plants that survive in such a system it is necessary to characterise the hydrology of the basin by generating frequency/depth/duration curves for a series of typical annual return rainfall events. Such an analysis of the hydrological character of the SUDS would enable the ecologist to determine which plants are the most appropriate for the conditions that would be found in the system. Without undertaking such hydrological characterisation and equating this to the tolerances of the plants available, the SUDS risks reverting into a species poor, low value and possibly high maintenance system.

With the pond’s ‘hydrograph’ in hand the next steps involves identifying those species that would tolerate such hydrometric ranges. A start on this can be made by referring to various texts and guidance documents[3]. Once you have a selection of species that are capable of tolerating the variations in water depth, the next step would be to characterise the water quality of the runoff being diverted to the SUDS and reference this against the trophic status of the individual plant species and their tolerance to metals and other pollutant types.[4]

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Having selected an assemblage of species that can withstand both the hydrometric and water quality regime of the SUDS, the next step is to assess their appropriateness against their inter-specific competitiveness, soil associations and successional characteristics[5]. 'Landscaped' urban SUDS that start off looking aesthetically pleasing can end up with limited biodiversity and management problems because highly competitive species were put in association with slower growing, less aggressive plants.

Selecting plants assemblages and habitat structures

Having determined which assemblages of plants might best fit the physical, chemical and biological features of the SUDS, there needs to be a following stage in which a rationale is provided for selecting amongst the options. To do this the ecologist would appeal to the local nature conservation character of the surrounding area. This may be achieved through site survey or, more generally, a desk based study where ecological data is collated for the development site or catchment. By designing the SUDS to conform to the nature conservation character of the surrounding area supports the long-term sustainability of the new habitat by providing nearby sources of appropriate colonisers should the SUDS habitat become degraded in some way.

As an alternative to using the nature conservation character of the surrounding area as the guide to the habitat selection and species for the SUDS, appeal could be made to local and national Biodiversity and Habitat Action Plans (see http://www.ukbap.org.uk/) or policies and aspirations of the local Wildlife Trusts (see http://www.wildlifetrusts.org/). Not only would this mean that the SUDS would be contextually correct from an ecological perspective but the system may take advantage of offering significant enhancements to biodiversity objectives, something the local planning authority may be keen to see!

Having the right plant groups is one requirement but another relates to the types of habitat structures and management regimes that may be integrated into the scheme. The structural balance between open water and reedbed in a wetland SUDS can significantly influence the capacity of the SUDS to support diversity in invertebrate fauna and bird life. Again, providing targeted plant assemblages and a suitable management regime may mean that the SUDS can sustain populations of water vole or even bat species, making the SUDS functional in terms of protected species support within the local area.

By selecting the most ecological appropriate species, assemblages and structures, the ecologist will be directly influencing the nature and extent of management of the system. It is a myth that habitat based SUDS require, specialist and expensive maintenance. The opposite is in fact the case with an ecologically well designed system providing a low maintenance option compared with orthodox landscape development approaches.

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Strategic wildlife opportunities

The general acceptance of the ‘fact’ of climate change is leading key nature conservation bodies to consider how strategic planning may be used to facilitate the response of wildlife to the changes that will occur in the distribution of environmental conditions with the country. This momentum is stimulating the production of vision statements for a range of habitats and species assemblages[6] which could be used to inform the nature of SUDS developments across the British Isles. As the impacts of climate change begin to manifest themselves in ecological responses, a key function of our green spaces will be to facilitate the movement of species. This would be achieved through construction of green networks and habitats acting as ‘steeping stones’ for species transition. The role SUDS could play in this process within the urban context is potentially significant as long as the design of the SUDS is guided by ecological principles and thinking.

By coordinating the three requirements of, which plants and habitats are viable; which are ecologically appropriate in the nature conservation context of the site, and whether these species and habitats could provide a means of achieving strategic wildlife goals, enable a SUDS design to claim true ecological sustainability. However, it may be argued that the ecological viability of habitat based SUDS is compromised by the nature of the runoff they receive from the built environment. It is well documented that habitat and species diversity may decline in response to increased nutrient and pollutant loading.[7] However, many wetland habitats are highly tolerant of and resistant to environmental stresses but it is not well understood how long SUDS habitats can retain viable nature conservation values.

To investigate this concern, a well established SUDS has been studied at Potteric Carr near Doncaster. This wetland nature reserve on the urban fringes of Doncaster, Yorkshire, comprises a complex of wetland habitats ranging from reedbeds to wet woodlands. At over 200 hectares, the site depends on a pumped water system to sustain the mosaic of wetland features. In recent years, the availability of water for managing the habitats has become critical. Urban runoff and sewage works effluent runs through the site via the Mother Drain but its water quality is not sufficiently good to support the Reserve. However, in 1998, the Yorkshire Wildlife Trust constructed a SUDS wetland system dedicated to abstracting the urban runoff from Mother Drain, treating the water and then using the resultant flow to help manage the more sensitive wetland habitats on the Reserve. The system was constructed with a number of inter-connecting cells, each with brick rubble inlet filters and deeper open water areas within the stands of wetland plant species. The design combined the need to treat the runoff with the aspiration to extend the ecology of the Reserve.

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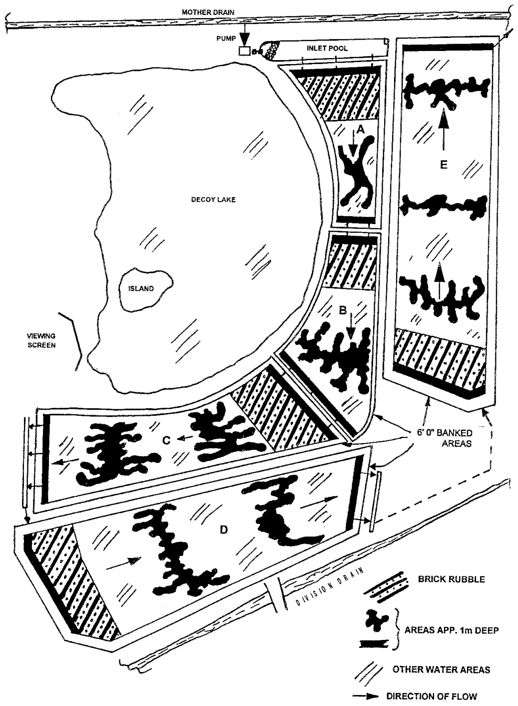

Plan 1: Layout of cells showing deep water areas, brick rubble beds and direction of water flowing through the system

As phosphorus was a key concern to the Reserve, the installation of the brick filters enhanced phosphorus adsorption and in the first years of operation phosphorus was stripped from the average inlet of 2.79mg/l to less than 0.5mg/l[8] at the outlet, making the water viable for use in the nature reserve. With targeted planting of various wetland species and the provision of structural diversity within the reedbed cells, the SUDS wetland rapidly evolved into a diverse habitat supporting breeding birds, water voles, reptiles and amphibians. Two years after commissioning, detailed surveys found a good assemblage of invertebrate species, primarily from rapid colonisers such as beetles, mayflies, diptera and hemiptera (bugs)[9]. Many of the species recorded where from pollution sensitive families suggesting that the water quality within the cells was good.

When the survey was repeated in September 2007[10] it appeared that the taxon richness[11] of the SUDS had increased but this masked the fact that the assemblage had shifted towards pollution tolerant species. Nevertheless, the SUDS in 2007 supported at least three invertebrate species of conservation interest. This shift in the ecology of the aquatic invertebrates may be as a result of the continuous environmental stresses imposed by the quality of the source water to the SUDS. However, two other factors may be involved in this apparent shift towards a more pollution tolerant species assemblage. The first may relate to the June 2007 floods which created a shock load of heavily polluted waters which may have temporarily (?) decimated the more sensitive species. The second factor that may have lead to a shift in the species character of the water bodies relates to the management of the system. Like so many SUDS, the Potteric Carr system has to some extent suffered from the ‘build and abandon’ approach. This has meant that the operational assumptions that were inherent in the design have not been fully met, leading to, for example, extended periods of stagnation where the source water to the system was not diverted into the wetland cells.

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[10] A detailed paper on the findings of the various surveys on the SUDS is to be published in 2008.

[11] This is the number of invertebrate taxa recorded, and is the most widely used measure of biodiversity. A taxon is a group of related animals, such as a species, genus or family.


Wetland SUDS at Potteric Carr Nature Reserve, Yorkshire.

The Potteric Carr SUDS is nearly 10 years old and despite an apparent shift in the invertebrate populations towards more pollution tolerant species, the wetland habitat still provides significant ecological services, as well as meeting water quality objectives and to a lesser extent flood management.

SUDS will inevitably be constrained in the ecological diversity they may support, in the long-term because of the character of their source water. However, from an ecological perspective even 'sub-optimal' habitats have the potential to support the delivery of local and national biodiversity objectives as well as providing a contribution to strategic nature conservation services.

The role of the ecologist in the SUDS design process is critical in contributing to the achievement of the 'sustainability' part of SUDS. With the current momentum towards management as opposed to protection from flooding, the use of SUDS will accelerate and a significant opportunity exists to capitalise on the ecological services that SUDS can offer. However, without good ecological knowledge and experience being applied to SUDS they will remain a flood management tool with a 'green wash' of limited sustainability.

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