Overview of SuDS performance

Information provided to Defra and the EA

SUDS in Leicester

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1. OVERVIEW OF SUDS EVIDENCE BASE

This report collates information on the main areas of interest with regards to the delivery of sustainable drainage. This is primarily based on the information and guidance that is currently in the public domain (as of October 2009).

1.1 SuDS performance

The SuDS philosophy is to replicate natural drainage that occurs prior to development and manage the water as close to its source as possible providing opportunities to manage flood risk, water quality and improve amenity/biodiversity. The benefits provided by SuDS are dependent on the specifics of the site. The SuDS scheme implemented at Lamb Drove, Cambourne achieves a runoff rate of 2 l/s and provided an £11,000 (10%) saving (as compared to the estimated cost of a traditional drainage system). It is important to note that even greater savings could have been achieved if the delivery had involved earlier consultation and more effective pre-application discussions.

1.1.1 Hydraulic performance

SuDS are designed to meet specific performance criteria, much the same way as traditional drainage systems. SuDS components are generally volume based whereas pipe design is entirely focused on conveyance. The majority of SuDS components provide larger storage volumes than traditional drainage systems. Therefore, these systems will only become overloaded by events occurring over a longer duration, which generally means that "failure" results in less impact. SuDS components manage the interaction between the drainage system (minor system) and built environment (major system) better and facilitate the management of exceedance flows. With the majority of SuDS components managing water on the surface this increased visibility may also contribute to improved flood risk management, particularly during extreme events.

In addition to the type of failure being very different, SuDS schemes retain and attenuate the runoff for longer, while pipe based systems pass all this flow downstream. This means that areas downstream at risk of flooding receive all the water from an upstream pipe based system, but only a limited amount of water from a SuDS scheme. Flood risk is managed by SuDS reducing the volume, frequency and flow rate of surface water runoff and during extreme events exceedance can be managed and in many circumstances can be visually monitored.

1.1.2 Water quality performance

The philosophy behind SuDS is that they also treat the surface water runoff often improving water quality as well as provide a drainage system. This is the main difference between traditional drainage systems based on the use of pipework and the SuDS philosophy. In general, the use of SuDS components, especially if a SuDS management/treatment train is used, can result in runoff water quality which is of a similar order to river water quality standards (HR Wallingford, 2003). This area of research in SuDS is continually evolving with research being undertaken particularly in Australia on the benefits of biofiltration.

1.1.3 Amenity and biodiversity performance

It is widely accepted that sustainable drainage, particularly landscaped SuDS can significantly contribute to the amenity value of an area and improve general quality of life. Several studies have identified the added value associated with the proximity of premises to open water areas. The resulting values range between 2% and 19%. HR Wallingford (2003a) suggest that land values and house prices located adjacent to SuDS water features may attract a 10% premium on resale. Other estimates suggest that a stormwater wetland “waterfront” location on a business park/commercial estate can increase rental rates by 3-13% (Ellis et al., 2003).

2. HYDRAULIC PERFORMANCE

2.1 Context for hydraulic design performance

All development has an impact on the environment in terms of the response of surface water runoff to the rainfall that falls over the site. These impacts can include:

- Increased runoff rates (including peak flows)
- Increased runoff volumes
- A deterioration in runoff quality
- Reduced groundwater infiltration volumes
- Increased risks of groundwater contamination

Each of these topic areas is addressed by a range of guidance and legislation. Methods continue to change (improve) based on increasing awareness, knowledge and technical capability. Suggestions as to possible future approaches are also presented.

2.2 Runoff rate

2.2.1 Greenfield equivalent

The rate of runoff has long been recognised as an issue related to urbanisation. Possibly the earliest reference worth mentioning is TN 100 by CIRIA "Guide to the design of storage ponds for flood control in partly urbanised catchment areas" (CIRIA, 1980). It not only raised the issue of increased runoff rate, but also drew attention to the additional runoff volumes and reduced recharge to ground. This work drew upon the flood studies report (NERC, ???) outputs in estimating flow rates and defining a methodology for sizing storage basins.

The next milestone is probably reports 123 and 124 again from CIRIA, "Scope for control of urban runoff" (1992). These documents also drew attention to the water quality aspects of urbanisation as well as providing a methodology for managing stormwater run-off. Current day guidelines are reflected in this document where it suggests that recharge should be carried out where possible and if not then detaining water prior to entering a drainage system would be beneficial. Pervious pavements are discussed and illustrated.

The main difference between this document and its guidance with the present position is that the focus was on ensuring that the downstream capacity of the specific river was not overloaded and therefore there was no prescriptive approach with regards to set outflow rates from any development or catchment.

However as a result of this document and the growing awareness of the need to control runoff from developments, the NRA (now Environment Agency) and planning officers of the time were starting to stipulate a range of criteria for the runoff. These were often a set flow rate, presumably based upon some general analysis, which initially ranged from around 5 to 12 l/s/ha. This flow rate was aimed at limiting the runoff from the site for a given return period event to the value which reflected the Greenfield runoff from the site. This was usually applied to a return period of 50 years though this increased to 100 years in the early 1990s.

As numerical modelling was not commonplace until the 1990s for small consultants and developers there was still wide use of a range of empirical formulae, such as Copas (1957). These were either to predict rural runoff rates or a direct method of estimating a tank size. However two favoured methodologies came to the fore; the ADAS 345 method, which arose out of the MAFF 5 report “The design of field drainage pipe systems”(1980) and the Flood Studies Supplementary Reports which produced a range of formulae, with the final version being IOH Report 124 “Flood estimation for small catchments” (1994). These had the advantage of being very simple methods of estimating Greenfield runoff rates.

Unfortunately discharge limits criteria started to evolve locally. The Greenfield flow rate calculated ranged from 100 year to the 1 year return period which was then deemed relevant for the hundred year development runoff state. Locations such as the Anglia region where the soil is generally SOIL type 1 (ie heavy clay with high natural runoff rates) were specifying limits of discharge of only 1l/s/ha.

In 1999 the Flood Estimation Handbook (FEH) arrived which officially replaced FSR. Unfortunately, because it is a digitally based system and relatively expensive, its use for estimating Greenfield runoff rates was generally found to be inappropriate as the digital pre-selected catchment areas were too large to be considered as representative of the development.

The Environment Agency recognised the problems associated with the plethora of various criteria and the frustration of the construction industry and this resulted in a guidance document “Preliminary rainfall runoff management for new developments” W5-074 (2005). This document provided a definitive position with regards to policy relating to controlling runoff from new developments. This document along with PPS 25 “Development and flood risk (2006) and The SuDS Manual CIRIA (2007) have all taken a common approach and therefore there is now consistency in this topic area in terms of design criteria.

In summary, developments are expected to control the rate of runoff to the calculated Greenfield runoff rate based on the IOH 124 report. There is an expectation that development runoff will be controlled to the equivalent Greenfield rates for the 1, 30 and 100 year return period events. A climate change factor is also required to be applied. Although there is some inconsistency between these documents, the guidance in PPS 25 is generally used. This applies an uplift to the rainfall intensities ranging from 10 to 30% depending on the design lifetime. In practice this tends to be 20%.

2.2.2 Re-development of a site (brownfield development or previously developed land)

The current official position for redevelopment of a site is that there should be a reduction in flood risk, but the degree of ‘betterment’ is not often specified. The approach normally taken is to assess the existing development for its performance for the 100 year event and to apply that value, or apply a reduction of 20%, as the limit of discharge. There is clearly frustration in not being able to set Greenfield criteria as there seems little logic in allowing the environment to continue to be ‘damaged’ just because a precedent has been set. However this is a matter of law and until it is resolved, the concept of some degree of betterment has to be applied.

However, there is no formal position on the best practice approach for assessing Brownfield runoff. There are two likely scenarios; firstly an area which still has a known and operational drainage system, and secondly an area where the system is not known or has fallen into disrepair.

Where the system is known, a detailed model of the network and the contributing area can be constructed. This could extend to doing 2D overland modelling as well. However other (less accurate) approaches are possible. It is highly likely that any drainage system which has a 100 year event applied to it will be surcharged and flooding. Therefore all that needs to be done is to assess the capacity of the outfall section of the system and assume it is fully surcharged. Any runoff which is lost from the catchment from overland flow is best ignored. This can be argued for on the basis of:

1. the drainage system 'exceedance' flows would be difficult to measure
2. trying to include these flows does not facilitate application of the principle of 'betterment'
3. inclusion of such flows would increase the peak flow rate significantly, but in practice this would only occur very briefly (the critical duration probably being 15 to 30 minutes)

There are a range of possible approaches that could be taken to estimate the capacity of a system which is either unknown or has fallen into repair, but the simplest approach might be to use the common rule of thumb (Kellagher 2004) which is to use 30mm/hr with 100% runoff for all paved surfaces.

2.2.3 The criteria limitations and possible future changes

There are two key points to note. Firstly, the formula for predicting the peak flow rate for Greenfield runoff is of limited accuracy and secondly, the use of design storms of specific return periods are an approximation for trying to ensure the catchment response to all rainfall post development is largely equivalent to the runoff that takes place before development.

The simplicity of the Greenfield rate formula is often criticised because there is no slope function in it, and therefore for small steep catchments it clearly under-predicts the rate of runoff. Therefore, although the estimate will be 'safe' technically, it may give rise to somewhat 'oversized' (and therefore costly) systems. The important aspect that therefore must be recognised is that this methodology should not be expected to provide an accurate value of the runoff rate, but it provides a simple and consistent approach that all stakeholders can understand and use and apply across all regions knowing that planning officers will be expecting calculations based on this approach. Any new, improved formulas proposed and adopted must be applied firmly at a national scale.

It can be argued that the rate of runoff from greenfield sites for 95% of rainfall events will be close to zero. This will clearly not be replicated by the post development situation when just attenuating flow rates. However from a flood protection and morphological protection (stream erosion control) this simple set of criteria, is probably perfectly adequate for the future. The issue of minimising runoff for small events is addressed in the section on volume control.

The current confusion on whether previously developed sites should use their current discharge characteristics as the runoff limits for new development needs to be clarified. This is more a matter of law than drainage methodology, as the Greenfield runoff rate is an obvious default condition to apply. However if the concept of existing performance is to be continued as the basis for the limit of discharge, then additional guidance on the approach to be used is probably needed.

2.3 Runoff Volume

2.3.1 Greenfield equivalent

Attempts to reduce the effect of the increase in runoff volume from rainfall due to urbanisation has been introduced into Environment Agency official policy since 2005 (HR Wallingford, 2004) and is also included in The SuDS Manual drainage design hydraulic criteria. However the concept is not included in PPS 25 and there have been difficulties in meeting this criteria for new developments. The approach currently taken in the Code for Sustainable Homes does not help in getting this concept introduced.

The concept of runoff volume being an issue needing to be addressed is commonly accepted in some countries (Australia etc), but work on this aspect and the impact of increasing runoff volume and its effect on the increase in risk to downstream flooding has been minimal in UK.

One study which has been carried out was done by HR Wallingford (Kellagher, 2002) tested the effectiveness of the concept of applying the limiting discharge from a site for a range of rates. Analysis was carried out on 20 test sites where development was assumed to take place at rainfall gauge locations. These test sites were selected on the basis of their close proximity to river flow gauges and also taking into account the characteristics of the catchment (Soil, size) upstream of the flow gauge. The analysis showed that, unless the limit of discharge was constrained to 3l/s/ha or less, the storage tank was often empty well before the flood flow in the river had diminished. Thus for the normal 100 year limit of discharge the full amount of runoff from a site was shown to contribute to the main body of the flood flow.

There are two simple approaches that have been defined for assessing and managing the ‘excess’ flow volume generated from a site. These are:

- The concept of ‘Interception’
- River protection for the 100 year flood event.

2.3.2 Interception

Analysis carried out by HR Wallingford (Audacious 2006) showed that around 50% of all rainfall events are 5mm or less. The idea of Interception is therefore to prevent all runoff taking place from a site for the first 5mm. This scale of event does not, obviously, represent a flooding issue, but such a control is aimed at minimising the polluting effect of small rainfall events in causing stressful pollution to biota in rivers.

Methods for managing and disposing of this initial runoff volume include:

- Infiltration (soakaways etc),
- Green roofs (runoff can be deemed to only occur for rainfall greater than 5mm)
- Permeable surfaces (runoff can be deemed to only occur for rainfall greater than 5mm)
- Rainwater harvesting (as long as annual yield is less than annual demand)
- Swales (runoff can be deemed to only occur for rainfall greater than 5mm)
- Detention basins (runoff can be deemed to only occur for rainfall greater than 5mm depending on contributing paved runoff area)

- Ponds (if liners are lower than the outlet and enhanced perimeter infiltration is provided)

It can therefore be seen that 'Interception' provision can be catered for relatively easily.

2.3.3 River flood protection

River flood protection would involve assessing the 100 year critical duration event for the catchment of the receiving watercourse, and restricting the site discharge volume for this event to greenfield. However a brief examination of the implications of this shows that, although theoretically logical, in practice it makes little sense to apply this approach. A small stream where the critical duration event might be 4 to 6 hours is likely to be very sensitive to any new development. However the Thames below Reading, with a critical duration of nearly three days would hardly be affected by a new development. However applying this logic would result in more than twice the volume of runoff having to be managed for developments on large rivers compared to streams.

The approach suggested by Kellagher et al (2002, 2004, 2007) was that the greenfield runoff volume for the 100 year 6 hr event should be allowed to be discharged at the greenfield rate post development, but that the additional volume (excess runoff) would be either infiltrated or 'lost' in some other way, or if this was not feasible, constrained to be discharged at 2l/s/ha (with a concomitant reduction in the main discharge). If this could not be complied with then all the runoff would only be allowed to be discharged at 2l/s/ha or Qbar, whichever is the greater.

There are various methods for analysing this excess volume. As with the assessment of greenfield runoff rate, there are a few very simple formulae for assessing runoff volume. FSSR 124 provides a simple method of calculation, which in practice amounts to the SPR value for the SOIL (1 - 10%, 2 – 30%, 3 – 37%, 4 - 47%, 5 – 53%). As the rainfall depth for the 100 year 6 hour event is of the order of 60mm across the country, it is very easy to obtain an approximate estimate for the greenfield runoff volume.

The calculation of post-development runoff is less clear in that there are a range of possible ways for assessing the runoff volume. These can all be defended and they are discussed briefly below. They include:

1. Using 100% runoff from paved surfaces and 0% from pervious areas.

2. Use 80% (or something similar) from paved surfaces and an allowance of between 0% and the SPR value for that land use type.

3. Use the standard New PR equation which is used almost universally in drainage modelling.

Option 1 is very practical as well as simple. It also is in line with the current approach in Sewers for Adoption. The use of 100% is clearly an over-estimation of runoff, which compensates for any underestimation of the pervious contribution, as long as it is a reasonably high density development. The argument that pervious areas will continue to contribute runoff in line with SPR is patently not correct as the development process results in most pervious areas being 'trapped' behind properties. Contributing runoff is almost certain to decrease.

Option 2 tries to be more exact, but uses the same principle of approach as that for option 1. Landscaping can be specifically assessed for areas which will and won't continue to contribute runoff.

Option 3 would be quite 'normal' for a drainage engineer to use if modelling a catchment. This method is not detailed here, but suffice to say that this is a very different approach, but it does assume some contribution of runoff from pervious surfaces.

2.3.4 The criteria limitations and possible future changes

As with the estimation of peak flow runoff from small sites, the estimate of volume cannot be accurately estimated. This means that pragmatism is needed in defining an approach which is consistent, can be used easily and which achieves the objective of protecting people and the environment. The use of the concepts of Interception and Flood protection, although simplistic, do effectively provide an approach which addresses protection of the environment.

However it must be acknowledged that the approach is simple and that other approaches might be possible. From the perspective of the receiving environment the morphological behaviour of streams are a function of all rainfall events and therefore another approach which uses time series rainfall would theoretically be more appropriate, but in practice the science is not yet there to support such a method. Some changes to the approach may be developed which fills in the gap between small events and a major rainfall event, but this needs to be developed on the basis of proof of need.

2.4 Groundwater recharge

Groundwater recharge is an important aspect to ensure aquifers are replenished. The evidence base for assessing the reduction in rainfall recharge due to site development is limited. The WaND project (a large EPSRC project completed in 2008) which looked at the total water cycle for new developments, included a component that looked at sustainable stormwater evaluation. This included the development of procedures and tools which considered the annual recharge of rainfall for a site and compared this with the annual recharge achieved by the post-development situation. It is important to note that the recharge mechanism after development compared to greenfield conditions requires an annual consideration (and therefore a continuous rainfall and associated recharge time series) as the recharge processes vary so significantly through the year.

In practice the existence of an urban area does not necessarily result in a reduction in recharge. Water supply losses from ageing pipework in older town and city centres can be very significant and can more than replace lost infiltration from rainfall. This should not be dismissed as not being relevant to drainage, as groundwater levels are an issue which need to be considered, whatever the source of the water.

Similarly in areas where soakaways can be used, it is quite possible for recharge volumes to be considerably greater as the interception and evapotranspiration effect of vegetation means that greenfield recharge tends to be effective for only a few months in winter.

2.4.1 Criteria and tools for groundwater recharge

Although there a number of tools for rural and national scale groundwater recharge analysis, the urban drainage fraternity have, until now, ignored this aspect of drainage design. This is clearly a gap in the drainage design criteria set to date. As source control and energy and water scarcity are all linked issues with this topic, it is thought that it would be appropriate for new criteria to be introduced, along with supporting tools and guidance, to encourage designers to take this aspect into account.

2.5 Observed hydraulic performance of SuDS

2.5.1 Level of service

Evaluating the merits and disadvantages of SuDS for flood risk management is not straight forward as the SuDS approach comprises a range of different drainage components. Therefore any site will have a unique capability in being able to deal with a large event. In spite of this difficulty, it is possible to make some generic assertions.

The level of service for which drainage is designed and built is stipulated in documents such as Sewers for adoption (WRc, 2006) and the Design manual for roads and bridges manual (Highways Agency et al., 2005). Theoretically, SuDS should provide a hydraulic capability similar to that of a pipe based system. However, flooding from a SuDS scheme that has been overloaded is very different to that which occurs in a pipe based system and there are very few instances where a pipe based system will outperform a SuDS scheme. SuDS will cater for a larger event than the original design event for a number of reasons.

Type of rainfall event

A pipe system has very little intrinsic storage and is designed to serve a rate of runoff based on a high intensity rainfall event. Due to the finite capacity of a pipe based system, if the critical upper limit of rainfall intensity is reached, flooding will occur. Any additional rainfall above and beyond the capacity of the drainage system will contribute to the flooding. The critical duration of a rainfall event with respect to a traditional pipe system is in the region of 15 minutes to 30 minutes. These rainfall events are usually thunderstorms.

In contrast, SuDS schemes tend to have large volumes and throttled outlets so their critical durations are in the order of 6 to 24 hours. This means that a road could have runoff from a 100 year event for 30 minutes which could easily be dealt with as the volume of runoff would be less than a lesser return period event which has a much longer duration. When failure occurs for the design duration event, the failure will tend to be relatively limited in its impact as excess volumes tend to be small and generated from relatively low intensity, long duration rainfall.

Flooding locally and downstream

In addition to the type of failure being very different and of lesser impact, SuDS schemes will have retained much of the rainfall runoff and discharged the runoff downstream relatively slowly. In many cases the volume of the runoff will be significantly reduced as well although this depends on the antecedent rainfall conditions, the type of soil in the catchment and the combination of SuDS components used. In contrast, all the water collected by a pipe based system will pass downstream rapidly and therefore all events, short and long, will receive the full volume of the rainfall runoff.

There is one circumstance when infiltration techniques might offer a less desirable solution than a piped one. Where soakaways have been used extensively, there is a risk that flows through the ground might resurface downhill, particularly on steep catchments. This situation will only occur in extended wet conditions and although it is yet to be documented, it should be considered during the design phase.

Safety factor

Because SuDS schemes often use vegetative and soil based systems, there is a level of uncertainty with regard to their hydraulic performance. This means that safety factors are applied to ensure adequate performance. For example, the design of a soakaway can incorporate a factor of safety of 10 on measured permeability rates. Another safety factor that can be applied is the use of freeboard on embankments to allow for wave effects and settlement. By contrast, pipe based systems serving paved surfaces rarely have any added safety factor as there is no uncertainty associated with the conveyance capacity of a pipe.

Designing for water quality

Certain SuDS are not primarily designed for their conveyance or storage capacity in terms of their hydraulic performance. For instance, swales are designed to provide water quality treatment and designed for ease of maintenance. They can offer a hydraulic capability far in excess of the hydraulic design criteria.

2.5.2 Research on the hydraulic performance of SuDS

There are two forms of research into the hydraulic performance of SuDS; the first is a theoretical approach using simulation software, and the second is field data collection.

Theoretical hydraulic performance of SuDS

HR Wallingford has carried out various analyses of the theoretical performance of SuDS schemes, both for extreme and frequent rainfall. **Error! Reference source not found.** summarises the research.

Table 2-1 Simulation studies on the hydraulic performance of SuDS

Research organisation and date	Project / Client / Lead contractor	Comment
HR Wallingford 2005	Performance and Whole Life Costs for BMPs and SuDS (Lampe et al, 2005) Client – UKWIR / WERF / AWaarf Lead contractor – BV	SuDS modelled using time series rainfall and design storms: Basins; Ponds; Swales; Filter trenches; Pervious Pavements 2 scenarios
HR Wallingford 2005	Use of SuDS in High Density Developments: a guidance manual Subsidiary research report SR648. Performance analysis of SuDS units. Client - Dti Lead contractor – HR Wallingford	SuDS modelled using design storms: Basins; Ponds; Swales; Filter trenches; Soakaways; Infiltration basin; Pervious Pavements Hydraulic efficiency in terms of peak flow and volume reduction as a function of area.
HR Wallingford 2006	Designing for exceedance in urban drainage (Balmforth et al, 2006. CIRIA publication C635) Client - CIRIA Lead contractor – MWH	SuDS modelled: Swales; Infiltration trenches; Pervious Pavements Developments of nomographs for assessing the return period performance of SuDS components
Sustainable Drainage Associates 2004	Sustainable Drainage Systems: Hydraulic, Structural and Water quality advice – (Wilson et al, 2004: CIRIA publication C609) Client – CIRIA Lead contractor – Sustainable Drainage Associates	Literature review of SuDS information. All forms of SuDS reviewed.
HR Wallingford 2007	WaND (water cycle for new developments) Client - EPSRC Lead contractor - Exeter Uni	SuDS modelled: Rain water harvesting, Combination of SuDS schemes for Elvetham Heath

The design and performance of SuDS is based on equal emphasis being given to ordinary rainfall events and extreme events. Therefore the analyses look at total rainfall response in terms of peak flows and volumes of runoff. The key findings from all of the reports are summarised below:

- Permeable pavements with granular media can provide a level of service of around 100 years even with a surcharge loading from an equivalent adjacent area of between 1 and 2 times the area of the pavement, depending on its infiltration capacity or the limit of discharge from it;
- As critical duration events are longer for SuDS schemes and because these rainfall events tend to be a collection of pulses of more intense rainfall, the analyses carried out indicate that the use of design storms should be replaced by the use of time series rainfall. This can only become a standard procedure when further testing of the accuracy of the current generation of stochastic rainfall tools is carried out;
- SuDS have particular value in areas of flat topography as the hydraulic gradient can be created within the SuDS unit and self cleansing is not an issue;
- The land take for each SuDS system varies and a ranking can be produced in terms of their efficiency for reducing peak flow rates and volumes. The ranking order for peak flow reduction is very different to volume reduction. This confirms the need for a train of SuDS to be used, which also includes source control;
- SuDS schemes are less effective in steep environments; the need for embankments and the risk of erosion due to high flow rates and the reduction in effective storage can reduce the overall effectiveness of the system. However, well designed systems can help reduce the velocity of flows;
- The hydraulic performance of permeable pavement is relatively well developed and understood;
- Rain water harvesting has traditionally been regarded as being of little value for stormwater management. This is largely true for the standard sizing of storage systems and also where yield (from the roof) is significantly greater than demand. However for most of England where the standard average annual rainfall (SAAR) < 1000mm. rain water harvesting based on tank sizes of 750 to 1000 l/person or bedroom results in major flood protection and reduction of flood flows from properties. Further work is needed in this area, particularly on extreme rainfall event profiles;
- Although some research has been done by Sheffield University and others on green roofs, detailed information on their hydraulic performance and response to extreme rainfall events is limited in the UK. Modelling of green roofs is still in its infancy. Generally speaking, the volume reduction of flow from green roofs is small for extreme events. Similarly although there is a reduction in peak flow, this is also thought to be small for extreme rainfall. There is a lot of information from Germany which could comfortably be used as a comparison (Newton et al., 2007, CIRIA C644 Building Greener);
- Software now has the capability to model nearly all types of SuDS schemes. Components requiring further research include rain water harvesting systems, green roofs and under-drained swales. Approximations and simplifications of these systems can be simulated, but with some difficulty;
- Although software now caters for modelling of most SuDS schemes, the uncertainty associated with the infiltration that takes place from vegetative

systems makes it necessary to adopt a cautious approach when making assumptions regarding infiltration rates for extreme events.

Field data on hydraulic performance of SuDS

Due to the time consuming efforts required to collect adequate field data, the recording of an extreme event is unlikely to occur by definition. As a result, there is very little recorded evidence of SuDS performance in the UK under these circumstances. Laboratory tests can provide measured performance under simulated extreme conditions, but real-life information is limited to a world wide literature data set where information has been obtained by chance.

Table 2-2 Principal monitoring studies on the hydraulic performance of SuDS

Research organisation and date	Project / Client / Lead contractor	Comment
CEH 2007	WaND Client - EPSRC Lead contractor - Exeter University	Collection of rainfall and runoff data from 4 sites for a range of SuDS components
HR Wallingford 2000	Monitoring performance of infiltration system Client – Dti Lead contractor – HR Wallingford	Record of soakaway performance checked against design guidance
HR Wallingford 2007	Physical and simulation modelling of permeable pavements Client – Formpave Contractor – HR Wallingford	Analysis and model development for permeable pavement performance under extreme rainfall
HR Wallingford 2004	Monitoring of Tesco's car park Wokingham Client - Environment Agency Contractor – HR Wallingford	2 year monitoring programme of large porous tarmac car park
University of Abertay 2001	Monitoring of permeable pavements Researcher – MacDonald & Jefferies	Long term monitoring of 2 car parks Royal bank of Scotland Airport
University of Cantabria 2007	Runoff infiltration to clogged permeable pavement Researcher - González-Angullo et al.	Laboratory study of blocked permeable pavement
Sustainable Drainage Associates 2004	Sustainable Drainage Systems: Hydraulic, Structural and Water quality advice (Wilson et al, 2004: CIRIA C609) Client – CIRIA Contractor – Sustainable Drainage Associates	Literature review of SuDS information. All forms of SuDS reviewed.
Newton et al., 2007	Building Greener (CIRIA C644) Client – CIRIA Lead Contractor – EPG, Ecology Consultancy, Livingroofs.org	Guidance document on designing for green roofs. Literature review information

Table 2-3 Hydraulic performance summary from monitored data

SuDS component	Hydraulic performance summary
Rain water harvesting	The is no or little information on rain water harvesting in terms of its recorded performance for stormwater management in UK or elsewhere that has been found.
Filter strips	Filter strips are aimed at water quality treatment. Although they provide attenuation to runoff as well, there is no record of any measured performance information for stormwater management.
Infiltration trenches and soakaways	The only record of soakaway performance found for UK was carried out by HR Wallingford in 2000. Although no extreme rainfall took place, the research indicated clogging did not occur and performance was as expected against the design method in Bettess et al., 1996: CIRIA report 156 (Manual on infiltration). Failure of soakaways is generally thought to be attributable to inadequate protection from debris in the runoff.
Green roofs	Vegetative roof systems are grown on a range of depths of natural and synthetic media. In addition, roof slopes vary from virtually flat to well pitched. Information on recorded performance against extreme events in the UK does not exist. Information from Appendix A3 of Building Greener (Newton et al., 2007) has a number of recorded incidences of extreme rainfall. Information indicates a wide range of difference with some measures indicating significant reduction in both volume and flow rate for large events, while others indicate very little reduction and attenuation. This is dependent on the makeup of the green roof, in terms of substrate and vegetation mix, the greater the substrate the more attenuation that is provided. Many parts of Europe utilise green roofs as part of an approach to management of surface water and evidence is available on their hydraulic performance. While parts of Europe share a similar climate to the UK, there may still be a need for monitoring research in this area as green roofs are likely to become much more popular over the coming decade.
Swales	The hydraulic performance of two swales has been monitored in Dundee, Scotland (MacDonald and Jefferies, 2003). Extreme rainfall was not recorded. The performance of the two systems varied greatly demonstrating that soil type, construction technique and topography will all significantly influence the system performance. The Centre for Ecology and Hydrology (CEH) are currently monitoring a swale as part of the WaND project. Output is yet to be made available. Extreme event information may be available from the event held on the 20th July 2007. The traditional position is to make the conservative assumption that there is no significant volume loss through infiltration during an extreme event.

Filter trenches (French drains)	A survey in Scotland on the hydraulic performance of filter trenches was found to be problematic and this led to a study commissioned by Sniffer which is about to be completed. Filter drains (receiving runoff from roads as sheet flow) is different to the use of filter trenches in Scotland, which are primarily designed as treatment units. Measured performance of a filter drain with gully inputs was found to be problematic due to sedimentation issues. The hydraulic performance of filter drains besides highways are generally considered to be robust, but actual measurements of performance have not been found.
Permeable pavements	Permeable pavements have received a great deal of attention in terms of hydraulic measurement. Unfortunately this has been bedevilled by the problem that flows are so low out of these (granular based) systems that many of the results are suspect. Apart from the attenuation and losses that take place, several of these monitoring studies have been on lined permeable pavements and the suspicion that the linings are often less than perfect has become evident. The most extensive analysis of recorded of a permeable pavement car park was the Bracknell study by HR Wallingford. Since then, laboratory tests have also been carried out by HR Wallingford applying simulated extreme rainfall on a small full scale model of a Formpave specified unit. This, together with other studies, has resulted in a clear understanding of the hydraulic performance of permeable pavements, both under extreme and ordinary rainfall conditions. Finally, an interesting study was carried out in the University of Cantabria which looked at the performance of a clogged pavement. The clogging was manually applied as a mixture of broken glass and sediments that was considered representative of a very long term process of blinding. This found that the pavement could still serve rainfall with an intensity of 50mm/hr.
Infiltration basins	There are very few infiltration basins used in the UK and no performance measurements are known to exist. Even if they were known, each basin would be unique. The key feature of concern is not their performance under extreme conditions but their long term viability and the amount of maintenance they might need to keep them operating efficiently. From studies done in the USA, a significant proportion of these are likely to have a reduction in their long term performance.
Wetlands	Wetlands are not specifically designed to cater for extreme rainfall.

Ponds	Ponds are designed to provide a level of service for attenuation of peak flows from extreme events without consideration of losses through infiltration or evaporation as these are likely to be small with respect to the flows taking place. Measurements have been made of flow balance through ponds and losses can be significant for normal operating conditions. No specific data has been recorded on flow balance for an extreme event. As with all vegetative structures, their hydraulic performance is entirely a function of the soil conditions and its shape. As with all water retaining structures, ponds can also fail catastrophically by overtopping and embankment erosion, due to either a storm that is greater than designed for, or blockage of the outlet structure. Failure of a pond is not known to have taken place, but this risk must be taken into account as part of the design process.

In summary within the public domain there is a dearth of long term recorded information on actual performance of most SuDS schemes to compare against their expected hydraulic behaviour. Where this information exists it is rarely available for extreme events.

The primary SuDS components of importance (basins, ponds, permeable pavements) are relatively well understood with respect to their hydraulic performance, both in terms of their robustness against deterioration and failure. Their variability in performance is largely related to small events where their soil characteristics, topography and shape results vary from the assumptions made in the design.

The SuDS components where greatest uncertainty arises with regards to their performance for extreme events are green roofs (both in terms of hydraulic behaviour and potential for damage) and under-drained swales, where the ability to predict the hydraulic inter-action between swales cannot be accurately simulated yet. In addition, areas where extensive use of infiltration is used, particularly where housing density is high, there is a perceived risk of groundwater flooding during long wet winter periods especially where the topography is sloping. Although rain water harvesting is yet to become common place, there is significant potential for improved management of extreme events through the application of these systems. Small studies have been conducted recently by HR Wallingford, but further investigation is required.

In the event of failure as a direct result of extended rainfall, SuDS will only fail “softly” in comparison to pipe based systems. They also provide more effective protection of downstream catchments than pipe based systems by retaining and infiltrating surface water.

The major SuDS components (ponds, basins and permeable pavements) are fundamental to the success of a SuDS based systems within an urban environment where densities are high as they provide the best facility to manage extreme events.

3. WATER QUALITY PERFORMANCE

3.1 Context for water quality design performance

There is no dispute that urbanisation has a detrimental effect on the environment in terms of its deposition of a range of polluting matter into the environment. Historically stormwater was seen as being ‘clean’ which resulted in the separation of sewers in the past. Now it is known that surface water can contribute to diffuse pollution and that the environment needs to be protected from direct runoff.

BMPs, the international equivalent of SuDS, have been in development for the last 40 years or more in the USA and elsewhere. SuDS was effectively introduced into the UK through Scotland when SEPA started to apply these principles in the early 1990’s. Due to their role, the emphasis in the first CIRIA SuDS manuals produced in 2000 was focused largely at water quality issues which resulted in the concept of the treatment train and limited amount of hydraulic guidance.

Guidance has therefore tended to be a function of where different types of SuDS should be used and the relative merits of the SuDS in terms of their treatment effectiveness. This rather prescriptive approach can fall foul of developments in research where recent findings have tended to overturn certain guidance (eg the benefits of retention ponds over detention basins).

Guidance and tools on how to design for water quality have fallen into two categories. The first is the attempt to produce tools which predict concentrations of a wide range of pollutants or more general measures (such as BOD and SS), while other methods effectively avoid attempting predictions of quality, but instead propose rules of thumb based on a treatment train approach of increasing the number of required components in series dependent on the risks associated with the development characteristics.

The SuDS Manual is the current ‘best practice’ and applies the concept of numbers of SuDS components in series. At present only this approach is applied in the UK (the number of SuDS units, or treatment stages in series) to assess the adequacy of treatment.

3.2 Future development of designing for stormwater treatment

This is an area of fundamental importance. SuDS have value in providing hydraulic control of runoff which adds to the existing arsenal of drainage products, but they are essential if water quality improvement is to be achieved for stormwater runoff.

The current lack of objective measurement is clearly a significant challenge and leaves local authorities and planning staff in an invidious position in being able to assess planning applications. However the use of tools which purport to be able to predict concentrations of pollutants seems problematic on two counts; firstly the accuracy of such tools is questionable, and secondly the principle of moving towards a concentration based consent for stormwater runoff is likely to lead to a whole gamut of difficulties. These relate to the current legal basis for consenting discharges through to having to monitor outfalls to demonstrate compliance.

There are a few tools which already exist which provide a more rigorous approach than current practice, but which do not provide predictions of pollutant concentration. It is suggested that one of these or other from similar methods is considered for development to meet this need.

3.3 Observed water quality performance of SuDS

3.3.1 Level of Service

Traditional drainage does not create pollution in stormwater runoff, however, they can collect and transport it downstream potentially to the wider environment. The use of SuDS presumes that the pollution in stormwater should be extracted and not discharged to the environment at large. This means that there is an implicit acceptance that SuDS components themselves may have quite high levels of pollution and like traditional drainage there are maintenance issues associated with this approach for some of the components, although design and maintenance procedures can help reduce the impact.

A prescriptive position on designing to achieve specific concentrations of various pollutants is unlikely to be an appropriate approach to water quality design. The industry now has enough knowledge to know what order of magnitude concentrations of pollutants in stormwater effluent from a SuDS component or scheme will be. The key issues associated with SuDS and their pollution control protection are:

- How effective are they in treating runoff?
- What are the maintenance implications as a consequence of their pollution protection function?
- What are the design issues in ensuring effective treatment?

The pollution control effectiveness of SuDS schemes has been researched extensively in both UK and other countries. The work carried out in UK has primarily been done in Scotland with funding by SEPA and SNIFFER (Scottish Northern Ireland Forum For Environment Research), though Coventry University has also contributed significantly to treatment performance of permeable pavements.

Table 3-1 Principal research studies on SuDS stormwater treatment

Research organisation and date	**Project / Client / Lead contractor**	**Comment**
Sustainable Drainage Associates 2004	Sustainable Drainage Systems: Hydraulic, Structural and Water quality advice – (Wilson et al., 2004: CIRIA C609) Client – CIRIA Lead contractor – SDA	Literature review of SuDS information. All forms of SuDS reviewed.
Scottish universities research group 2000 – 04	SuDS in Scotland: The monitoring programme; Final report Client - SNIFFER Lead contractor – Abertay University	5 year programme of research into SuDS research (primarily associated with water quality).
Middlesex University 2005	Daywater project Client – EU Commission Lead contractor – Middlesex University	List of pollutants found in rainfall runoff; Multivariate method of risk analysis.
HR Wallingford 2003	Maximising the ecological benefits of sustainable drainage schemes Client – Dti Lead contractor – HR Wallingford	Comparison of SuDS water quality performance against river performance requirements.
Abertay University 2008	The fate of traffic related pollutants in soft engineering SuDS: an experimental and field	Investigation into soil and sediment contamination in ponds.

	approach (Jefferies et al., 2008) Client – SEPA et al. Lead contractor – Abertay University et al.	
HR Wallingford 2003, 2006	SuDS: Increased liability for the water industry on design, operation, maintenance, performance and costs – Phase 1 and 2 (Kellagher et al., 2003/2006) Client – UKWIR Lead contractor – HR Wallingford	A range of topics covered including maintenance issues and pollution loads associated with pollution control

As with the hydraulic performance of SuDS schemes, the treatment effectiveness of SuDS components varies between the different types as well as being influenced by the variations in soil and physical characteristics. It is therefore difficult to generalise on SuDS efficiency when dealing with the range of pollutants that is found in stormwater. Each SuDS component will therefore be addressed separately.

Before examining their treatment performance, a brief overview of the pollutant categories that exist and the issues associated with them are presented below. There are five principal categories into which pollutants are placed. These are:

- Hydrocarbons;
- Metals;
- Sediments and organic matter;
- Nutrients;
- Pesticides, herbicides and other industrial chemicals.

Hydrocarbons can be subdivided into a number of categories, but for the purpose of treatment the differentiation between soluble and particulate is particularly important. Soluble hydrocarbons, particularly those that act as solvents are more serious as are those which are of high density and “sink” or mix in an aquifer, thus polluting the whole water body.

Similarly metals are classified into these two categories. Different metals have different characteristics and the chemistry of the location affects this balance. By and large, metals are adsorbed by fine sediments and the soluble fraction tends to be small.

As well as being a pollutant in its own right, sediments are associated with many pollutants (metals, organic material etc.) Therefore its removal is fundamentally important. Very fine and colloidal material is very difficult to remove by settlement, but it is imperative that sediment component is addressed, due to the harmful metals and organic particulates that are particularly associated with this fraction.

The nutrient load in urban rainfall runoff is surprisingly high and its removal is important. As this exists largely in a dissolved form, removal can only be achieved through take-up by vegetation if chemical processes are not to be used. This is a ‘grey’ area where a full agreement on water quality performance has not been reached. Despite this, it is generally acknowledged that SuDS have limited effectiveness in treating these pollutants.

The use of pesticides and herbicides are becoming less common practice and those that are being used are designed to be less harmful and to degrade fairly rapidly over time. Again, these tend to be in soluble form. However, there are many other harmful chemicals, which are considered in this general category, which can be found in industrial areas, or even used by people as part of their domestic activities. Much greater care is needed in designing

SuDS in areas where industrial pollutants can be expected. Emphasis on prevention of pollution at source is important.

Table 3-2 SuDS water quality performance summary

SuDS component	Water quality performance summary
Rain water harvesting	Rain water harvesting is usually collected from roofs and is therefore largely unaffected by the surface water pollutants, though pathogens are of interest. Although rainwater from roofs is generally regarded as being relatively clean, atmospheric deposition of hydrocarbons, is a potential pollutant. In addition, roofing material can contribute to pollutant levels. Lead flashing and other metals may be found in the runoff. This tends to be less of a problem in the UK compared to other countries as slate, concrete or clay tiles are usually used.
Filter strips	Filter strips act as sediment filtration devices. Their performance is extremely variable and is very much a function of the vegetation management, slope, length and uniformity to avoid development of small flow channels. Commonly used in the USA, these are rarely used in UK due to space constraints. The take up of nutrients is thought not to be significant. Although they are primarily designed to treat stormwater runoff, they also act as a useful barrier for accidental spillages on the highway or car parks.
Infiltration trenches and soakaways	Soakaways are usually used where soil types are permeable for roof drainage disposal. Some highways authorities use them, but the risk of clogging over time due to the sediment load generally discourages their use for disposing road runoff. Although rainwater from roofs is generally regarded as being relatively clean, atmospheric deposition of hydrocarbons, (PAHs), can be a potential pollutant. More information on pollutant loads of runoff from industrial roofs is needed. Road runoff has high concentrations of all forms of pollutants. However, research indicates that, although sediments and oils found in soakaways are often at hazardous levels, the pollution in the soil/ground below rarely extends more than 300mm or so. This has to be qualified by the fact that as loading rates and soil conditions vary, a larger data set of information is required.
Green roofs	Runoff from green roofs is very different to hard surfaced roof runoff. The bedding material can act as a sink for hydrocarbons, but runoff tends to be a little higher in organic loading and fine particulates (depending on the materials used) and may need treatment if it is to contribute to rain water harvesting.. However, disposal to soakaway is not thought to be a constraint, subject to addressing sediments and organic debris.
Swales	Swales are commonly used in the USA. and other countries due to their high value in both reducing runoff volumes and their treatment capability. Analyses show that although swales do not reduce pollution concentrations very much (Lampe et al., 2005), they can reduce runoff volumes by up to 80%. This means that the pollutant load is significantly reduced even though concentrations are only reduced by a small proportion. They appear to be most effective in reducing metal concentrations and reasonable reductions in Total Suspendable

SuDS component	Water quality performance summary
	Sediments (TSS). The relationship between physical characteristics of a swale and its treatment performance (length, width, slope, soil type etc.) is not well known. However, as its water quality performance is more a function of flow volume reduction, the hydraulic performance is the most important aspect to consider. This data is based on standard conveyance swales. Under-drained swales, where flows pass to a form of land drain below the surface it is likely that water quality performance will be substantially improved. The long term implication of the toxicity of soils and their rehabilitation requirements is yet to be clarified. There is no indication of a drop in operational performance as long as standard maintenance is carried out.
Filter trenches (French drains)	The performance of standard filter trenches (French drains) has not been widely researched. However, as they work much in the same way as trickle filters, their water quality performance can be reasonably predicted. Lampe et al. (2005) state that Nitrates should be reduced by 30% and Phosphorous by 60%. TSS could be reduced to 5mg/l and 80% of metals could be removed. Maintaining and rehabilitating filter trenches is widely understood as these units have been in use for many years in serving major highways. In Scotland, filter trenches are designed as water quality treatment units with an inlet pipe above an outlet pipe within a stone media trench. These have had a bad report in terms of their robustness due inadequate sediment protection and blockage. A recent report (Atkins, 2006) stated that a well designed system was very effective in providing treatment.
Permeable pavements	Permeable pavements have been researched quite widely (Coventry University, Abertay University etc.). There are differences in performance (partly depending on the type, use and location of the geotextile), but unless there is a large spillage of oil the performance of permeable pavements is good for virtually all forms of pollution removal. A high level geotextile is particularly important in terms of hydrocarbon interception and treatment.
Infiltration basins	Infiltration basins are quite effective in capturing pollutants. Measurement of pollutant concentrations in the soil below the base of the basin has been shown to be quite shallow, but soluble components such as nitrates and salts are likely to pass through the soil and into the groundwater below if it is permeable.
Wetlands	Wetlands are very effective treatment units. As there is a continuous water surface, oils tend to be less effectively addressed than infiltrating units (basins and swales) where they get trapped in the soil structure and break down over time. In addition, the seasonal aspect of plant growth and die-off results in periods of nutrient stripping and release. This can be controlled to some degree by the annual vegetation maintenance regime, but it is unwise to assume high levels of soluble nutrient removal. Vegetation growth is significant and therefore the treatment performance

SuDS component	Water quality performance summary
	of the system, which is dependent on the hydraulic behaviour, requires a maintenance regime to be adhered to.
Basins	Basins have been shown to have quite high levels of infiltration. Although their water quality performance is known to be less effective than ponds, the total pollutant load is probably of the same order, though this very dependent on the design and other circumstances. Reduction of nutrients is thought to be minimal.
Ponds	Ponds achieve very similar treatment characteristics to wetlands. Theoretically they are slightly less effective, but the differences are small. Treatment effectiveness is linked to issues such as short circuiting and possibly stratification which can result in anaerobic effects in the settled sediments. They are probably more robust than wetlands in terms of the relationship between maintenance and water quality. Phosphorous reduction appears to be a function of retention time and therefore large ponds are particularly good at reducing this nutrient.

3.4 Water quality benefits of source control

Key research on the Source Control of Pollution in Sustainable Drainage was undertaken by the University of Abertay and ADAS for SNIFFER and published in 2008. This work concluded:

- The risk to groundwater from passing highway drainage on to soil based SuDS is low. There is evidence of very low rates of downward movement of contaminants.
- In general, contamination from the highway runoff in the basin soils was found to reduce horizontally from the inlet to the outlet. There was a noticeable difference in the magnitude of horizontal change between the basins studied, most likely as a function of the variation in inlet basin design. Where flow could spread across the broad basin, pollutant concentrations dropped sharply. Where inlet flow was confined to a narrow channel, concentrations remained higher. This points towards effective attenuation of pollutants in the soil based systems.
- The vast majority of heavy metals, PAHs and petroleum hydrocarbons (TPH) are retained in the top 10 cm of soil. This accumulation may impact on soil function with time and has potential implications for long term maintenance. Pollutant levels in the pond sediments were generally higher than in the soil.
- The highest TPH and PAH contamination found in the study came from one of the filter drain catch pits. Average pollutant concentrations in filter drain sediment were all lower than found in the upper 10 cm soil samples of the downstream basin suggesting accumulation in the basin soil over time.
- At the grass filter strip monitored, which was located at a motorway service station, no sediment had accumulated in the downstream filter drain at all, implying that it is all being retained on the grass strip.
- Metals will accumulate in the surface soil layers of infiltration based SuDS. The tests were on bare soil lysimeters but in practice there would be a vegetative layer that would take up some of the pollutants retained in the soil, reducing further the risk of movement to ground water. The data generated in these experiments would suggest that infiltration based SuDS represent a low risk to groundwater.

- Of the eight ponds sampled, the sediment from six would be classified as having a severe effect on the aquatic environment. Sediment from all of the ponds would be precluded from inert landfills because of TPH concentrations, and could potentially be classed as hazardous waste. There may be waste management issues if sediment which has been submerged in a pond is required to be transported and disposed off site.

A second phase of the project concluded:

- It is better to control oils and Poly Aromatic Hydrocarbons (PAHs) in soil based SuDS at locations which are periodically wet and dry such as in the base of detention basins, swales or infiltration basins.
- Basins and swales are good for sediment removal and, by association, oils and PAHs will also be best removed there and not in ponds or wetlands.
- This research supports guidance that a soil based system should be used as the primary control of sediments, with the pond or wetland as a polishing component where required.
- For the traffic loadings in this study, the degree of contamination found suggests road traffic is a significant source of oil, but SuDS are effectively trapping them, protecting the receiving water environment
- Waste arisings from SuDS serving busy highways will most probably have to be treated as contaminated waste and reduced and recycled. However, the amount of waste which might arise can certainly be minimised using the results of this research.
- Results from this study suggest that source control measures such as grass filter strips, swales, and detention areas, should be priority features of sustainable drainage networks serving urbanised areas and highways, where oil contamination may be significant. This is entirely consistent with the treatment train and stormwater management concepts for sustainable drainage systems.

Long term monitoring is required to established the rate of accumulation of pollutants in vegetative, soil-based systems and the level at which concentrations are so high that pollutants remobilise and/or increase the risks to groundwater. Maintenance schedules may need to include for removal and rehabilitation of the top 10-20 cm of the surface soils if risks are established within the scheme design life (or beyond).

3.5 Groundwater pollution

Groundwater contamination from anthropogenic activities is a serious concern which has long term consequences. Groundwater is a precious resource, which when polluted, may have consequences measured in decades or much longer in terms of being a useable source of water. This has been recognised and the implications of legislation on groundwater pollution is severe for those who create or mobilise contaminants in groundwater.

Surface water runoff from urban areas can contain a variety of pollution including oil, heavy metals, sediment and organic matter, and therefore poses a potential risk to any receiving water. Although pollution poses a greater risk to groundwater as a result of its greater vulnerability to damage, groundwater resources tend to benefit from the natural protection of overlying soils and the pollutant decay processes that will be ongoing during the generally long transfer times between pollutant source and points of abstraction. A growing body of evidence shows that naturally occurring subsurface processes can reduce the mass, toxicity, volume or concentration of both organic and inorganic contaminants in both the unsaturated and saturated zones.

The intrinsic vulnerability of a particular location to groundwater pollution will depend on the physical, chemical and biological properties of the underlying soil and rocks. The specific vulnerability associated with a particular SuDS site will take into account additional factors, including the extent to which infiltration is being promoted (drainage system design), the characteristics of the contamination present within the runoff and the frequency of pollutant application. There is very little evidence of groundwater contamination from stormwater runoff even from long term infiltration systems and there is a growing body of evidence that shows that the potential for contamination of groundwater from SuDS systems is generally low, except from industrial areas where the potential for serious pollution is associated with accidents rather than the continuous background pollution from these areas. However, to date, systems that convey potentially polluted water across a range of soil types have not been actively promoted and research is required to determine whether there may be any risks resulting from a proliferation of such systems across the UK as a result of revised statutory drainage requirements.

The Environment Agency must ensure compliance with the groundwater regulations and environmental permitting and the Groundwater Directive (80/68/EEC). The key requirements of the Directive are that:

The Water Framework Directive (WFD) lists broad bands of substances called Main Pollutants, which comprises a list similar to the combined lists of the Groundwater Directive.

The Water Environment and Water Services (Scotland) Act 2003 (WEWS) places specific duties on Scottish Ministers, SEPA and the responsible authorities to act in a way best calculated to contribute to sustainable development so far as is consistent with the purposes of the relevant enactment or designated function in question, and to adopt an integrated approach. The Act is the enabling legislation for the Water Framework Directive. It identifies SEPA as the competent authority. The main groundwater objectives of the Act are to:

- Prevent deterioration of the status of groundwater bodies;
- Protect, enhance and restore all bodies of groundwater with the aim of achieving good groundwater status by 2015;
- Prevent or limit the input of pollutants to groundwater and reverse any significant and sustained upward trends in the concentration of pollutants in groundwater;
- Achieve compliance with any relevant standards and objectives for protected areas.

As pollutant concentrations in surface water runoff are usually orders of magnitude greater than allowable limits, acceptable discharge of water into the ground relies upon natural treatment processes taking place to protect the groundwater.

It is easiest to consider all contaminants by classifying them under a number of categories. This is useful as their behaviour and impact are often fairly similar, though it is always important to be aware that there are always exceptions. The following are the main pollutant categories:

- Pathogens (Bacteria, Viruses, Protozoa)
- PAHs
- Hydrocarbons
- Solvents

- Pesticides & Herbicides
- Metals
- Anions (Chlorine, Nitrate, Salt etc)
- Sewage

The fate of each of these pollutants varies from being a totally conservative material, such as salt, where only dilution makes it meet a threshold in terms of acceptable water quality, through to degradation, die off or other reduction mechanism. An additional complexity is the fact that issues such as co-solvency and varying climatic or chemical conditions may alter the risk to groundwater contamination.

The prevalence of each type of pollutant is a function of land use category (roof, minor road, major road, commercial area etc). It should be noted that this requires the dual consideration of whether the contamination is regular and frequent low level pollution or a function of rare, but potentially more serious incidents. The fate of the pollution is related to various physical and chemical conditions and a key aspect of groundwater protection for many pollutants is the use of soil as a treatment zone as part of the process of infiltration.

The potential for contamination of groundwater from SuDS schemes appears to be low, except from industrial areas. The potential for serious pollution is associated with accidents rather than the continuous background pollutions from these areas.

Although there has been good research on the performance of SuDS in reducing pollutant levels as well as measuring the risk to ground and groundwater contamination, there is still a need to continue investigate soil and groundwater contamination levels associated with SuDS (which can be assessed and classified in terms of whether they are Hazardous or not).

3.5.1 Future criteria and tools

At present guidance is largely based on the concept of adsorption taking place in the unsaturated zone between the base of any infiltration device and the highest groundwater level that can occur at any time. There are no tools currently applied in the UK to standard drainage design which addresses water quality impact due to infiltration.

It seems unlikely that the use of any other approach would be better unless there was a high risk of groundwater contamination. In this situation current groundwater models would be required to be used.

4. AMENITY

As part of the DTi project, Benefits & Performance of SuDS (HR Wallingford, 2003), a study was undertaken of potential amenity benefits of surface water management systems. In collaboration with the University of Abertay, Dundee, HR Wallingford structured and implemented a series of questionnaire surveys to determine the public perceptions of SuDS within or close to residential developments. These surveys were undertaken in seven sites across southern and northern England, and several more sites in Scotland. The studies gathered data on the level of understanding, and the perceived benefits and risks associated with the drainage components.

4.1 Attitudes towards SuDS

The study on Benefits & Performance of SuDS (HR Wallingford, 2003) aimed to collect and analyse information on attitudes of people (whose homes are served by ponds) towards SuDS, and to use this information to answer the following key questions presented in Box 4-1.

- **Do SUDS influence the decision to buy a property?** Public perception of SUDS may result in either a motive for, or a deterrent against the acquisition of property close to a scheme.
- **Do people perceive SUDS to impact on property prices?** Depending on public attitudes, SUDS may have an impact on the development value and/or cost of individual properties. Alternatively, schemes may influence property saleability.
- **What factors influence the public's perception of SUDS?** Public perception of SUDS is likely to be linked to several factors, including scheme performance, biodiversity issues, education strategies, aesthetics, perceived health and safety risks, water quality and respondent socio-economic status.
- **How does perception of the sustainability of SUDS compare to that of other sustainable technologies?** Public perception of SUDS needs to be interpreted in relation to their views of other sustainability initiatives, e.g. recycling.
- **How do people perceive the safety of SUDS ponds?** Safety has already been proven to be one of the main concerns regarding SUDS application, for both developer and the public.
- **What role does education play in the way people perceive SUDS ponds?** Public education in the field of stormwater pollution and management may be an important contributory factor.

Box 4-1 Factors that impact attitudes towards SuDS

4.1.1 Public awareness of SuDS

The research demonstrated a lack of public awareness of SuDS as a whole, although most participants in locations where SuDS have been used had formed strong opinions about the specific systems within their residential areas. Overall, attitudes towards SuDS were positive, although knowledge of their flood prevention and water treatment benefits was poor. This lack of knowledge is considered to be one of the main factors that can generate negative attitudes towards SuDS. It appears that public education can have a critical role in influencing acceptability of new or innovative practices within residential areas.

4.1.2 Public perception of SuDS ponds & wetlands

In areas with well-established ponds, the main advantages were considered by residents to be:

- Attraction of wildlife to the ponds and the creation of new habitats;
- Increase in the amenity and recreational value of the surrounding areas;
- Improvement in the landscape;
- Their role in reducing flood risk.

All of the above topics played an important role in formulating positive attitudes towards the systems. Increased safety risks, and specifically the potential danger of children drowning, was indicated as the main perceived disadvantage of the ponds.

4.1.3 Safety concerns

In areas with well-established ponds, with rich marginal vegetation, safety was rarely perceived as an issue. At sites comprising newly established ponds, with limited or nonexistent marginal vegetation, or where slopes were perceived to be over-steep, safety concerns were high. Whenever safety was cited as a concern, the vast majority of participants (about 85%) still preferred to live next or near to a pond; rather than further away. In all areas, a busy main road was considered to be the most dangerous hazard to live close to, while ponds were considered safer than rivers or landfill sites.

4.1.4 Suggested improvements

Increased maintenance of the ponds and their surroundings were the most frequent suggestions. Requested maintenance included pond cleaning, removal of silt, and vegetation management. In sites where concerns over safety were high, the introduction of natural barriers around the pond was also suggested. Other proposed improvements included the provision of benches and the creation of walkways to increase the amenity value of the pond.

4.1.5 Links between SuDS & property values:

Well designed and managed SuDS appear to have a positive affect on house saleability and on house prices. In areas with well-established ponds, there is perceived belief among the residents that their properties would fetch a 10% premium, along with an increase in saleability. Where houses were sited close to poorly designed and / or maintained ponds, it was felt that the saleability and price may be compromised.

4.1.6 Public interest in further SuDS information

The majority of the participants (70%) were keen to receive more information regarding the SuDS ponds. They particularly asked for information about the function and efficiency of the systems, the reason for their existence in that particular area, and the flora and fauna present in them. The most appropriate method for receiving this information (as indicated by the respondents) would be the distribution of leaflets or newsletters.

4.2 Improving the amenity value of SuDS

The information from Benefits & Performance of SuDS (HR Wallingford, 2003) were supported by additional research on amenity benefits undertaken in Scotland. The SuDS Manual (CIRIA, 2007) contains a chapter on Community Engagement which gives guidance on the following topics:

- Public communication
- Public awareness
- Public engagement principles
- Public engagement methods (including leaflets, signage, media coverage, dedicated websites, focus groups and industry collaboration)
- Community friendly design and detailing
- Maintaining SuDS for the community
- Managing public health and safety concerns
- Examples of community engagement strategies for water features.

Unlike conventional drainage, SuDS often form part of public open space, with the potential to promote interaction between communities and their local environment, resulting in additional amenity benefits. With SuDS being championed within the UK, public understanding of the philosophy driving their implementation becomes increasingly important for the contribution to sustainable development and acceptance by local residents. The criteria set for SuDS amenity benefit provision are given in Table 4-1.

Table 4-1 Key factors for SuDS evaluation

System performance	Do the public have an understanding of their function and purpose? Do the SuDS meet acceptable design criteria in terms of reduction in flood risk and pollution control?
Landscaping and aesthetics	Are the SuDS sympathetic and enhance the local environment? Are they maintained to an appropriate standard?
Amenity and recreational value	Is there an added benefit to local residents for leisure activities? e.g. walking, jogging, picnicking, cycling, bird watching?
Contribution to biodiversity	Do the SuDS contribute to positive and diverse flora and fauna at the site?
Education strategy	Are members of the public adequately informed regarding the multiple purpose benefits of the SuDS to the local environment and how they can contribute to their performance and value?
Health and safety risks	Have site-specific issues raised by the local community been adequately addressed through sensible design and the provision of warning signs, fencing, etc
Socio-economic status	Have appropriate educational campaigns been launched taking into account the socio economic background of the local community? Research has identified that people in a high socio economic group more positively accept environmentally sound practiced.

4.2.1 Integrating the amenity of SuDS with urban design

There are currently a number of initiatives to improve place making and urban design within the built environment. Many local authorities are developing green infrastructure strategies and CABE (the Commission for Architecture and the Built Environment) has produced a number of guidance documents that may be relevant and useful to the delivery of SuDS.

5. BIODIVERSITY

As part of the DTi project, Benefits & Performance of SuDS (HR Wallingford, 2003), Jeremy Biggs of the Ponds Conservation Trust undertook a study to evaluate methods to maximise the effectiveness of SuDS schemes in mitigating impacts on receiving waters, and to optimise design and management techniques to maximise their intrinsic value as habitats. The following areas were studied:

- water quality;
- proximity to existing habitat;
- physical structure;
- landscaping practices;
- planting practices;
- management practices (including silt and vegetation) of both the drainage system and the adjacent land.

Box 5-1 summarises the techniques developed for maximising the value of SuDS ponds and swales as wildlife habitats.

1. Maximise water quality in ponds by fully implementing SUDS treatment trains.
2. Where possible locate SUDS basins in, or next to, non-intensively managed land where natural sources of native species are likely to be good.
3. Locate treatment ponds near to (but not directly connected to) other wetland areas e.g. natural ponds, lakes and river floodplains. Plants and animals from these areas will colonise the new ponds, and potentially recolonise if pollutant flushes impact the ponds.
4. Create habitat mosaics with sub-basins of permanent, temporary and semi-permanent ponds; vary these in size (from 1 ha down to 1m^2) and depth (1m down to 5 cm).
5. Ensure that some ponds are not exposed to the main pollutant burden so that more sensitive animals and plants can exploit the site.
6. Create small pools around the margins of larger ponds, fed by clean surface runoff from non-intensively managed grassland, scrub or woodland.
7. Create shallow grassy ponds along swales, particularly towards their cleanest ends: pools just 1 or 2 metres across and only 10 cm deep will be valuable for wildlife.
8. Maximise the area of shallow and seasonally inundated ground dominated by emergent plants: these are generally more tolerant of pollutants than submerged aquatic plants. To do this, create very low slopes at the water's edge (e.g. 1:50) and try to avoid fixing pond levels at a predetermined height.
9. Create undulating 'hummocky margins' in shallow water; these mimic the natural physical diversity of semi-natural habitats.
10. Avoid smoothly finished surfaces which, although giving an impression of tidiness, provide less habitat diversity for plants and animals.
11. Plant trees, scrub and wet woodland around ponds: these provide a valuable habitat for amphibians; a food source for invertebrates and tannins from decaying bark will help to suppress algal blooms.
12. Encourage development of open, lightly shaded and densely shaded areas or pools; this will add to the diversity of habitats available.
13. Add dead wood to new ponds. Dead wood provides firm substrates for pond animals (e.g. egg laying sites for dragonflies).
14. Encourage the development of mosaics of marginal plants (rather than single species stands) to maximise habitat structural diversity.
15. Avoid planting-up ponds (other than the plants needed for the water treatment function of the pond or the creation of safety barriers). This will allow native plants more opportunity to colonise.
16. Don't plant non-native water plants, trees, shrubs or grass mixes; take special care to avoid invasive alien plants such as *Crassula helmsii*.
17. If planting is essential, stick to native plants of local origin. Include species which are wildlife friendly e.g. grasses such as *Glyceria fluitans* (Floating Sweet-grass) and *Agrostis stolonifera* (Creeping Bent).
18. Check planting schemes 1 and 2 years after establishment to ensure that specifications have been carried out and undertake immediate remedial action if invasive alien species are found.
19. Consider whether grazing livestock can be given access to ponds; grazing has been shown to be a viable and effective way of managing some SUDS schemes in agreement with conservation organisations or farmers.
20. Wherever possible include a brief post-implementation stage about 1 year after SUDS creation. Use this to (i) undertake fine-tuning of the pond design and (ii) capitalise on new opportunities that have arisen (e.g. pooling of natural areas of standing waters or natural seepage areas etc.). Fine tuning of this sort costs very little but will often greatly increase the biodiversity value of a SUDS scheme.

Box 5-1 Summary of techniques for maximising the biodiversity value of SuDS ponds

These recommendations were taken into account wherever possible in developing the design, construction and maintenance guidance for the SuDS Manual (CIRIA, 2007).

6. SUDS OPERATION & MAINTENANCE

As part of the DTi project, Whole Life Costs of SuDS (HR Wallingford, 2003), a study was undertaken by Bob Bray (of Robert Bray Associates) to map out the philosophy and principles behind the operation and maintenance procedures required for SuDS (these being based largely on landscape management practices). Maintenance schedules were developed for individual SuDS components, and costed using recent contractor quotations.

6.1 Ease of maintenance

Standard landscape management techniques dictate that SuDS should be highly visible and their function should therefore be easily appreciated by those charged with their maintenance. When problems occur, they should generally be obvious and should be able to be remedied simply by using standard landscaping practice. The long-term deterioration of SuDS tends to be gradual and, if the systems are properly maintained, can be managed out.

One of the advantages of SuDS is that they are robust and easy to maintain. However, the effectiveness and ease of their long-term management will be dependent to a certain extent on their initial design characteristics. Considerations that affect the design of SuDS structures, methods and components should include:

- The drainage and water quality functions they are required to perform;
- The maintenance required to ensure they continue to work as intended;
- An assessment of the future repair or replacement requirements.

The full report provides tables for the complete range of SuDS components highlighting design issues that are likely to influence their long-term performance, and that may impact on the feasibility of important operation and maintenance activities.

The report also discusses whole life design criteria for associated features and structures that service the main control methods. These include inlets, outlets, storage structures, silt traps, flow control devices, headwalls, low flow channels, and overland flood routes.

6.1.1 Landscape maintenance

A key feature of SuDS is their integration within the local landscape and their amenity contribution, and it is appropriate therefore that landscape maintenance practice is applied to their management. An advantage of using site managers and landscape contractors to maintain SuDS is that they are likely to have an intimate knowledge of the development and already visit the site on a regular basis to undertake routine care such as grass cutting, sweeping and litter picking. This attendance should ensure regular monitoring of the drainage system, a rapid response to maintenance needs, and a feeling of ownership of the SuDS features.

The principles of landscape maintenance have been established for some time and designers of SuDS have an opportunity to use existing management techniques to develop management plans and maintenance contracts. For large complex sites, the landscape maintenance procedures in **Error! Reference source not found.** are usually applied.

Table 6-1 Maintenance procedures

Procedure	Purpose
Management plan	Describing the management objectives for a site over time, and the management strategies that will be employed to both realise these objectives and reconcile any potential conflicts that may arise.
Specification	Detailing the conditions under which the work will be done, the materials to be used and the standard of work required.
Schedule of work	Itemising the tasks to be undertaken and the frequency at which they will be performed.

The full report contains detailed maintenance specifications for each component, for use in designing and implementing a SuDS management plan.

6.1.2 Maintenance practices

A detailed maintenance assessment study was undertaken as part of the UKWIR/WERF collaborative project (UKWIR, 2005). The primary source of maintenance information was derived from facility inspections, monitoring, and direct interviews with stormwater agency and unitary authority personnel together with other operators and experts in the US and UK. The most detailed information was obtained for the most commonly used systems: retention ponds, extended detention basins, and vegetated swales. This maintenance assessment sought to:

- Gather comparative maintenance data and information from the U.S. and UK.
- Define the maintenance inputs (tasks, person-hours, equipment, etc.) and frequencies required to keep structural controls functioning and avoid failure.
- Define the tasks which give aesthetic benefits (non-essential to function) as opposed to functional benefits (performance or public health failure).
- Obtain information to derive costs and provide information for a Whole Life Cost Model which was being developed as a separate strand of the project.
- Evaluate possible variation of maintenance requirements by climate or geography.
- Identify designs that will reduce maintenance costs and inputs.

A wide variety of maintenance practices and preferences were noted over the many agencies and organizations interviewed for this project across two nations. Detailed maintenance tasks and respective costs were estimated for each of the six system types. The basis for the estimations is presented and explained, especially where data is limited or varies. Maintenance data were collected and organized specifically for inclusion in the Whole Life Cost model.

Conclusions reached were that:

- **Maintenance drivers:** These were primarily to retain hydraulic, water quality and amenity performance as well as managing/minimising health and safety risks.

- **Inspection programs:** numerous problems and costs can be avoided by using an adequate inspection program. Inspection during the design and construction phase helps ensure proper design, construction techniques, and sediment and erosion controls. Inspections following the construction phase serve to inspect, track maintenance activities, and help ensure that BMP/SuDS continue to exist and function properly. Visual inspection of the components is required in order to ensure continued operation within design guidelines. Regular monitoring not only ensures that maintenance activities are being carried as per specification but also identifies any areas where there is a potential for system failure.
- **Timely maintenance: preventative vs. corrective costs.** Agency representatives uniformly agreed that lack of routine maintenance leads to disproportionately greater long-term expenses.
- **Research into maintenance of SuDS/BMPs:** The project was hampered by the lack of detailed information about the number of hours spent on the various maintenance activities

The 'Flows' project implemented sustainable drainage systems within Lamb Drove in Cambridgeshire as part of a European funded project, and produced a document - Sustainable Drainage Systems for New Homes: Best Practice guidance (2006) which good practice on the operation and maintenance of SuDS (based on the HR Wallingford report (2004) referred to above).

Good Practice • Incorporate maintenance considerations into the design process and ensure minimum whole life costs. • Monitor operation and maintenance costs for the measures following the implementation. • Engage early with all stakeholders likely to have maintenance responsibilities. • Incorporate maintenance of soft SUDS features within general landscape maintenance regime to minimise additional costs. • Provide a simple schedule of maintenance tasks required. • Adoption of SUDS should be passed onto local authorities using Section 106 agreements and commuted sums, especially where located within POS, off-site and access roads. Monies allocated for commuted sums should be ring fenced to ensure that they are not spent for other reasons. • Consider adoption of measures by site owners (e.g. housing associations) where possible. Appropriate private management companies (approved and evaluated by local authorities at regular intervals) could be used for SUDS maintenance where there are no other practical alternatives. • Holistic consideration to attract local interest and community engagement on promotion and general up keep of SUDS by linking to education of children (e.g. bio-diversity trailing, drainage patterns and water cycle management) involving local schools, Stibington Environmental Centre and Cambridgeshire Wildlife Trust; publicise activities in their magazines/ newsletters.
Potential Pitfalls • Lack of control over construction issues/ programme, prevention of siltation, monitoring and future disturbance of SUDS measures. • Initial observations indicate construction defects may influence effectiveness of SUDS features. • Failure to recognise additional costs of maintaining permeable paving in the long-term and need for commuted sum, which can be expensive until these techniques become more widespread. • Failure to maintain local democratic involvement (e.g. Local Members, Parish Council and general public) to enthuse the process/ champion SUDS schemes helping to address the common barriers including maintenance and health and safety concerns. • Lack of consideration to people tendency for vehicle parking on SUDS features and risk of vandalism in the scheme development.

Figure 6-1 Guidance on management and operation of SuDS (Gunasakera et all 2006)

6.1.3 Waste management

Waste management (and the associated liabilities) was studied in detail in the UKWIR Liability Report (2006), with the following conclusions:

- that there is considerable uncertainty regarding the typical pollutant characteristics found in SuDS systems and that the variability between sites is significant;

- that sediment characteristics in a SuDS structure are not only a function of land use, but are very much a function of the performance of the upstream drainage system (SuDS treatment train);
- that there are a number of policy constraints which prevent best practice of drainage design being implemented, thus reducing the opportunities for limiting liability risks;
- and that hazard assessment of sediments is too complex to enable a proper evaluation of risks from most existing data sets. There is an urgent need to do investigative field work to obtain a definitive position on whether SuDS sediment from various land use categories is hazardous or not.

The Environment Agency has developed an approach to pragmatically manage the waste arisings from a SuDS scheme.

7. COSTS & BENEFITS OF SUDS

While there has been significant research into SuDS costs and benefits, and whole life costing approaches this has been limited by the number of SuDS schemes implemented and eventually monitored.

Table 7-1 Principal research studies on SuDS costs

Research organisation and date	Project / Client / Main contractor	Comment
CIRIA, HRW, MWH, 2008	Collating the urban drainage evidence base	Evidence was collated on the performance of SuDS and costs and benefits. Some heroic assumptions were used to extrapolate potential wider savings.
WRc, 2007	SuDS: costs and benefits of retrofit SuDS for urban areas	
HR Wallingford/Land & Water Remediation Ltd, 2006	SuDS – Increased Liability for the Water Industry – Phase 2 (Kellagher et al., 2006) Client - UKWIR Lead contractor - HR Wallingford	Extension of the UKWIR Whole Life Cost model to include various legislative options and costs associated with waste processing and disposal. Detailed review of waste management regulations, options and associated costs.
Interpave, 2006	Initial Construction Costs for Various Pavement and Drainage Options Client - Interpave Lead contractor - Scott Wilson	Calculation and comparison of permeable pavement with traditional asphalt and concrete paving solutions.
Interpave, 2006	Whole Life Cost Analysis for Various Pavement and Drainage Options Client - Interpave Lead contractor - Scott Wilson	Development of maintenance schedules and associated whole life costs of permeable pavement and traditional paving solutions.
HR Wallingford, 2005	Post Project Monitoring of BMPs/SuDS to Determine Performance and Whole Life Costs (Lampe et al., 2005) Client - UKWIR, WERF, AWaaRF Lead contractor - Black & Veatch	Collation of capital costs, maintenance schedules and costs for SuDS/BMPs across Europe and the USA. Development of spreadsheet model that allows construction and operation & maintenance costs to be built up systematically and combined within a whole life cost assessment. Limited benefit assessment methodology also included.
The Solution Organisation, 2005	Whole Life Costs and Living Roofs / Client - Sarnafil Lead contractor - The Solution Organisation	Estimates of green roof capital and maintenance costs, environmental benefits and net whole life costs
HR Wallingford, 2004	Whole Life Costing for Sustainable Drainage Client - Dti Lead Contractor - HR Wallingford	Literature review of SuDS costs, and whole life costing approaches including environmental benefit valuation. Development of SuDS cost components and WLC methodology appropriate for SuDS.
HR Wallingford/Robert Bray Associates, 2004	The Operation and Maintenance of Sustainable Drainage Systems (And Associated Costs) Client - Dti Lead contractor - HR Wallingford	Review of SuDS operation and maintenance requirements and costs.
Atkins, 2004	Scottish Water SuDS Retrofit	Assessment of SuDS retrofit

Research organisation and date	Project / Client / Main contractor	Comment
	Research Project Client – Scottish Water Lead contractor - Atkins	opportunities to achieve water quality improvements. Cost comparisons of SuDS vs. conventional solutions, including limited benefit review.
HR Wallingford/Abertay University, 2003	An Assessment of the Social Impacts of Sustainable Drainage Systems in the UK Client – Dti Lead contractor – HR Wallingford	Study of perception and understanding of people living close to SuDS. Conclusions on the impact of SuDS design and maintenance, and public education on influencing perception.
HR Wallingford/Pond Conservation Trust, 2003	Maximising the Ecological Benefits of Sustainable Drainage Schemes Client – Dti Lead contractor - HR Wallingford	Review and guidance on the ecological benefits of SuDS. Design and maintenance regimes to maximise ecological performance.

The original work on costs and benefits of SuDS in the UK was published by HR Wallingford in 2004. Two projects were commissioned by the then DTI to look at the life cycle costs associated with implementing and maintaining SuDS, and the breadth and scale of both measurable benefits (specifically flood risk and water quality management contributions) and intangible benefits such as ecological and amenity value.

7.1 Whole life costing of SuDS

The report on Whole Life Costing of Sustainable Drainage (HR Wallingford, 2004) sets out a Whole Life Costing methodology that is appropriate for undertaking an appraisal of the costs and benefits of sustainable drainage systems. A Whole Life Costing framework allows the planning costs, capital costs, land-take costs, residual costs, environmental benefits, operation and maintenance, and disposal costs to be accounted for in a consistent manner.

The study concluded that:

- sustainable drainage systems need regular inspection and maintenance in order that risks to performance are minimised and the system continues to function effectively. SuDS performance failures are as often due to lack of proper routine maintenance as to poor initial design or installation. To date, operation and maintenance of source control facilities has generally been a very low budgetary priority, which is often reflected in either structural or aesthetic deficiency or failure. If the structure is perceived as a public eyesore and not as an amenity, it is much more likely to become a convenient local dumping ground compounding any existing maintenance problems (such as clogging due to dumping of grass clippings) (Ellis, 2004). Poorly maintained sites are also often perceived as a health and safety risk by local residents and visitors.
- Whole Life Costing can be used as a tool to quantify the level of financial commitment required at the outset to ensure long term operational performance of a SuDS scheme, to design standards. If operation and maintenance requirements are evaluated and costed during the early planning stages of a development, agreement can then be sought for the sustainable, long-term resourcing of these activities.

- The literature review and cost collation exercise undertaken as part of this project identified a range of capital costs and theoretical cost relationships. Poor availability of capital cost information was attributed to:
  - Drainage costs being hidden within larger landscaping / road budgets
  - Drainage costs hidden within lump sum fixed prices
  - Reluctance to publish costs due to confidentiality / competition issues
  - Lack of requirement to record costs in a systematic way.
- The literature review and cost collation exercise undertaken as part of this project identified a small body of information on operation and maintenance costs. Poor operation and maintenance cost data availability was attributed to:
  - Low levels of operation and maintenance of SuDS undertaken to date and lack of formalised maintenance regimes
  - Maintaining authorities have little time to record and archive information of this nature
  - Split of responsibilities between landscape and drainage maintenance
  - Lack of requirement to record costs and activities in a systematic way.
- Where costs have been published, there was often little or no system design criteria with which to characterise the system and appraise the costs. Therefore the best indication of capital costs for a specific SuDS scheme would be arrived at by pricing the design using unit costs from published manuals and/or price guides. Similarly, the best indication of operation and maintenance costs for a specific SuDS scheme would be arrived at by pricing appropriate maintenance schedules, based on site-specific characteristics.
- Regular, annual monitoring and maintenance is relatively straight forward and low cost. However, where poor design or lack of regular maintenance means that rehabilitation and remedial works are required, costs can rise rapidly. Sediment excavation and disposal are, for example, high cost activities that could pose a significant burden to any adopting authority. Schemes must be designed to facilitate and enable appropriate future maintenance, and sediment build-up and removal processes must be considered and appraised at scheme planning stage.
- Capital costs vary widely as they depend on a range of site-specific factors, including:
  - Design criteria
  - Design and construction detailing
  - Diversity and density of planting
  - Amenity function
  - Land take and land value.
- Breakdowns of capital costs should be recorded, together with site characteristics and design criteria. Proposed operation and maintenance schedules and costs should be archived, together with monitoring records, any schedule revisions, and unplanned, rehabilitation and remedial works that may be required during the life of the drainage system. Systematic recording of such information will enable Whole Life Costs of SuDS to be predicted with confidence in the future.

This work was taken forward in the UKWIR/WERF Project 'Post Project Monitoring of BMPs/SuDS to determine Performance and Whole Life Costs', published in 2005. In this study, an extensive survey of the experience of U.S. agencies with BMPs was conducted to document differences in cost and maintenance requirements as a function of climate and other factors. This information was supplemented with site visits to seven cities across the U.S. to record differences in design elements and to identify the reasons for these differences. A similar effort was undertaken in the UK, with a greater emphasis on repeated visits to the same facilities to record the maintenance activities, the time to complete these activities, and, to the extent possible, the impact of these activities on facility performance.

A whole-life cost model was developed in a spreadsheet framework to allow calculation of the expected cost of a facility based on drainage area, maintenance expectations, and other factors. Separate models were developed for five of the selected systems (swale, detention basin, pond, filter drain and permeable pavement). The default values for many model parameters were extracted from the information gained in the survey of systems in the U.S. and UK.

The cost component concluded that the cost of constructing any drainage system is inherently variable and will depend to a large extent on local site conditions and arrangements. The model presents an estimate of average or likely costs for an assumed set of conditions and characteristics, but with the overriding recommendation that these require review and adjustment for all site-specific applications

7.2 Costs associated with waste management

HR Wallingford, in collaboration with Land & Water Remediation Ltd, developed this work further within a project undertaken for UKWIR to look at the potential liabilities of SuDS (SuDS: Increased Liability for the Water Industry, 2006). A key focus of this was the assessment of the likely hazard status for SuDS waste and the potential costs associated with its removal and disposal. Waste management regulations and disposal options have been subject to significant change over recent years and concerns have been raised over the potential costs of sediment extraction and disposal from SuDS schemes. Research in this project demonstrated that costs could be significant but can be reduced through appropriate design and maintenance regimes (currently being explored by the Environment Agency). The UKWIR Whole Life Cost Model was enhanced for retention ponds and detention basins to include the full suite of potential waste management options and their associated costs. Conclusions included the following:

- Over-sizing of systems to accommodate sediment deposits over extended periods is likely to be the most cost-effective means of managing waste, whether or not the waste is hazardous.
- Apart from Exemption 25 (REF?), disposing of sediments via other exemption clauses is not likely to be cost-effective unless large volumes of sediment are being managed at a single site or sediment is being managed across several sites under the same contract, due to the overhead costs involved. A suitable threshold volume of sediment is likely to be between 100 and 150 m3. For a 10 ha catchment draining to a single pond, such volumes would only have been deposited after approximately 50 years.
- Disposal of green waste to landfill rather than allowing composting and disposal on site, will increase management costs considerably.
- Where volumes of hazardous sediment are large (i.e. of the order of 100 m^3 plus), pre-treatment via bioremediation to non-hazardous material, should be undertaken wherever possible to achieve maximum cost savings.

- Routine maintenance of detention basins appears to be more costly than for retention ponds (due to the regular mowing of additional grassed areas), however sediment management costs are reduced by 25 percent . Overall, the management of detention basins are between 25 and 30 percent cheaper than ponds.

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