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SUDS in Scotland – The Monitoring Programme

of the Scottish Universities SUDS Monitoring Group

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Final Report
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PART A REPORT

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PART A REPORT

Executive summary

1. Background and purpose of the research

Sustainable Urban Drainage Systems (SUDS) are storm or surface water drainage facilities designed to address three essential issues: water quality, water quantity, and amenity (including biodiversity).

The purpose of this research was to provide a substantial body of knowledge on the performance of SUDS (in terms of water quality, hydrology and amenity) and the factors that affect performance. The project involved the continuation of a five year programme of monitoring and assessment of SUDS performance. Two principal categories of SUDS system were monitored: source control and site/regional control systems. Assessments of the quantity and quality of sediments, biodiversity at ponds and public perception have been investigated.

The project draws together results from the work of the ongoing Scottish Universities SUDS Monitoring Programme which was supported and encouraged by the Sustainable Urban Drainage Scotland Working Party (SUDSWP).

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This research project was funded by SNIFFER, Environment Agency and SEPA. The monitoring programme was supported by the Sustainable Urban Drainage Scotland Working Party (SUDSWP), and received financial support from the Environment Agency, SNIFFER, Scottish Water, the Scottish Environment Protection Agency (SEPA), Wilcon Homes, Formpave Ltd., Yorkshire Water and Dundee City Council.

2. Structure of the report

The report has two sections.

Part A contains detailed monitoring and performance information on most of the types of SUDS encountered in Scotland, including ponds, detention basins, swales, filter drains and infiltration trenches and porous paving.

Further sections provide the results of analysis of public perception, of pond sediments, and of surveys of aquatic and riparian vegetation and macroinvertebrates.

Part B comprises fourteen Site Summary Sheets including details of results from five ponds, two detention basins, two porous paving installations, three filter drains and two swales. The purpose of these sheets is to give a ‘snapshot’ of all aspects of behaviour of the SUDS systems.

3. Key findings

The implementation of SUDS in Scotland has been a great success in achieving the water quality and flow control objectives for which they were planned. A wide range of systems has been monitored, and although many examples of poor practice have been found and highlighted, it is clearly demonstrated that the systems are all producing at least the hydrological and water quality benefits desired.

The research demonstrates that:

- most source control SUDS in Scotland serve contributing areas which have relatively low levels of contamination;
- source control systems investigated operate primarily hydrologically, and have been found to effectively control rates of surface runoff and these SUDS localise and treat contaminants;
- only exceptionally will SUDS not mitigate against pollution or lead to contamination problems themselves;
- site/regional control systems provide significant hydrological benefits, but in addition they attenuate peak concentrations of pollutants.

Maintenance is an absolute necessity for all drainage systems and SUDS are no exception. Observations on maintenance are an underlying theme of the report.

The local acceptability of SUDS depends on their appearance, and some of systems monitored have an entirely unsatisfactory appearance. However, a number SUDS which were in need of maintenance to improve their appearance also afforded excellent performance.

Below ground assets were generally found to be in poor condition and those monitored did not perform well.

A number of discrepancies between design and installations were found although more recent examples have been designed to a better standard than earlier systems.

4. Implementation and dissemination

This report is intended to be of interest to several stakeholder groups including environmental regulators, water service providers, local government, developers, national government, environmental consultancies, non-governmental organisations; and researchers.

Research findings have been incorporated into CIRIA publications and the studies reported here can be expected to inform design guides through information details such as: treatment volume, percentage runoff, changes in water qualities, inlet and outlet design.

Key words
Sustainable Urban Drainage Systems; SUDS; Best Management Practice (BMP); Surface Water; Storm Water; Source Control; Scotland; Amenity; Maintenance; Hydrology; Water Quality; Diffuse Pollution; Performance.

1. REPORT OVERVIEW

1.1 Report Aims and Objectives

This report presents the applied outcomes a range of studies in Scotland. Its aim is to provide directly applicable information on the performance and behaviour of SUDS systems based on results from the Scottish SUDS monitoring programme.

The objectives which have been used to meet these aims have been;

1. To identify clearly those parts of the monitoring programme where valid observations and conclusions can be drawn, and to draw conclusions wherever possible.

2. To provide a summary of the results which can be used to inform other SUDS research in the UK including a revision of CIRIA Report C521 - Drainage Systems; design manual for Scotland & Northern Ireland (CIRIA 2000).

3. To focus on areas where continuing monitoring is appropriate.

1.2 Context

The policy to encourage implementation of Sustainable Urban Drainage Systems (SUDS) for new developments in Eastern Scotland was introduced in 1995 by the Forth River Purification Board. This policy was adopted by SEPA after its formation in 1996 and it was extended to the whole of Scotland, being promoted by the inter-institutional Sustainable Urban Drainage Scotland Working Party (SUDSWP). The inclusion of SUDS in the Water Environment and Water Services (Scotland) Act 2003 will result in the adoption of public SUDS systems by Scottish Water, requiring key performance information to facilitate production of standards.

The successful passage through the Scottish Parliament of the Water Environment and Water Services (Scotland) Act 2003 on 29th January 2003 amended the Sewerage (Scotland) Act 1968 to include a definition of SUDS as follows:

Sustainable urban drainage systems (in Scotland)

"SUD system" means a sustainable urban drainage system;

"sustainable urban drainage system" means a drainage system which—

(a) facilitates attenuation, settlement or treatment of surface water from 2 or more premises (whether or not together with road water), and

(b) includes one or more of the following: inlet structures, outlet structures, swales, constructed wetlands, ponds, filter trenches, attenuation tanks and detention basins (together with any associated pipes and equipment);".

This gives public SUDS the same legal status as traditional sewers. These measures clarify the scope of the water utility to adopt and maintain public SUDS in Scotland, ultimately recovering costs from customers. This definition does not include private SUDS which are located entirely within the curtilage of a property, or SUDS which convey road drainage only.

In 1997, following encouragement by SUDSWP, a group of academics commenced monitoring the systems which had been installed. This group, the Scottish Universities SUDS Monitoring Group, has since been very successful in securing support for SUDS research and thereby providing invaluable information on SUDS; their performance, costs and maintenance. This report has been prepared on behalf of the Scottish Universities SUDS Monitoring Group, and their details are included in Appendix D.

A full range of SUDS systems are now to be to be found in Scotland including ponds and wetlands, detention basins, roadside swales, pervious pavements and filter drains/ infiltration trenches. A database of sites, initially developed in 1999 has been extended and now lists 767 sites with 3913 identifiable system components at the end of 2001 (Wild et al 2002). This report presents the results of a range of studies of these systems and draws as many general conclusions as are appropriate at this time. The first stage of the monitoring programme finished in spring 2001 and an interim report was produced at that time (Jefferies 2001).

The principal funders of the monitoring programme have been SNIFFER, SEPA, the Environment Agency, Wilcon Homes, Scottish Water and the Carnegie Trust. Funding from Scottish Water and SNIFFER has been extended for a further three years to Spring 2004 and detailed reports are in preparation for Scottish Water. The monitoring programme reports to SUDSWP via the programme managers, Mr Brian D'Arcy and Prof. Chris Jefferies.

1.3 Approach

Inevitably much of the work has been driven by the particular requirements of funders and by the locations of the academics. Environmental research requires significant resources, particularly to undertake fieldwork, and it has been inevitable that a limited number of sites have formed the focus for the research. This has resulted in a range of studies being carried out at a 350 Ha development near Dunfermline known as the Dunfermline Eastern Expansion Area (DEX) since this was used as a demonstration site for the development of SUDS principles and inter-institutional relationships in Scotland.

Investigations have followed four key routes.

a. Full hydrological, water quality and sediment investigations at fifteen sites.

b. Routine visits supported by visual inspections and recorded on tick sheets

c. Other information, anecdotal and otherwise, on all types of SUDS in Scotland

d. A selected number of laboratory investigations.

Conclusions are based on the current state of knowledge (at June 2003) and several studies are ongoing.

1.4 Report Structure

The issues which the report attempts to address are very diverse, and several topics (for example maintenance issues) cross boundaries. There are two parts to the report. **PART A** reviews the issues at all sites where relevant, and **PART B** consists of fourteen site summary sheets, a series of snapshots of the behaviour of different types of SUDS as built in Scotland. In **PART A,** Chapter **2** commences by reviewing the principal conclusions from the monitoring programme. The major thread of the investigations has been hydrological and water quality studies, and the results of several investigations are compared **in Chapter 3** in a way which can be used by practitioners. **Chapter 4** examines the amenity and appearance of above ground SUD systems and reports on the outcomes of studies of public perception. **Chapters 5** to **7** give details of ponds, detention basins and swales respectively. The problems and imperfections of below ground systems are addressed in **Chapter 8**. Findings of studies of porous paving are included as **Chapter 9**, sedimentation issues in ponds as **Chapter 10** and aquatic & riparian vegetation in **Chapter 11**. **Chapter 12** deals with cost and maintenance issues.

At the end of the report **Chapters 13, 14** and **15** are sections on the Database, the SUDS Monitoring Group and a list of references. At the end of the main report are summaries of the findings at fourteen of the sites monitored are presented in the **PART B**. This is the first time that these results have been drawn together in a consistent format.

1.5 Using This Report

This report has been written for practitioners in drainage planning;

- Those seeking general guidance on SUDS appearance and have a general view of performance should read chapters 2-4 of **Part A**
- Those requiring more detailed information on performance and operation should read the text of chapters 3-9 in **Part A** and the Site Summary Sheets in **Part B**.
- Those wishing to understand specific aspects of particular types of SUDS monitored should read the site summary sheets in **Part B**.

1.6 Definition

This report considers SUDS as they have been defined in legislation in Scotland – Sustainable Urban Drainage Systems (see section 1.2). Their principal function is the control of flow and pollution at source and as part of a storm water management or treatment train. The labels ‘source, site and regional’ SUDS are used throughout to indicate in a general sense the scale of the system and location being studied.

2. PRINCIPAL CONCLUSIONS

2.1 In General

The monitoring programme has encompassed a wide range of studies, mirroring the multidisciplinary skills in the development of SUDS. This report collates outputs from many different researchers in a consistent form. Its principal function is to inform the debate on SUDS systems, and the conclusions are not necessarily based on great depth of analysis in any one discipline.

2.2 Hydrological Behaviour

Hydrological performance was assessed at fourteen different sites representing five different types of SUDS systems or components. Key summary information which has been prepared to inform the design process is given in tables 3.2 and 3.3.

The key conclusions from the hydrological studies are:

- All SUDS systems monitored were found to operate effectively principally by flow attenuation even though there was a range of different arrangements.
- The results of the monitoring show that the source control systems had a greater influence on flows than the site and regional control systems.
- Within each category (source and site/ regional) there was little difference in hydrological performance between different types of SUDS system.
- No evidence was found to suggest that the SUDS studied will not continue to operate as designed provided they are maintained properly.

Many of the results from the hydrological studies have implications for modelling and it is anticipated that improved models of SUDS systems will result from the results summarised in section 3 and reported in detail in the Site Summary Sheets.

2.3 Water Quality Behaviour

The monitoring results for water quality were less conclusive than for hydrology. The prime reason was that funding limitations prohibited very extensive water quality monitoring programmes, in particular the amount of water analysis carried out had to be restricted. Despite this, the following generalised water quality conclusions can be drawn;

- The SUDS studied were chosen to reflect the range and diversity of installations in Scotland and, while minor levels of contamination were frequently noted, no cases of extreme pollution were observed during the monitoring period. It is concluded that most SUDS in Scotland serve urban areas which would cause low, but in many instances chronic, levels of receiving water deterioration if not protected by SUDS.
- The hydrological performance of many types (not necessarily ponds) is such that the flow of surface water is reduced. This indicates that key pollutants (particularly those associated with sediments) are retained locally by the SUDS systems.
- The volume of surface water discharged from SUDS was always found to be less than the inflow and, by inference, the pollutant load potentially reaching the environment must be significantly reduced.
- All SUDS types appeared to contribute to retaining pollutants locally.
- All observed pollutant peaks were reduced, in most cases significantly. i.e. pollutant concentration peaks were attenuated.

2.4 Amenity and Appearance of SUDS

Integrated SUDS Systems

Few examples of integrated SUDS treatment trains were found during the survey period, the principal location being the Dunfermline Eastern Expansion area development DEX, (sometimes also referred to as Duloch Park) and on new highway construction funded by the Scottish Executive. At DEX, six ponds and a wetland form the regional SUDS facilities, and with two exceptions (both relatively small areas), every site also has a detention basin. Where there are also developments incorporating higher pollution risk activities (for example a superstore with filling station) there is an additional level of SUDS upstream. Studies from DEX are reported here with the permission of Wilson Connolly Homes.

Ponds have become rapidly integrated into landscapes and most housing developers locate the higher value properties in view of the ponds. Surveys of flora and fauna (see chapter 11) show rapidly increasing species numbers and richness, evidence that they can provide a focus point of biodiversity. The maintenance regime in place has a significant effect on the plant species. However, at some locations the developer applies herbicides regularly and the numbers of plant species is restricted. Where herbicides are not used and only cutting and replacement of vandalised plants is practiced, native species tend to dominate rapidly.

Some facilities have suffered from vandalism, newly planted trees and shrubs being frequently uprooted. Temporary paling fences tended to be broken in places, but once low level, toddler fences have been erected, the level of vandalism dropped. In general, after approximately two years, the vegetative barriers began to be established, vandalism reduced and at the same time, a more general use by the community increased.

At least one of the detention basins is seen as being of high visual importance by the developer who has invested considerable time and effort into landscaping maintenance, using it as a selling point. The grass is cut and other vegetation maintained in most detention basins which have the appearance of small, tranquil areas of parkland. There is evidence that they support wildlife, particularly as temporary refuges. Unfortunately, during the construction phase, most developers showed little concern for the detention basins and many receive high sediment loads during the construction phase. This suggests that better control of building practice is desirable. See chapter 12 for more information.

Public Perception

A number of surveys of public perception of SUDS ponds have been undertaken in Scotland and England & Wales (see section 4.6). The surveys showed a clear belief that SUDS ponds add to the amenity of an area. In general, ponds are considered to be aesthetically pleasing when they resemble a natural pond as far as possible. Shallow slopes around a pond in combination with rich marginal vegetation serve a double purpose, acting both as a safety barrier reducing accessibility for young children and also improving the appearance of the pond. Safety is only one of a number of concerns expressed during surveys, the perceived dangers from ponds ranking below the risks from a busy road or from a landfill site. Residents in areas with well-established ponds tended to be fully aware of the risks posed by open water yet in spite of any danger there may be, they see the risks in a positive light since there were many benefits from ponds.

The following design recommendations arose from the surveys of public perception (more information may be found in section 4.6.2):

- Make the pond appear to be as natural as possible.

- Improve marginal vegetation.
- Introduce more vegetation (native preferably).
- Introduce more wildlife or protect the species of wildlife already existing in the pond.
- Make shore slopes softer and introduce of natural barriers.
- Introduce signs warning only where there is deep water.
- Introduce benches and picnic tables.
- Create children playgrounds.
- Create walkways.

2.5 Ponds

Most ponds appear to have been designed according to current advice, probably reflecting the greater concern about ponds which in turn has resulted in a greater input by experienced designers. Chapters 4 and 5 are principally concerned with ponds, but the key messages from the performance observations (in addition to those in section 2.4) are;

- Exert as much control as possible on the activities of contractors upstream – particularly in the amounts of sediment produced.
- Sediment production rates after the initial construction phase are likely to be so low that significant reduction of storage is not likely. Fill up rates of around 300 years have been predicted.
- Mean metals concentrations of sediments in the SUDS ponds studied complied with most sediment standards.
- Where the ponds were designed in accordance with current guidance (CIRIA 2000), a rich and virtually impenetrable vegetation barrier developed.

2.6 Detention Basins

The recommendations for detention basins in chapter 6 are:

- Inlet detailing – The inlet should incorporate a greater drop to accommodate sediment accumulations. Access to the inlet area is critical to facilitate removal of sediment.
- A sacrificial zone for sediment accumulation in detention basins should be considered.
- It is highly likely that the hydrocarbons are being trapped. At one location, where accumulation of hydrocarbons is noticeable, there is no evidence of their being carried into the basin downstream.
- Extended detention basins may give sufficient pollutant removal in a number of locations where retention ponds are currently recommended.
- Outlets should stand proud of surrounding soil and vegetation where possible to prevent blockage during vegetation maintenance (see figure 6.2).
- Sacrificial detention basins have been used successfully for construction runoff at a number of locations.

Further observations on detention basins are:

- Dry weather ‘channels’ had noticeable sediment accumulations within 4 years. This was even with no construction activity. See figures 4.11and 4.12.
- Planning constraints have led to exceptionally deep detention basins. While these are not dangerous, they are generally unsightly (see figure 4.15). Changed approaches to open space requirements would correct this issue.

- The impression was formed that vegetation cutting at detention basins has no impact on water qualities (see figure 4.12). This hypothesis will be tested in a currently ongoing monitoring project.

2.7 Roadside Detention (Swales)

The following detailing changes will improve the performance of roadside detention basins (swales) Greater detail may be found in chapter 7 and Site Summary Sheets 13 & 14:

- Keep a shallow gradient and ensure full length of swale is utilised by modifying the gradient appropriately.
- Use a gravel layer below the growing medium.
- Install a raised outlet.
- Rough base in swale with natural vegetation.
- Use drop kerb entries; clearway drainage inlets should be discouraged.

2.8 Filter Drains and Infiltration Systems

The examination of filter drains and infiltration trenches has shown clearly that the two principal causes of poor hydraulic performance (as SUDS) were as follows:

- Poor design concept & detailing, and;
- The lack of post construction performance checks. Such checks are necessary to initiate remediation maintenance.

Filter drains have been found to operate well in a range of ground conditions, countering the perception that SUDS must rely on infiltration. Where the design has been well though out and precautions have been taken against construction stage runoff, filter drains and infiltration systems have been shown to be operating well, even in ground of low permeability. Greater detail may be found in chapter 8 and in site summary sheets 11 and 12.

Bad Practice/ Design

Many systems had been put into service before construction was terminated and they have silted up. A number of installations were found where the storage volume cannot be utilised effectively due to the absence of flow control devices. Trapped gully pots were installed at a number of sites alongside highways, but cleaning was found to be problematic due to poor detailing. Offlet kerbs, a common detail were found to be blocked at several locations. One commonly used detail has been to terminate the outlet from trapped gullies in the filter media. However, this detail has been found to block relatively quickly, particularly with leaves. At Lang Stracht in Aberdeen, all 40 gully outlets became blocked within three years.

Good Practice/ Design

A number of designs appropriate to soils of low permeability have been found and some designs for end of pipe filter drains operate satisfactorily in soils of low permeability which include the facility for jetting. All filter drains and infiltration trenches should have a sediment sump at the inlet. This sump must be in an easily accessible location for suction equipment. Notwithstanding these improved details, filter and infiltration systems are being dropped in favour of surface systems where problems are more easily identified and rectified. Most of the more recent systems have been sized to include the treatment volume Vt, and incorporate flow control devices to throttle the flowrate and ensure that the storage volume is used. Flow monitoring at two sites (see site summary sheets 11 and 12) shows good flow attenuation with an average 20% peak flow reduction.

2.9 Porous Paving

Three field studies of porous paving have been undertaken. Two were of ‘live’ in-situ porous pavements used as car parks in Edinburgh constructed of Formpave blocks in 1997 and 1999 respectively. A further small scale study was undertaken at a purpose built pilot installation at Dundee airport to examine the removal of heavy metals. All studies have shown significant attenuation of flows and retention of contaminants locally. Observations have shown that lined systems perform almost equally to systems with no lining in soils of low permeability. Greater detail on porous paving installations may be found in section 9 and site summary sheets 6 and 7.

System blockage was found at locations where there was soil and vegetation wash off from slopes higher than the paving system. This is prevented by good landscaping practice, avoiding the transport of fine material, and by good construction detailing. Typical points of detail for landscape architects are:

- Slopes higher than the paving area (i.e. slopes which have been cut) should be protected; slopes below (i.e. embankments) are unlikely to impact on the paving.
- A cut off drain at the base of the cut might assist in preventing high soil moisture which weakens and makes soils more easily eroded. This will assist in avoiding easy mobilisation of soils.
- Use rapid, growing low vegetation to stabilise soil quickly.
- Avoid rotovating vulnerable cut slopes.

To avoid structural failure, the following guidance is being used:

- Heavy goods vehicles and buses should be prevented from accessing porous block paving systems.
- Only the actual car parking bays can be of porous construction since this permits the required treatment volume and surface area to be incorporated. Access roads of ‘adoptable’ standard should be specified between the parking spaces in heavily used car parks.
- Porous construction should be used for the full car park only where the turnover of vehicles is less frequent, and for office parking.

2.10 Pond Sediments

The sediment survey of the Dunfermline SUDS shows that sedimentation rates vary from year to year, probably due to changes in site development and rainfall variation. The SUDS management train appears to be effective in trapping sediment in detention basins upstream of retention basins, thereby reducing the costs of sediment removal from retention basins. Sediment quality varies spatially in the Dunfermline SUDS, with the highest contaminant concentrations occurring near the inlets. Metal concentrations in SUDS sediment have increased as the Dunfermline site developed, probably due to increased traffic and the size of the developed areas. Mean metal concentrations of sediment from the Dunfermline SUDS complied with different sediment quality standards, although “hotspots” of contamination occur within each SUDS.

2.11 Aquatic and Riparian Vegetation in Ponds

The experience of conducting botanical surveys of SUDS ponds in Central Scotland reveals a need for much greater dialogue between developers, landscapers and ecologists. Even the choice of native species for deliberate introduction indicates some curious decisions. For example, the Common Reed, *Phragmites australis*, has been planted around many ponds to form an impenetrable screen and thereby deter children. Reed can penetrate to much greater water depths (1.5m) than most emergent species and forms particularly recalcitrant litter so will encroach into the centre of ponds and lead to a more rapid loss of volume. Such problems would be much less severe with the use of other emergent species such as Branched Bur Reed.

On the basis of existing metal concentrations in sediment and plant tissue there would seem little justification for plant harvesting or for concern over the effects of metal contaminants on plant growth. However, this situation may change appreciably with continued urbanisation of catchments. Currently, reduction in pond performance due to loss of volume caused by sediment accumulation should be a more immediate concern than contaminant build up.

2.12 Maintenance and Costs

At the time of writing, several studies of SUDS performance are underway, and Whole Life Costs and reporting is anticipated in late 2003 / 2004. It is not appropriate to give significant details of costs and performance here. However, a number of general points can be made;

- The amount of maintenance requiring to be undertaken is less than was feared at the inception of the SUDS policy.
- Landscaping requires to be compatible with the type of system being used – for example, there is little to be gained by installing a porous paving system only for it to become blocked due to wash-off of sediment from slopes higher up.
- There is likely to be little sediment accumulation in SUDS ponds where they are constructed as part of a treatment train.

3. COMPARISON BETWEEN SUDS

3.1 Overview of systems and results

This section includes a comparison of the hydrological and water quality performance of the different SUDS sites studies. The key conclusions from the hydrological studies are:

- All SUDS systems monitored were found to operate effectively, principally by flow attenuation even though there was a range of different arrangements.
- The results of the monitoring show that the source control systems had a greater influence on flows than the site and regional control systems.
- Within each category (source and site/ regional) there was little difference in hydrological performance between different types of SUDS system.
- No evidence was found to suggest that they will not continue to operate as designed provided they are maintained properly.

The systems investigated are detailed in <u>**Part B**</u> of the report, and are summarised in table 3.1:

Table 3.1 Sites Monitored

Number	Name	Brief description
1	Clayland Pond	Pond serving busy motorway
2	Newbridge Pond	Pond serving busy motorway
3	Hallbeath Pond	Regional pond serving retail park
4	Linburn Pond	Regional pond serving mixed residential / commercial
5	Stenton Pond	Former flood pond serving housing estates
6	NATS	Permeable paving car park
7	RBS South Gyle	Permeable paving car park
8	Detention Basin D/M	Detention basin serving highway
9	Detention Basin G	Detention basin serving highway
10	Lang Stracht	Filter drain on a 750m stretch of busy urban road
11	Broxden	Filter Drain serving housing estate
12	Walker Dam	Filter Drain serving housing estate
13	Emmock Woods	Roadside Detention
14	West Grange	Roadside Detention

Most of the systems were constructed between 1995 and 1998 with the exception of Stenton Pond which was built in 1978.

3.2 Comparisons of SUDS studied

This section presents results from studies at seven SUDS sites and draws common conclusions. The principal results discussed are summarised in table 3.2 as <u>averages</u> of the many events monitored at each site. The table has been separated into two sections, principally because of durations of events required to cause significant runoff are much greater with the second group.

Table 3.2 (a) Hydrological Parameters - Source Control SUDS – Mean Values

Parameter (for definition see section number in brackets)	Royal Bank	NATS		Emmock		W Grange	
		Tarmac*	Porous	Road*	Swale	Road*	Swale
IRL (mm) (3.4)	2.27	0.9	4.2	0.4	5	0.3	1.2
Lag time (min) (3.5)	83	9.59	180	9.2	11.6	3.7	14.3
% Runoff (3.6)	46.5	48.2	22.2	44.3	6.5	33.8	6.3
% Reduction of Peak (3.7)	N/A	N/A	77	N/A	52.2	N/A	65
Benefit Factor (%) (3.8)	N/A	N/A	75	N/A	82.4	N/A	80.1
Events Retained (%) (3.9)		N/A	60	N/A	52	N/A	40

* Conventional (non SUDS) surfaces

Table 3.2 (b) Hydrological Parameters – Site & Regional Control SUDS – Mean values

	Broxden	Walker Dam	Lang Stracht	Linburn DEX	Halbeath DEX
IRL (mm) (3.4)			1.98		
Lag time (min) (3.5)			203	130	100
% Runoff (3.6)			36	40.0	10.4
% Peak Reduction (3.7)	76	74			100

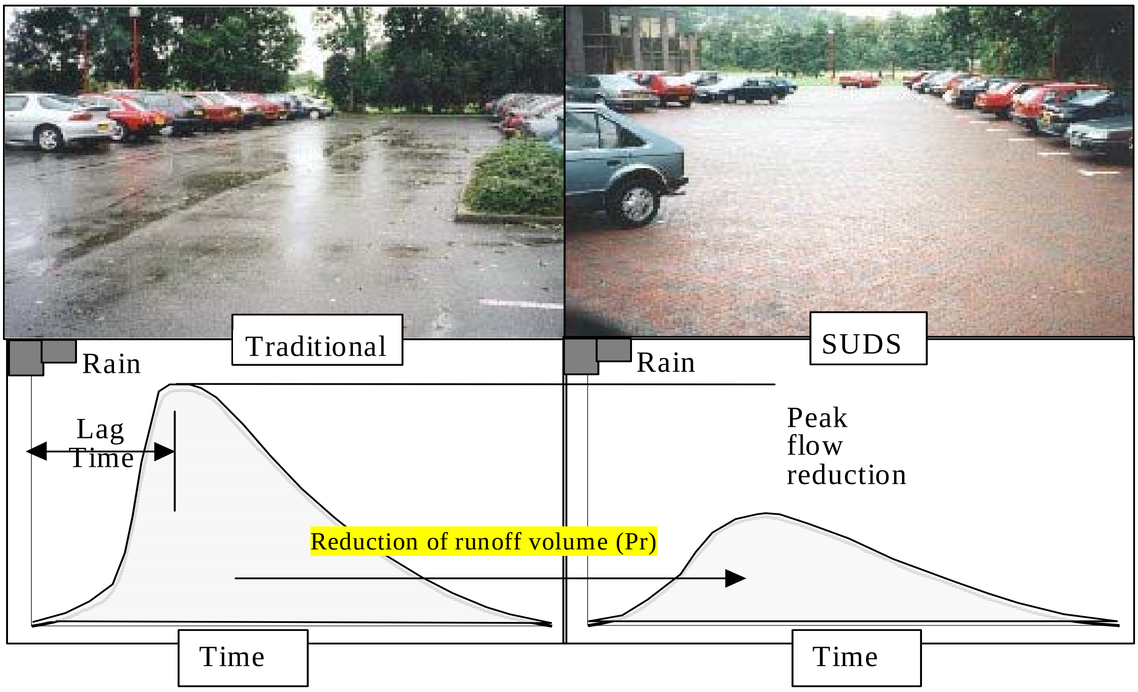


Figure 3.1 Interpretation of Key hydrological Parameters

Since hydrological performance can be expressed in a number of ways, figure 3.1 has been included to give an overview of the hydrological interpretation at each location. Each hydrological parameter is examined in the subsequent sections.

3.3 Conventional runoff

Three examples of conventional drainage were monitored by Macdonald (2003) immediately adjacent to SUDS locations. These were at the NATS Tarmac site in Corstorphine, Edinburgh, and the two areas of road at Emmock Woods and West Grange in Dundee. It was necessary to monitor these locations to understand properly the behaviour of the adjacent SUDS component. Almost without exception, these conventional locations gave the least value of initial runoff loss, the shortest lag time and highest percentage runoff – all to be expected from conventionally drained surfaces. The parameters monitored at the conventional sites give clear evidence that the SUDS studied at the same places have a positive hydrological effect.

3.4 Initial Runoff Loss

It is concluded that the source control systems studied delivered an Initial Runoff Loss (IRL) which was between 2 and 4mm more than the conventional road surfaces.

Initial Runoff Loss represents the amount of rainfall required before surface runoff actually occurs. As a concept, it can apply to any rainfall-runoff example, but in this context it is only relevant to the source control systems. IRL is comparable with depression storage (DEPSTOG - HR 1983). IRL for the tarmac car park at NATS was 0.9mm while the two conventional road sites produced IRL values of 0.4 and 0.3 mm, the lower values due to the rapid runoff from conventional road drainage.

‘Losses’ in the SUDS facilities, in contrast, were significantly greater (good), and the lowest value of IRL was 1.2mm at West Grange (roadside detention). IRL at the Formpave (pervious paving) sites at Royal Bank and NATS were 2.27mm and 4.2mm respectively, while the long filter drain at Lang Stracht in Aberdeen gave an IRL value of 2.0 mm. These values clearly demonstrate that the SUDS components all produce increased surface runoff losses, with roadside detention basins at Emmock Woods providing the greatest initial loss of runoff.

3.5 Lag Time

It is concluded that significant lag times were monitored at all of the SUDS monitored, although this was least marked at the roadside detention basins.

Lag time is the time of the peak of the outflow measured from the time of the centroid of the rainfall, and is a key measure of attenuation of flows. The greater the lag time, the more the drainage system produces attenuation of flows. It is clear that the permeable paving systems produce exceptional attenuation of flows, increasing the lag time by up to three hours. The uncontrolled road runoff times were in the order of ten minutes for the flatter sites, and 4 minutes for the steeper West Grange site. In contrast, the time delay of the peak from the permeable paving at NATS was 180 minutes and at RBS it was 83 minutes. This is evidence of very significant attenuation. By contrast, the effect on lag times of the roadside detention basins, at 12 min and 14 min respectively, was much less (but other parameters; e.g. percentage runoff and peak flow reduction, were similar). Lag times in the larger systems investigated were over 200 minutes for the Lang Stracht site, and in the order of 100 – 130 minutes for the two Duloch Park ponds monitored.

3.6 Percentage Runoff

The runoff from the three conventionally surfaced areas must first be considered when considering percentage runoff. Values of 48.2%, 44.3% and 33.8% by volume respectively were recorded at the three sites, much less than the 100% commonly thought - although in heavy rain, these values will rise. Firstly, a comparison is made with the permeable paving at the Royal Bank site which has a high value of 46%. This system is fully lined and there is no possibility of exfiltration and the percentage runoff value reflects the ability of the system to drain down very well. This value of percentage runoff must be considered in the light of the high lag times at the same location which mean that, although it behaves the same as a tarmac or asphalt surface in terms of total runoff volume, there is significant attenuation of the runoff.

The total outflow volume from the NATS site was 50% of that from the neighbouring tarmac, while the swales produced only 6.5% of the rainfall as runoff. Note that this is surface runoff only and does not include interflow or flow through pipe bedding. These are highly significant values and represent very significant reduction of flows.

The Lang Stracht filter drain system in Aberdeen delivers 36% runoff – probably not a great deal different from the road itself (but the lag time is long) – while the value for Linburn Pond is 40%. These two results may not be so surprising since longer events produce greater percentage runoff values. Halbeath pond is exceptional with its tiny amounts of outflow, and it is suspected that there is leakage beside the outlet structure and not all flow is measured – however, this is normally advantageous from the SUDS point of view, provided there are no issues of structural stability, erosion or groundwater contamination.

It is concluded that the roadside detention basin systems (or swales – see summary sheets 13 & 14) perform best in terms of percentage runoff and this is principally due to the outlet arrangements which encourage losses from the base of the swale set up. The in-ground systems perform less well in terms of percentage runoff, principally because their outlets are lower and any storage is less effectively utilised.

3.7 Reduction of Peak Flows

It is concluded that peak flows from the SUDS components studied were at most 50% of the peak flow from the equivalent paved surface.

Peak flow reduction has been determined at the three sites where the conventional runoff was measured concurrently with the SUDS outflow. Thus this measure represents the reduction of flow based on conventional drainage. By many criteria, this is a key measurement since it is the peak flowrate which has the greatest potential for watercourse damage due to erosive forces (Gardiner 1994, Roesner et al 2001). The average peak flow reduction at Emmock was 50% and this rose to as great as 77% at the two other sites where this information was gathered. The extreme value for Halbeath is again a reflection of the leaky embankment at that location.

3.8 Benefit Factor

In order to show the relative value of the SUDS installations monitored compared to conventional, Kirsteen Macdonald has developed the concept of Benefit Factor. This is computed from those events producing runoff by expressing the total volume of runoff from the SUDS component compared to the conventional system. It can be seen as an alternative means of expressing percentage runoff and three sites produced Benefit Factor values of at least 75%. It should also be noted that this parameter can only be calculated where both the conventional and SUDS systems produce runoff which was only 60% of the time at NATS.

3.9 Events Retained

This parameter has been used to indicate the effectiveness of a SUDS component in reducing surface runoff, particularly during low flow events, is analogous to the reduction of peak flows, but is an expression for the full event. The definition of event gap (time between rainfall) and the depth of the event both heavily influence the value of events retained. It is particularly appropriate for source control systems which temporarily store surface water, and to infiltration systems. Its use in expressing retention of events may be seen in site summary sheet

3.10 Comparison of performance of source control SUDS

A detailed comparison of the performance of three source control SUDS; the porous paving car park at NATS, Edinburgh, and two roadside detention basins (swales) at Emmock Woods and West Grange in Dundee. Further information may be obtained from Dr Kirsteen Macdonald (kirsteen.macdonald@ewanscotland.co.uk)

Porous Paving:

Treatment volume (Vt) equates to 16.45m^3, the pore space volume of the sub-base is approximately 98m^3, and thus Vt is effectively a depth of only 59mm of the sub-base. CIRIA guidance (Pratt et. al. 2001) quotes: sub-base > 450mm, time to half empty = 24-48 hrs . Observations at NATS (350mm deep) show that the time to half empty was approximately 3.5h.

The following detailing changes will improve the performance of Porous Paving. They have minor cost implications, yet is not likely to be associated with issues of space and would significantly enhance hydraulic performance:

- Increase the depth of stone layer beneath porous block
- Increase the potential for storage in sub-base

Swales

Treatment volumes at the two swales studied were as follows:

	Vt (m^3)	Swale vol. (m^3)	% of Vt
Emmock Woods	5.96	1.2 + 0.7	30
West Grange	6.03	1.25	20

The following detailing changes will improve the performance of roadside detention basins (swales):

- Keep a shallow gradient and ensure full length of swale is utilised by modifying the gradient appropriately.
- Use a gravel layer below the growing medium.
- Install a raised outlet
- Rough base in swale with natural vegetation
- Use drop kerb entries; Clearway drainage inlets should be discouraged

Comparison of porous paving and swales:

Modelling exercises showed that surface water ponded on the porous pavement (hydraulic capacity exceeded) due to high return period longer duration storms – due to the storage capacity being exceeded. In contrast, the swale became full and spilled over the side banks (hydraulic capacity exceeded) with high return period medium duration storms – due to capacity of outlet pipe being sensitive to higher intensity storms.

Porous paving prevents runoff from smaller events & attenuates flow longer than swales (due to storage in the sub-base). However, once outflow commences the reduction of % outflow & peak runoff rate was greater than the swale sites. The most significantly different performance parameter was the lag time which was much greater at the porous pavement, indicating the attenuation achieved in the porous paving system.

3.11 Conclusions on Hydrological Observations

All of the SUDS systems studied have produced clear hydrological benefits. Some of the parameters produced surprising values – for example, lag times for the two swales were low – but this was compensated for by very low percentage runoff values.

Peak flowrates were at most 50% of the uncontrolled values. This is a clear benefit which enables pipe diameters to be reduced significantly.

The lined Formpave system at the Royal Bank of Scotland site performed equivalently to the NATS site, in spite of the former being lined and even though the outlet arrangements at the latter provide added flow attenuation.

In general, discharges of water from SUDS to the receiving environment were limited - percentage runoff (over all events) was as low as 6.3%. This is of great significance in terms of environmental protection: a reduction in runoff means limited hydrological impact. Similarly, if pollutants are not discharged to watercourses, they do not cause environmental damage to aquatic ecosystems, and if they are retained in the SUD they are treated therein, or at least can be removed and treated offsite. More information on water quality treatment is presented below.

3.12 Water Quality Investigations

The objectives of the studies was principally to confirm that the behaviour of the Scottish SUDS sites was similar to similar sites elsewhere in the UK and from the literature. As a result, there were only limited budgets for water quality monitoring. In spite of budgetary constraints, most of the studies undertaken included water sampling and quality monitoring using multi-probe sondes. The majority of the sites were either of low (suburban housing) or medium pollution risk (large car parking areas) while only two sites had a risk of high levels of contamination (The ponds at Clayland and Newbridge which serve motorways). The water quality from adjacent impermeable surfaces was monitored concurrently with the SUDS system at three of the sites, and at one location (porous paving at the Royal Bank site at South Gyle, Edinburgh) the inflow could not be measured because of the inherent nature of porous paving systems. A variety of laboratories were used for sample analysis, but the most commonly used was the SEPA lab at Riccarton.

Inflow and outflow budgets were possible at four of the source control systems and an overview of the results are given in table 3.3. There is a paucity of data from the swale at Emmock Woods site, principally because flow at the outlet pipe only occurred on a very limited number of occasions, a reflection that source control swales have a very significant effect on smaller rainfall events – which are those that are potentially the most polluting. Studies at four SUDS ponds produced assessments of reduction of peak concentrations and the results are shown in table 3.4. Full pollutant budgets could not be made because of time and resource limitations – and this exercise could not be done at one site (Linburn Pond) because it has five inlets!

Table 3.3 Water Quality Parameters - Source Control SUDS (based on event mean concentrations (From Macdonald (2003))

	Royal Bank	NATS			Emmock Woods			W Grange		
		Tarmac	Porous	+/-	Road	Swale	+/-	Road	Swale	+/-
TSS (mg/l)	14.9	30	19	32%	1057*	299*	72%	343	96	54%
BOD (mg/l)	2.2	4.8	1.7	49%				5.4	4.5	14%
CU (µg/l)	5.2	5.05	10.9	+25%				28	52	+85%
Ni (µg/l)	1.7	4.64	3.8	63%				6.3	3.1	50%
Zn (µg/l)	22.2	29.5	42	+42%				82.1	93.7	+14%
Hydrocarbons (mg/l)	1.97**	1.07	0.47	69%				1.4	0.9	36%

+/- Values are reductions except where shown positive (+14% indicates increase of zinc in swale)

Tarmac/ road are the conventional (non SUDS) surfaces at the respective locations

* Only one event was sampled at Emmock Woods

** From one event. Data from a second event was all below detection limit

Table 3.4 Water Quality Parameters – Site and Regional SUDS -Percentage Reduction
Where values are available, these are indicated. (From Macdonald (2003))

	Stenton EMC	Clayland Peak	Newbridge Peak	Halbeath
TSS (mg/l)	83			
BOD (mg/l)	90			
CU (µg/l)	82	77	84	
Ni (µg/l)	87	61	-	
Zn (µg/l)	87	42	68	
Hydrocarbons (mg/l)		*		

* Below detection limits

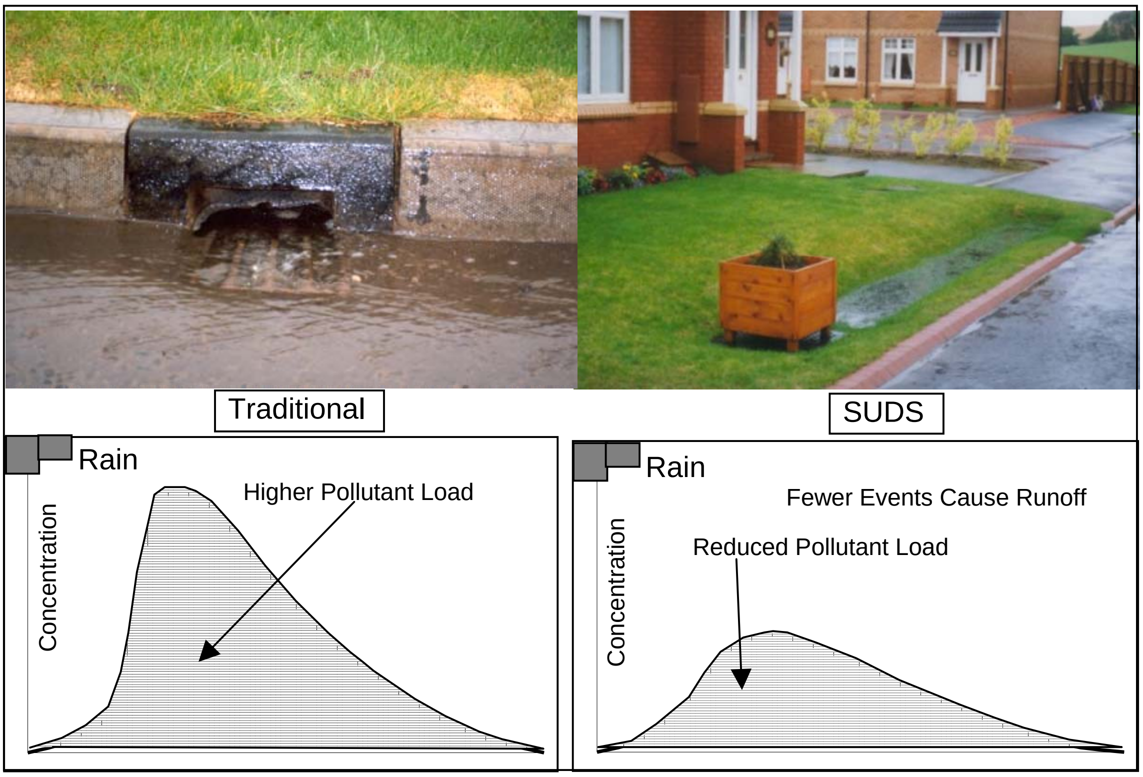


Figure 3.2 Interpretation of Key Water Quality Parameters

3.13 Comparisons of Water Quality Observations

Source Control Systems

The results from monitoring at source control systems shown in table 3.3 indicate that the sites are located in inherently low pollution risk areas where the inflow concentrations of contaminants are low. This means that the performance of each system – expressed as reductions of concentrations – are very variable and there was actually an increase of concentrations (expressed as means over the events monitored). This was particularly true for the heavy metals measured. The reductions of BOD_5 and TSS concentrations were modest.

Ponds

The monitoring has shown that the SUDS ponds studied deliver very consistent water qualities, the variability of concentrations at the inlets not being monitored at the pond outlets. A full flow and load balance was only possible at Halbeath pond (Site Summary Sheet 3). Table 3.3 shows very significant reductions in the parameters measured, the lowest level (42%) being for zinc which has an unpredictable behaviour in this context. Table 3.5 has also been included to illustrate the reduction of peak concentrations. It is likely that this effect is dominated by dilution, and it is replicated by observations at Linburn and Clayland Ponds. It should be noted that all parameters were always reduced at Halbeath – and this statement accounts for the time lag between inlet and outflow peaks.

Table 3.5 Sample Analysis – Halbeath Pond

Parameter	No of Inlet Samples	Min Inlet	Max Inlet	No of Outlet Samples	Min Outlet	Max Outlet
Total suspended solids (mg/l)	153	4	32,792	62	0	26
Turbidity (FTU)	115	11	16,960	62	0	12
Chemical oxygen demand (mg/l)	51	62	756	21	95	630
Biological oxygen demand (mg/l)	15	0.32	80.48	5	1.70	11.21
Ammoniacal nitrogen (mg/l)	45	0.00	216.00	30	0.01	1.04
Orthophosphate (mg/l)	38	0.01	0.11	-	-	-

4. THE AMENITY OF ABOVE GROUND SUDS SYSTEMS

The following section is one of the outcomes of a programme of regular visits to a range of above -ground SUDS facilities in Scotland. Observations were made using tick sheets and a photographic record has been kept. When considered to be of merit, particular observations were noted – for example including obvious deterioration in water quality, wildlife, appearance and evidence of vandalism. Plant and wildlife comments are given only to inform and provide interest since detailed biodiversity studies have only been undertaken at a small number of ponds, most observations were made by well informed lay persons and not by trained biologists. Section 11 reports on ecological monitoring.

4.1 Overview of Amenity Considerations

The meaning of amenity is not well defined, and recent work on social and perception issues (Apostolaki et al. 2002) may result in a better understanding of the complex issues which have been lumped together in the word amenity. The purpose of this chapter is to draw together some of the visual observations which have been made during the course of the monitoring programme so that the debate on amenity can be better informed.

Amenity as a concept can only satisfactorily be applied to above ground systems, and in this chapter, systems which are wholly below ground are assumed not to have any amenity potential. A wide range of above ground SUDS components are potentially available, but many were not to be found in the study areas and in this report, only the following above - ground SUDS components are considered in terms of their amenity potential:

- Retention Ponds/ Wetlands
- Detention Basins
- Roadside Detention[1] and Swales

Just under 30% of all SUDS sites in Scotland are drained using at least one of these components and it is clear from observations that, with notable exceptions, the public response to the appearance of ponds and swales has been positive, whereas they have been indifferent to detention basins. Unfortunately, opinions are adversely biased by the poor appearance of particular ponds.

From routine inspections, there is little doubt that virtually all of the SUDS have been successful in retaining pollution (for example, surplus cement, oils, litter, wrong foul sewer connections) although, to date, contamination has mainly resulted from construction activities. Oil or tar has been observed at the inlets to most facilities but it is clear these materials have not reached the receiving waters, indicating on a very general level that the systems have performed. Furthermore, there is no evidence to suggest that sediment needs to be removed from any of the ponds at present, and accumulation rates are slow. Sediments and maintenance are covered in more detail in chapters 10 and 12.

Fences have been installed around virtually all newly constructed ponds and many detention basins. This is driven by the safety concerns of the developers and planning officials. However, there is no apparent effect of the fencing on habitat development and it is highly

[1] Small grassed areas alongside roads. Many examples may be found in Dundee and the type is illustrated in figures 4.17 and 4.18.

improbable that there will have been any impact on the hydrological/ water quality performance of the facilities.

Rich biodiversity is restricted to the retention ponds and wetlands. There is also some anecdotal evidence that detention basins are forming basic components of wildlife corridors – especially where they are allowed to become overgrown - and some locations appear to be forming parts of wildlife corridors. Swans and other bird breeds are known to have nested on many ponds, and fox tracks have been noted around one pond in Dunfermline.

The areas surrounding almost all ponds examined have a lower biodiversity potential than might be possible. The facilities have been treated as parkland, grass has been kept short, weed killers have been applied and the range of flora and fauna severely suppressed. The emphasis by the developer on rapid growth of garden plants and shrubberies has inhibited biodiversity, but it is likely that this will only be in the short term. Once good growth has developed, the application of chemicals normally reduces to near zero and a proportion of native species develops. Most planting schemes have included a number of non-native species both on the ponds (for example water lilies) but especially on the margins (e.g. berberis and cotoneaster).

4.2 Regional Ponds Constructed as Components of Treatment Trains

Linburn pond, This is one of the regional SUDS ponds in the Dunfermline DEX development. The vegetation was planted in March 1998 was expected to suffer from vandalism but this has been much less than was anticipated. Perennial shrubs and reeds have flourished by this pond and they now present a formidable barrier round most of its perimeter in addition to the low metal fence. The appearance of Linburn Pond and the detention basin across the road is very pleasant and has a feeling of being a wild place within the city which is unpolluted and supports wildlife.

Figure 4.1 Linburn Pond 2001

On at least one occasion, a large quantity of oil was observed discharging from the north inlet but it appeared to be trapped by the reeds and did not reach the open water. It is felt that, although only observed on one occasion, this represents typical behaviour. The appearance and perception of this pond was best summed up in June 2000 when a local paper ran an article under the headline 'Swan Lake' which included a very similar photo to figure 4.1.

Halbeath Pond (also in the Dunfermline DEX development) initially suffered from serious vandalism, but this has now reduced, or at least is less obvious. The reeds grow well here and a number of species (Iris, Lilies and Marsh Marigold) are now competing for space in the pond margins. This pond was built close to existing housing and the surrounding area has been litter prone. Rubbish noted in February 2000 included '..a swimming float, 3 office chairs, a child's bicycle, bicycle helmet and a significant quantity of litter. Large sections of the fence were vandalised..'. However, the pond is becoming more popular with local residents, and a path formed round it in summer 2000. This reflects an apparent change of perception by residents who were initially very hostile to the pond's construction.

Cement was spilled into Hallbeath pond in Sept 1999, covering the sediment in the inlet section for a period, but none escaped to the watercourse and no trace is now visible. Although the area has suffered from vandalism, abundant wildlife may now be observed, and swans have been resident every summer since 1999. Algal mats have routinely formed on Halbeath Pond although there appears to be very little nutrient sources on the contributing catchment area. Sediment continues to accumulate close to the inlet, but this is more or less what would be expected, and measurements show that it amounts to no more than 10% of the total water volume.

Figure 4.2 Hallbeath Pond 2001

Pond 6 (DEX Dunfermline) has three sections in a cascade arrangement. This pond has not provided any sort of amenity at all (apart from dog walking) since its construction in 2000. It has suffered from low water levels and the proximity of house construction for the majority of its life. It is clear that the amenity value of ponds with development close is greatly reduced during the house construction phase. For the first three years of its life until the wet summer of 2002, only one section of this three-cascade pond held water to anywhere near design levels and the remaining two sections were in poor condition since they will not fill up. This caused the appearance to be poor and the reed growth has been limited.

To compound matters, during late 2000, the detention basin at the head of the cascade was filled in by the contractor without permission in spite of being advised of its importance. Since then, construction has progressed extremely close to the pond margins. Runoff into the detention basins and pond has been uncontrolled with resultant soil erosion problems. A significant amount of construction material also made its way into the ponds to join the numerous shopping trolleys, most probably thrown in by local children. In December 1999, six bitumen canisters were dumped in the facility. Vandalism has been an ongoing problem, large numbers of fence post and trees having been snapped.

Virtually no wildlife has been observed at pond 6 due to the disruption of the construction work, and lack of water, but this is expected to improve as the site settles down and remedial measures succeed in keeping up water levels. However, the new houses are now very close to this pond which has become a favourite dog walking area, so even this relatively unsightly SUDS facility does provide some amenity value. Although there has been no monitoring or sampling programme at this pond, there is good visual evidence to show that it has satisfactory hydrological and water quality performance.

Figure 4.3 Pond 6 – There are three ponds in a cascade

The housebuilders at the site (Including a major contracting company) has had a particularly cavalier attitude to construction of houses in the catchment of Pond 6 and this has impacted severely on the appearance of the SUDS system. The only control over the developer has been due to the efforts of the agent of the lead developer who has made particular efforts to control development activities in order to avoid the SUDS system from being overwhelmed with construction runoff – with very little effect. Particular issues are:

- Excessive soil stripping leading to deep mud banks during house building. These have washed off into the detention basins.
- Failure to construct a filter cut off trench to intercept construction runoff.
- House building closer to Pond 6 than was planned.

Pond 6 is the only pond on the DEX development to have become so downgraded. Most of the house builders have recognised the importance of maintaining the ponds' amenity during construction and attractive ponds which are appreciated have resulted. The exceptional practice around pond 6 shows the need for close development control to ensure ponds develop properly.

Pond 7, at the south-eastern side of the DEX development has also developed as an amenity. The reeds developed as did large quantities of duckweed at the outlet. Wildlife noted within the pond area was limited, but the tracks of a fox and rabbits have been observed around the margins. A large quantity of red chipping must have been dumped on a road near this pond since they accumulated at one inlet.

Figure 4.4 Damsel Fly at Pond 7, DEX

Within a year, the majority of this pond was encircled by a broad band of reeds, with the exception of the north east shore where house building had started. Outside the reed zone, a good cover of perennial herbs and shrubs surrounded the pond to the north and there were well-established grass banks to the south. Both diesel and gulley liquor (from gulley emptying tankers) have been noted at the north inlet. The diesel was traced back to the site, but was no longer evident two months later, it had most probably settled on the bottom of the pond where it would either have become immobilised or degraded.

Figure 4.5 Pond 7

In the summer of 2001, nesting sites were built to encourage swans to breed, but in common with most pond locations, a pair of swans tried to build their own nest at the east inlet. However, the swans failed to complete their own nest and they were not seen during any of the visits that year. It is almost certain that this was due to house construction just to the north of the pond. Within three years the barrier planting had become almost impenetrable for most of the pond's perimeter. Wildlife appeared to be gathering, albeit slowly, by the end of 2001 when coots and swans were observed.

The wetland at DEX was constructed in 1997 and planted out in 1998 within a natural marshy depression. It is located close to an extensive woodland for community use, and to a 'city park' which will contain football pitches and other recreational facilities that were under construction in early 2003. The wetland was planned to become a focus for wildlife and Fife

Council is being pressurised to adopt it as a Biodiversity Action Plan location. Monitoring has focussed on the development of habitats within the wetland area, and on the interaction of human activities with those habitats and the wildlife present.

The reeds were slow to become established and in 1999 this was possibly due to the low water temperature or due to reeds being notoriously difficult to transplant. Other possible reasons which have emerged are the large fluctuations of water level and the exposed nature of the area which has very little wind breaks. From May onwards, the water level tends to be low and cyclists regularly use the outlet structure as a route. The wetland has areas of algal growth in the shallow water.

A large amount of re-grading work was carried out on one inlet stream in 1999 discharging moderate amounts of oil and sediment. Wildlife observations at this time included: mallard ducks and ducklings, Teal, Coots, Swallows and Dragonflies. The wetland is developing very diverse habitats.

Figure 4.6 DEX Wetland August 2000

4.3 Other Ponds

Figure 4.7 Stenton Pond, Glenrothes

Stenton Pond in Glenrothes, Fife, was originally constructed in 1987 as a flood control facility and was later converted to a joint water quality and flood control facility. Monitoring has shown significant flow attenuation and water quality improvements between inlets and outlet, and sediment assessments have been undertaken. Figure 4.7 is a general view showing the pond and surrounding trees and shrubs which screen the open space. Although the photograph suggests a parkland location, housing areas are very close as may be seen in Data Summary Sheet No.5.

This pond is fully accepted by locals and the surroundings are fully integrated into the open space of the neighbourhood. There is unlimited pedestrian access to virtually all of the pond perimeter. In general the margins have extensive areas of shallow water and there are significant stands of reed beds. Stenton pond is a magnet for bird life.

Algal blooms are common in early summer and their growth is exacerbated by intermittent discharges of combined sewage at one inlet arising from a poorly operating combined sewer overflow and illegal connections. In spite of the inflow of sewage, the pond provides a very high quality amenity for local residents and the general water quality is high.

Figure 4.8 Ardler West Pond Dundee

Ardler Pond was constructed in 1999 as part of a major project in which four multi- storey buildings were demolished, and replaced by low cost units. Part of the pond's function is to control flood flows in a small watercourse, but it also receives flow from the redevelopment areas via conveyance and treatment swales. This facility was constructed in an area of open space close to low income housing, and was relatively unpopular on construction, partly because of safety concerns and also because an area of a traditional type of open space (a large open grassed area) had been lost. The temporary fencing, installed both to prevent toddler access and to protect a growing vegetation barrier is unsightly and presents only a slight challenge to young people. However, wildlife quickly colonised the area and figure 4.8, taken in spring of 2000, shows a nesting swan which reared a pair of young within a year of construction. It is anticipated that residents of the new housing will have a more benign attitude to this pond and its associated SUDS components.

Figure 4.9 Ornamental pond at LexMark factory, Rosyth

LexMark Pond was built as an architectural feature, storing water for fountains at this industrial development, in addition to SUDS and flow control functions. It is located alongside a busy road and projects a fine open image of the company. There are very few pedestrians or family based activities in the area, so few children come close. A significant drawback of the pond is that it suffers from severe algal growth in early summer when an algal mat covers the pond surface. The algae growth may have a number of causes including high nutrient loadings which may be due to the application of fertiliser within the company's property, inflow from the small surrounding catchment, or from sediments within the pond itself. It may also be due to the depth of pond, or the absence of marginal vegetation.

4.4 Detention Basins

The function of detention basins in the SUDS management train is to provide control of flows and pollutants from sites. Experience in Scotland has shown that basins are being built to serve developments of up to 150 houses, superstores, or small retail parks. The detention basins discussed here were all designed in accordance with the treatment train philosophy.

In general, the appearance of detention basins in summer is acceptable, since the banks are grassy, but in winter, their appearance is poor mainly due to vegetation die back. Almost uniformly the designers have assumed that they will have a short cut grass surface, although a few are sparsely planted with shrubs. The significant amounts of debris and sediment noted in many basins indicates that they are retaining pollutants but this detracts from their appearance. In spite of the relatively low quality of habitat that they provide, it is likely that detention basins will provide potentially important wildlife features, principally as wildlife refuges.

Linburn Detention Basin, Dunfermline

This is an excellent example of a detention basin which also has a high amenity value. It is located at a busy road junction in a triangle of land with a pylon on a high voltage electricity line. The basin serves a development of approximately 150 houses and has been landscaped with a flat base so that it has been turned into an impromptu football pitch by local residents.

In the five years of operation, no pollution incidents have been noticed and the surface is clearly safe for children playing. However, construction activity on the adjacent housing development has caused a bank of sediment to form at the inlet and this will need to be removed at some time. The high quality amenity provided and the basin's prominent location means that any malfunctioning is likely to be noticed early and action taken – due to community pressure as much as actual malfunction.

Figure 4.10 Linburn Detention Basin during a July thunderstorm

Detention Basin B – Roundabout (DEX)

This basin has been constructed in a roundabout in the DEX development, and required much inter-agency negotiation to resolve safety and ownership issues. The basin serves access roads which link the development to a motorway.

Figure 4-11 (a) Basin B in summer

The base of basin B is frequently marshy, but ponding has only been observed on one occasion. A moderate amount of sediment had accumulated at the outlet and this has continued even though construction has ceased. In 2000 it was reported that sediment accumulation was not a problem at any of the inlets, but had accumulated at the outlet, and grass and sediment partially blocked the outlet throughout the year. Oil was observed on several visits, but never in significant quantities. Tar was discharging from the east inlet on one occasion and accumulated on the rocks below the device. Even during heavy rain, the amount of water in the basin has never been more than a large puddle. The side slopes are regularly mowed, while the base is left to grow uncut.

Figure 4-11 (b) Basin B in winter

The base was waterlogged on several occasions in 2001 leading to areas absent of vegetation, which was unsightly and can hardly be considered to be satisfactory. Erosion at one inlet became noticeable with a channel appearing to the side of the inlet. Sediment which is accumulating at the outlet is probably being scoured from the areas with no vegetation within the basin, from the gullying at an inlet and fine sediments from road runoff.

Detention Basin D-M (Dunfermline)

Detention basin D-M clearly functions as designed and ready for development in the field in the background. The rich green grass is thriving on sediment from the section of road which is currently served through the inlet pipe in the foreground of figure 4.12. The accumulated sediment has raised the bed of the basin at the inlet by about 150mm and this is causing a slight pool, but the outlet is clear of debris and the gravel there has not been covered with fine material. The sediment in the basin means that it has not reached the Linburn Pond, nor the receiving water body. The grass on the sides was recently cut and most litter removed. However, there is a small amount of wind blown paper. There is also strong anecdotal evidence that wildlife use this facility and this is likely to be as a refuge location.

Figure 4.12 Basin D-M after grass cutting (above); before cutting (below)

Figure 4.13 shows a large but shallow detention basin serving a building site in the DEX development. The particular configuration was needed because of very slack gradients downstream. Some recent detention basins have been constructed with larger areas so that they have less depth for a given volume, thus avoiding the perceived dangers when the basins contain water. In these cases, builders are opting to sacrifice land to avoid the perceived risks and potential liabilities.

This particular basin has a permanently wet base and is likely to be poor as a football 'kickabout' area, reducing its usefulness to locals, while at the same time potentially having a greater potential for habitat formation.

Figure 4.13 New Detention Basin, DEX

Figure 4.14 illustrates the need for training of construction supervisors and contractors together with better detailing. The basin is in an excellent location at the entry to a new development on the edge of a rural village and has an open appearance. The detention basin receives inflow from one inlet and, once the basin is full of water, it will spill over the weir in the foreground. Unfortunately, no draindown arrangements were made and the basin has permanent water, killing vegetation and having an unsightly muddy appearance. Appropriate draindown details might have been permeable material in the bank to the right of the photograph, permitting slow drain down, or small diameter pipes. Remediation works were implemented after this photograph was taken.

Figure 4.14 Detention Basin, Balmullo

Figure 4.15 illustrates a detention basin serving a superstore during and after prolonged rainfall. Runoff from the store roof enters the pond uncontrolled, while the car parking areas drain through Formpave blocks. The basin (designed as extended detention) has an unkempt appearance since little or no landscaping was carried out. It is also relatively deep and small and to many, does not have a satisfactory appearance. However, native species are colonising the base and, from all appearances, the basin has a positive effect on water quality.

Figure 4.15 Detention Basin, Tesco, DEX during (above) and three days after (below) prolonged rainfall

Detention Basin G – Aberdour Road, DEX

This basin was completed 1998 and suffered from a blockage of the outlet. This was the only example of a serious blockage encountered during four years of monitoring of basins and notes from routine visits are included here to illustrate some of the issues involved.

Figure 4.16 Detention Basin G

The basin worked effectively throughout 1999, although sediment accumulated at both the north and south inlets, no doubt due to the large number of construction vehicles in the area at the time. Sediment which was supporting grass growth also accumulated at the outlet. Plastic sheeting was blown into the basin at the beginning of December, partially blocking the inlet and had not been removed within two months. This caused the pond to have a very untidy appearance. By Spring 2000 there were significant sediment accumulations at the inlets and outlets of the basin, leading to clogging. This sediment and construction debris was removed during the last week of March 2000, but a large proportion was left on the base of the facility or on the rocks downstream of the south inlet. The outlet became completely submerged on two occasions after heavy rain during 2000.

In 2001, sediment continued to accumulate at the outlet, on the base and in the south inlet. New houses were under construction to the west of the basin, and a water main was installed in the surrounding footpath. Debris from the construction site and litter again accumulated in the basin – plastic sheeting, a bag of cement etc. The majority of the litter in the basin would appear to be windblown and the adjacent shrubs have similar litter throughout. Ponding is occurring on the base of the basin as water is unable to flow in the low flow channel from the inlets through to the outlet. It is expected that this ponding will eventually lead to die-back of vegetation and subsequent erosion of the base and this may be a serious long term problem.

The basin was found to be full of water one day in October 2002 and on a visit three days later - no rain over the weekend - the level had dropped ~ 0.5m and the inlet structure was just visible. By December the whole of the southern inlet structure and the tip of the north-western inlet were visible. The outlet structure remained submerged for the rest of 2002 showing that the outlet was once again blocked as in 2000.

4.5 Swales and Roadside Detention Basins

Roadside swales represent a radical paradigm shift in the philosophy of drainage planning in the UK because they encourage above-ground storage close to the point of runoff (the road). The runoff is visible while at the same time being in a constructed system. Two approaches to swales have been adopted to suit different building densities. Previously these were both termed 'swales', but to avoid confusion, the terminology should be separated as follows:

- Roadside detention – small detention basins linked with small diameter pipes and having raised outlets. These systems are designed for detention, not for conveyance.
- Swales – larger structures with multiple lateral inlets and normally incorporating an element of conveyance of flows.

Roadside Detention Basins

Roadside detention basins have been installed in many new developments in Dundee, frequently in relatively high density developments (for example social housing) and the City Council has generally assumed maintenance responsibility. The council has adopted a policy that the runoff should be visible while at the same time being in a constructed system. An example in the Ardler area of Dundee is shown in Figure 4.17.

Figure 4.17 Roadside Detention Basins in Ardler, Dundee

Roadside detention basins have been constructed on either public or private property. At the construction stage, the swale may be grass seeded or turfed, the latter having the added advantage of rapidly producing a surface which is erosion resistant. A number of types of inflow arrangements have been used and depressed kerbs have been adopted as standard. The most common type of outlet is via a chamber constructed from manhole rings which has a raised grating cover. The chamber has a high level outlet, enabling considerable redundancy to be built in. Figure 4.17 is an example of a roadside basin built in the service margin of a medium density housing development in Dundee, while the swale in figure 4.18 also serves road drainage but is on private property.

Figure 4.18 Roadside Detention Basin on Private Property

Roadside detention basins produce an undulating appearance to the road margins and are relatively easily maintained. Surveys have shown that there is little resistance from residents even though they are periodically full of water. Figure 4.19 shows two further examples.

Figure 4.19 Roadside Detention under different weather conditions

Swales

A number of large grassed swales have been constructed at DEX and these are typical of swales on more commercial developments and where space is not at a premium.

Figure 4.20 Swale at DEX

The overall appearance of the swales investigated has been excellent, but there has been little construction close by and the contributing areas are not yet complete. Figure 4.20 has been included to highlight the effect of the retention of permanent water in some swales leading to a small channel forming. Either under-drainage or a steeper gradient is needed to solve this type of problem.

Swales appear to be restricted to particular areas within Scotland and it is suspected that this depends on local preferences and willingness to adopt rather than, for example, land value, climate or ground conditions. There are distinct differences in preference for different SUDS types. For example, filter drains have become popular in Aberdeen and surroundings, swales in Dundee and permeable paving in the Lothians.

Figure 4.21 Conveyance Swale in Ardler, Dundee

A few conveyance swales have been found in Scotland and an example is shown in Figure 4.21. This system conveys a permanent stream in a drain below the swale which has been designed to convey high flows approximately ten times per year.

The final image in this section shows an excellent example of SUDS in a retail/ commercial development. Surface water from each of the six sites of the development drains to soakaways, with excess flowing overland via swales, one of which can be seen in figure 4.22. This arrangement has permitted maximum flexibility within the development through the very cost-effective drainage which avoided the installation of storm sewers.

Figure 4.22 Swale at Dundee Medipark

4.6 The Public Perception of SUDS

A series of social perception surveys in areas with SUDS ponds were applied during the spring and summer of 2002 at:

- Clayton Le Woods, and Kirkby in Lancashire;
- Coy Pond, and Alder Pond, in Bournemouth;
- Brookfields Park in Worthing ;
- Emerson's Green and North Common in Gloucestershire.

All sites studied in 2002 were in England to meet the requirements of the funders but the results mirror those obtained in Scotland in 2001 and, since they relate to ponds, are considered to be applicable. There was an attempt to reach every house at each site which either had direct access to the pond or that was located close enough to ensure that residents were aware of the existence of the pond. However, only about one third of the householders in each location took part in the survey. Roughly half of the householders were absent, and some of those who answered their doors were unwilling to participate. Second attempts were made at all sites to question householders who were unreachable in the first instance. In total, in each area, around 60% of the householders who were approached agreed to participate in the surveys, which was an expected response rate.

Figure 4.23 Highly valued wildlife in SUDS ponds (Dunfermline)

4.6.1 Overview of Public Perception Results

Overall, attitudes to SUD ponds were more positive than attitudes to swales, as evaluated during previous work by the author (Apostolaki et al 2002). Although the flood prevention function of swales was appreciated, the benefits from ponds were more obvious. The attraction of wildlife to the ponds, the increase in the amenity and recreational value of the surrounding areas, the improvement of the landscape, and the environmental way of treating runoff, all played an important role in achieving positive attitudes towards the systems.

4.6.2 Recommendations from Perception Surveys

A number of recommendations are based on the results of the public perception surveys. It should be understood that the recommendations are derived from perceptions of the schemes' appearance, design characteristics, and maintenance issues in order to enhance their acceptability within residential areas.

Aesthetics play a very important role in formulating public attitudes. The more aesthetically pleasing a SUDS pond is, the more it is welcomed. Even the perception of sensitive matters such as safety can be influenced by the aesthetics of the schemes. In general, people consider a pond to be aesthetically pleasing when it resembles a natural pond as much as possible. Non-steep slopes around the pond in combination with rich marginal vegetation serve a double purpose, acting both as a safety barrier reducing accessibility for young children and also improving the appearance of the pond. Steep slopes can be proven very dangerous especially for young children and the elderly. Many participants who expressed concerns over safety made a request for the introduction of natural barriers around the ponds as a safety precaution that would at the same time improve the pond's aesthetics. The introduction of warning signs around the pond, mainly signs warning of deep water, was proposed by many householders.

Figure 4.24 Pond serving a housing area (Kirknewton)

However, a number of respondents pointed out that the introduction of warning signs could be a drawback since it underlines the non-natural character of a pond.

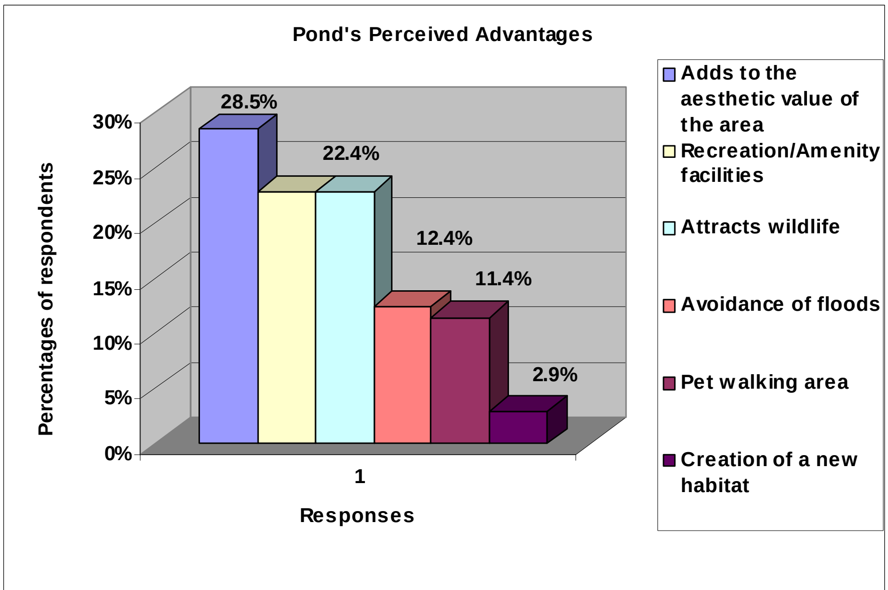


Figure 4.25 Perceived advantages of a well-established pond (Coy Pond)

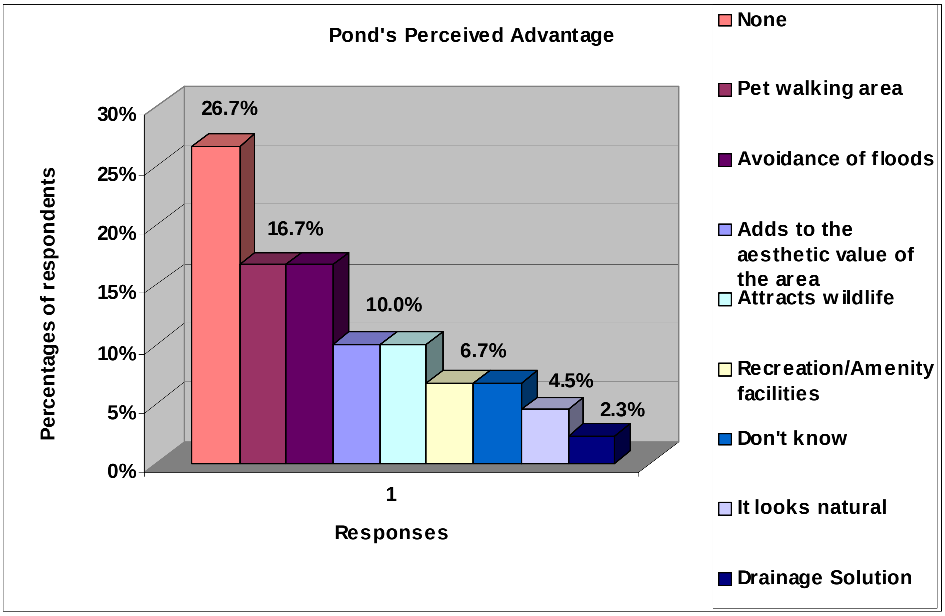


Figure 4.26 Perceived advantages of a newly-established pond (Kirkby)

The introduction of native vegetation for the area is recommended, as it will make the ponds appear to be more natural and at the same time reducing maintenance requirements. The attraction of wildlife is seen as being essential, particularly indigenous species. The presence of wildlife and rich plant life in a SUDS pond can be of crucial influence in ensuring positive public opinion. Explanatory boards providing information on the wildlife and plant life present in the pond have always been welcomed by the public in all areas where they have already been introduced. People consider them as educational for young children and consequently their use is recommended.

Figure 4.27 Play area close to pond (Telford)

Several recommendations in relation to the surroundings of ponds were made by householders. A frequent recommendation was the introduction of benches and picnic tables, overlooking ponds. The creation of children's playgrounds and walkways close to pond was also suggested as possible improvements. Even the introduction of fish was recommended by several respondents wherever applicable. The transformation of the ponds into amenity features is increasingly important for local communities.

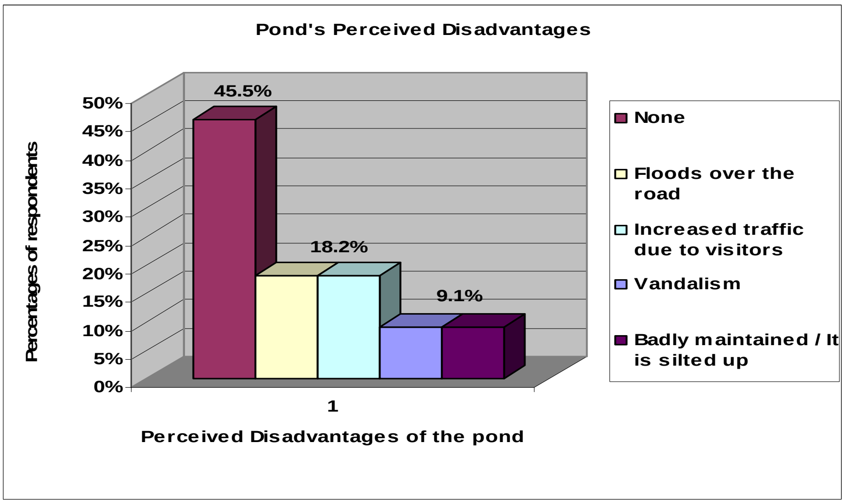


Figure 4.28 Perceived disadvantages of a well-established pond (Coy Pond)

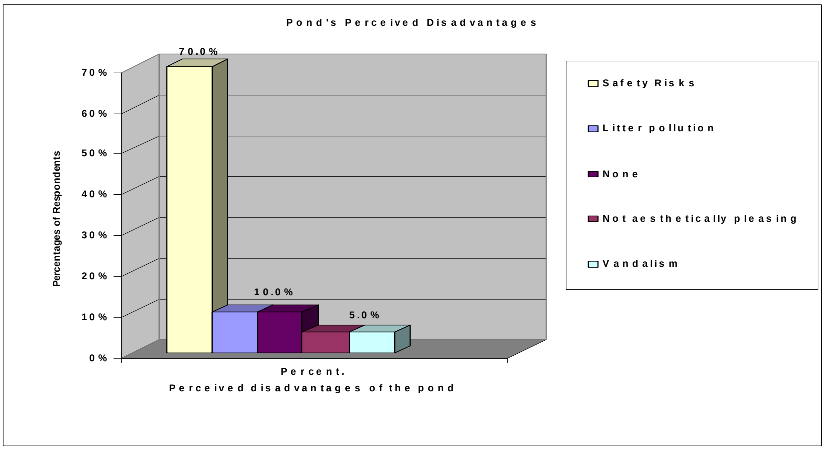


Figure 4.29 Perceived disadvantages of a newly-established pond (Clayton Le Woods)

4.6.3 Operation & Maintenance

Maintenance was a major public concern in all areas where SUDS are in place. Litter, pollution and silt accumulation in the ponds, were perceived to be the main problems involved with SUDS. There is a need for regular cleaning of inlets and outlets of the ponds to avoid blockages as well as for silt removal. Regular care of the surrounding plants is also needed to ensure that they are properly supported and not dying out. Maintenance responsibility is a sensitive issue, which must be resolved so as to enhance public acceptability.

4.6.4 Education Strategies

The research results show that public information and awareness are closely linked to public acceptability. In areas where residents were better informed about the purpose of SUDS ponds, the overall perception of the systems was much more positive than in areas with little information. Information needed includes the reason for their installation in that particular area, the advantages of SUDS compared to traditional drainage, and their function and performance. According to the majority of participants in all areas, the provision of relevant information is a task which should be undertaken by the developers of the site who should inform the householders about the existence of SUDS in their local area. There were particular comments that information should be provided in advance of the householders purchasing their houses. Additionally, the local Councils could also inform the public on SUDS related issues and promote the application of the systems within residential areas. This could be achieved by educational campaigning which would provide householders with information and would also involve public participation, such as open day activities around the local pond.

4.6.5 Summary of Recommendations

All recommendations from the public perception survey are listed in table 4.1

Table 4.1 Design recommendations from perception surveys

Design Characteristics	Make the pond as natural looking as possible
	Improve marginal vegetation
	Introduce more vegetation (native preferably)
	Introduce more wildlife or protect the species of wildlife already existing in the pond
	Make shore slopes softer and introduce natural barriers
	Introduce signs warning of deep water
	Introduce benches and picnic tables
	Create children's playgrounds
	Create walkways
	Introduce fish
Operation & Maintenance	Remove litter more frequently
	Remove silt
	Clean the inlets & outlets of the pond to avoid blockages
	Maintain marginal vegetation
Education	Provide pre-purchase information to householders
	Application of educational campaigns even when the pond is already established in the area.

4.6.6 The Perception of Safety

Questionnaire participants were asked to compare the perceived safety risk of their local SUD pond with other safety risks present within urban environments. Although the ratings given were slightly influenced by the aesthetics and the performance of the scheme, the overall perception did not demonstrate big differences. In all areas, a busy main road was considered to be the most dangerous hazard to live close to, while a natural pond and a SUDS pond were classified as the safest features of all. Residents in areas with well-established ponds tended to be fully aware of the risks posed by open water – yet saw these risks in a positive light. Those participants concerned over the pond's safety tended to accept the risk, with 45% of them rating the SUDS pond as safe enough to live close to. Results from two different types of area are presented in Figure 4.30.

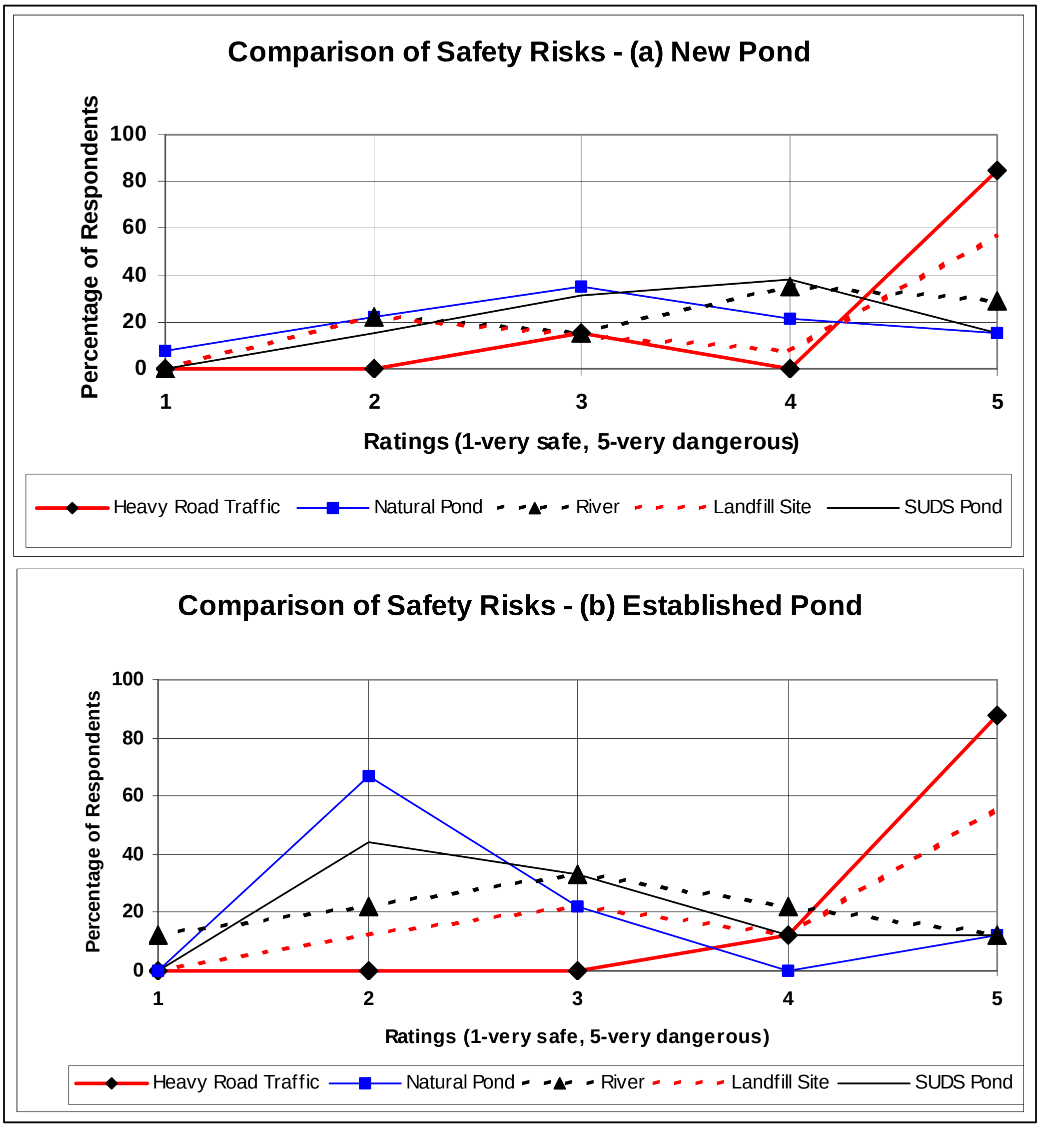


Figure 4.30 Comparison of Safety Risks

5. POND DETAILING

The purpose of this section is to draw together the key issues learned from the monitoring of ponds undertaken by the monitoring programme. Observations on pond systems are included throughout the report, but in particular in the following sections:

PART A	Section 4	The amenity of above ground SUDS systems
	Section 10	Pond sediments and sediment quality
PART B	Summary sheet 1	Clayland Pond
	Summary sheet 2	Newbridge Pond
	Summary sheet 3	Hallbeath Pond
	Summary sheet 4	Linburn Pond
	Summary sheet 5	Stenton Pond

5.1 Pond Components

Pond inlets

A wide variety of inlets are used and examples each of small and a large inlets are included in figure 5.1. In general it was clear that the designers were aware of good practice and the inlets were appropriate for the locations, where major flows and velocities were expected, inlet structures tended to be constructed from concrete. In contrast, most small inlets where erosion control was not a significant issue, were formed by pipes protruding from the sloping bank. Erosion around inlets was rarely noted indicating generally appropriate engineering detailing, examples of deficiency generally being rectified at the end of the construction maintenance period. Overall, there was no evidence of recurrent problems arising from poor inlet detailing.

Figure 5.1 Typical Pond Inlets (equally applicable inlets are shown in figure 6.1)

Pond Outlets

A variety of outlet control devices was found on pond systems. Many smaller pond and detention basin controls use Hydrobrake flow control devices which have the advantage that they offer control of relatively small flows with a larger opening than would be the case with a simple pipe. An example of a stage discharge curve for a Hydrobrake is shown in site Section B, summary sheet 8. Flow control devices are generally located in manholes to avoid vandalism. Examples are given in figures 5.2 & 5.3.

Figure 5.2 Underground pond outlets – (a) slotted standpipe pipe; (b) Multiple 90^0 Vee notches

Figure 5.3 Exposed pond outlets using Hydrobrake (a) and Narrow vertical slot (b)

Barriers

Most ponds and many detention basins which have been constructed in the past five years have surrounding fencing. The need for fencing is driven particularly by the developers and arise from considerations of saleability and safety. This is in spite of the frequently expressed view by householders that safety risks posed by ponds are of less concern than, for example, a busy road or a landfill site (for more information see section 4.6).

In general, if and when installed, high fencing is erected for the immediate post construction phase of certain housing developments to form a screen and to protect barrier planting. The choice of erecting high fencing is made by the developers and some appear to have adopted a policy that all detention basins should have high fences, while others avoid this type of barrier. Planted barriers are successful where space is available, and many examples of impenetrable vegetation barriers are to be found. At locations where particular vandalism is expected two parallel temporary fences are erected to protect the long term barrier planting. The causes of failure of barrier planting have been due to vandalism and to the failure of one pond to maintain water level – due to leakage. Some fencing arrangements are shown in figure 5.4.

Figure 5.4 Planted and erected barriers at three ponds and one detention basin (bottom left).

Side slopes

All SUDS ponds constructed since 1997 pay strict regard to above and below water slope guidance given in CIRIA (2000). Safety has been a prime design and siting consideration for most ponds and underwater slopes appear to comply with the need for an under water platform for reed growth and to form a safety barrier.

6. DETENTION BASIN DETAILING

Detention basins have proved very popular with developers of medium sized sites and a wide range of examples can be found. Detention basins are used for residential areas because they satisfactorily address the pollution risks arising from most residential developments, and are equally effective to ponds for the control of high flows. Observations on detention basins are included throughout this report, but in particular in the following sections:

PART A	Section 4	The amenity of above ground SUDS systems	
PART B	Summary sheet 8	Detention Basin D/M	(Dunfermline)
	Summary sheet 9	Detention Basin G	(Dunfermline)

6.1 Detention Basin Components

Detention Basin Inlets

The inlets to many detention basins have become problematic due to the amount of construction stage runoff being washed off sites. Two main problems have been noted ;

- A rise in ground level close to the inlet due to the deposited sediment, causing submergence.
- Passage of fines – frequently cement rich material passes for a distance and occasionally through the low flow channel of the basin.

A change in design approach is suggested which will create a construction phase sedimentation zone. An increased drop at the inlet is likely to be required to ensure that detention basins function properly throughout their design life.

Figure 6.1 Detention Basin Inlets

Detention Basin Outlets

Most outlets from detention basins serving small areas have relatively small diameter openings which have a propensity to blockage unless well protected. Fully submerged outlets are uncommon, although in a number of arrangements, the outlet pipe is completely covered by rock armour or gabions. An example of a protected outlet may be observed on a swale in figure 7.2.

The fundamental principles of outlets are well known to design engineers. Unfortunately, several examples of blockage or potential blockage have been found and an example is shown in figure 6.2. It is apparent that insufficient thought is often given to access for blockage clearing. For example, manholes become surcharged making it impossible to clear a blockage. A further example is given in summary sheet 9.

Figure 6.2 Detention basin outlet flush with the ground and likely to block with grass cuttings.

Detention Basin Side Slopes

The guidance on side slopes in CIRIA (2000) is normally followed and figure 6.3 illustrates common detention basin solutions. Fencing is only erected where there is permanent water or the basin is closely associated with housing.

Figure 6.3 General views of detention basins giving examples of appearance and access arrangements

Maintenance of all of the basins illustrated is currently limited to grass cutting and repair of fencing where appropriate.

Figure 6.4 Detention basin constructed originally as a pond and later converted to a detention basin by infill with gravel

The basin shown in figure 6.4 serves a small development of social housing. Originally constructed with a permanent pool, local concerns led to it being filled with gravel to prevent access to the water. A very high volume of storage is provided and the basin is obviously operating satisfactorily with little or no maintenance.

6.2 Improving Detention Basin Detailing

Revisions are recommended to inlet detailing principally to avoid any problems occurring with the deposition of coarse sediments close to inlets. Comparisons should be made with the approach used for ponds where a specific zone for sedimentation should be incorporated. Experience has shown that a zone at the inlet for deposition is at least as important at detention basins as for ponds. Most detention basins built in Scotland are immediately downstream from housing or retail developments where there is little control of the polluting effects of building activity, in particular the amount of mud or loose earth which potentially can wash downstream during rainfall. Since material washed out of a building site will in most cases reach the detention basin prior to the pond, should one be required, most of the coarse sediment will deposit in the basin and not the pond. Best practice recommends the protection of storage during the construction phase, or re-instatement afterwards.

Current guidance does not require a specific zone for this sediment accumulation, and this has led to the build up of sediment which has been observed. Two alternative detailed modifications are proposed;

- The inlet should incorporate a greater drop to accommodate sediment accumulations. The need for this is illustrated in figure 6.1, a basin where the inlet pipe has a good gradient and the drop at inlet could have been significantly greater. The area immediately around the inlet should be constructed to facilitate the removal of material.
- A sacrificial zone for sediment accumulation in detention basins should be considered. This approach acknowledges that significant amounts of sediment will be trapped in the detention basin, and the volume should be increased appropriately.

The sediment itself has only low level contamination, and eventual grassing over within the area of the basin is an appropriate disposal solution. This approach is particularly appropriate where the basin has multiple inlets which would complicate the removal of the material required in the approach above. Once the construction phase is completed, regrading of the sediment surface would be all that would be required.

Access to the inlet area is critical to facilitate removal of sediment. However, should the second option above be adopted, only very limited access with, at the most, light machinery will be required and access should not be seen as being particularly critical when finding locations for detention basins.

Visual evidence from one of the treatment train sites in Dunfermline suggests that detention basins can trap hydrocarbons along with sediments. Accumulations of hydrocarbons are noted at one basin serving a length of dual carriageway and there is no evidence of the material being carried into the retention pond downstream. This observation is not based on sample analysis, however, the visual evidence is that the hydrocarbons are attached to road grit which is retained in the basin. Prolific vegetation growth is observed in summer.

It can be argued that extended detention basins may give sufficient pollutant removal in a number of locations where retention ponds are currently recommended. This comment is based principally on interpretation of visual observations with some sampling data. The inflows to the retention pond on one treatment train system have low pollutant levels and, since the catchment is being developed for housing, severe pollution will only occur accidentally. In view of the removal of sediment at the detention basins, sufficient removal of pollution may occur at the basins to reduce or even eliminate the need for a retention pond.

There is no evidence of widespread blockage of detention basin outlets, although one example of persistent blockage has been noted. Outlets should stand proud of surrounding soil and vegetation where possible to prevent blockage during vegetation maintenance (see figure 6.3).

Sacrificial detention basins protecting the permanent SUDS structure have been used successfully for construction runoff at a number of locations. One example of very good practice was noted at Brightons near Falkirk, where two end of pipe systems were constructed for a housing development discharging directly to a small stream. The conventional drainage system terminated in a flow splitter manhole which permitted flow to the construction phase basin until building work was substantially complete. At that time a plug in the permanent outlet was opened to permit long term runoff to flow into the permanent basin which by that time had a very good growth of grass.

Some dry weather ‘channels’ had noticeable sediment accumulations within 4 years. This was even with no construction activity. Examples are given in figures 4.11and 4.12.

Planning and space constraints have led to exceptionally deep detention basins. While these are not dangerous, they are generally unsightly (see figure 4.15). Changed approaches to open space requirements would correct this issue.

The impression was formed that vegetation cutting at detention basins has no impact on water qualities. This hypothesis will be tested in a currently ongoing monitoring project.

7 SWALE DETAILING

In many ways the incorporation of swales into drainage systems has been one of the most innovative aspects of source control SUDS in Scotland. Most of the swales noted serve small sections of road and the inflow is at a number of discrete points rather than continuously over a length. Consequently, many are in effect small detention basins. Swales are considered in a number of sections of this report:

PART A	Section 4	The amenity of above ground SUDS systems
PART B	Summary sheet 13	Emmock Woods Dundee
	Summary sheet 14	West Grange Dundee

7.1 Swale Components

Swale Inlets

One great advantage of a swale is that inflow can be at a range of points including lateral inflow. Many examples of inflow at discrete points have been noted, this arrangement being necessary in suburban areas. Some examples of swales with lateral inflow may be found on access roads to commercial and retail developments.

Figure 7.1 Swale inlets through depressed kerbs (above) and rock protected pipes (under steps on right)

Frequently space for swale installation is limited and kerbs are needed to protect the road edge and prevent vehicles running on to the soft swale. Consequently, lateral inflow is relatively rare in Scotland.

Several developers elect to install swales in preference to detention basins for two principal reasons;

- ➢ The detention basin is seen as a potential hazard since periodically it will contain a significant amount of water.
- ➢ As a result of the above point, the developer feels obliged to erect a high fence around detention basins and this detracts from the amenity of the area.

These house builders lay great emphasis on the appearance of their developments and swales have become an integral part of some housing estates.

Figure 7.2 Swale inlets a) through Clearway units (no longer used due to frequent blockage); b) lateral inflow.

Swale Outlets

Most swales have raised outlets which cause a pool to form, together with a grating through which the outflow drops vertically.

Figure 7.3 Swale Outlet arrangements a) small diameter pipe under rock protection in foreground; b) Planter placed to conceal grating on raised outlet to small roadside swale; c) Raised outlet at lower end of stepped swale illustrated in figure 7.1.

Figure 7.4 Conveyance swale arrangements

A relatively small number of conveyance swales (to carry flow from one location to another and not having appreciable storage volume) are to be found in Scotland. Examples at two locations in Dundee are shown in figure 7.4.

8. FILTER DRAIN AND INFILTRATION TRENCH DETAILING

8.1 Section Overview

Below ground SUDS systems have a strong attraction to developers mindful of increasing pressures on land costs and the need to increase housing densities. In many small sites, there is little possibility to incorporate any consideration of amenity in developing a SUDS solution, apart from aesthetically pleasing car parks. Ideally, systems are required for which any land take is no greater than for traditional drainage solutions. Long term responsibility should normally be of little concern to the developer which should pass on maintenance to the adopting authority. Unfortunately the lack of clear long term standards for adoption and maintenance responsibilities have been major problems for developers but this has been resolved with the passing of the Water Environment and Water Services (Scotland) Act 2003. In the past, developers have opted for below ground systems which can be easily adopted.

Following the introduction of the SUDS policy, below ground systems have become widespread. The database survey undertaken in 2001 (Wild et. al. 2002) showed that they constitute the majority of systems which have been installed in Scotland and nearly 70% (by number of units) of all SUDS systems in Scotland are filter drains or infiltration trenches. Unfortunately, although well designed and maintained systems appear to work well, monitoring has revealed many instances where poor design or construction practices have produced systems which do not perform satisfactorily. It is particularly noticeable that minor detailed improvements might be made which would make systems relatively easy to inspect and maintain.

The evidence collected to date suggests that underground systems which are badly designed, or which have been compromised during construction phase, provide little or no attenuation or treatment of pollutants. While SEPA and the Water Authority may jointly have powers to remediate badly working systems after they have been built, the problems may not be sufficiently closely identified to enable a remediation solution to be developed. This means that considerable effort may have been expended to produce drainage solutions which have a reduced environmental impact only for them to be compromised by poor concept or maintenance.

This section has been included to inform discussions on the performance of underground SUDS by presenting as much information on the subject as possible. Two phases of investigations have been undertaken:

- Detailed investigations at three filter drain sites.
- General investigations into fifteen below ground sites around Eastern Scotland.

Some suggested improvements are included, although the research which is informing this work was ongoing at the time of writing.

8.2 Detailed information

Detailed information on three filter and infiltration systems is given in Appendix D which contains performance summaries. The sites are:

- Summary sheet 10 Lang Stracht Filter drain on a 750m long stretch of busy urban road
- Summary sheet 11 Broxden Filter Drain serving housing estate
- Summary sheet 12 Walker Dam Filter Drain serving housing estate

8.3 General assessment

A total of fifteen sites were investigated in detail to understand their performance, and flow and load monitoring was undertaken at three, with a further three sites in 2003. Appropriate developer, Water Authority and SEPA personnel were contacted for information on systems' concepts, record plans and for other paper information. All sites were inspected by manhole entry and CCTV where possible.

The general assessment led to the following observations:

- Most were end of pipe systems and more than 60% discharge directly to local watercourses.
- Construction details of a number do not match record drawings.
- Several were patently poor designs concepts which were unlikely ever to work as SUD systems; out of eleven, five have little chance of removing pollutants and out of twelve, three are unlikely to attenuate flows.
- A number have been installed to permit development on the periphery of established towns where sewerage capacity is limited and drain to public sewers.
- Anecdotal evidence indicated that later systems were better conceived and executed, reflecting the need for training / education of all parties involved in implementing SUDS.

Initially, fifty sites were considered for detailed examination, but retrieving site information from authorities, owners and contractors proved to be very difficult. Most of the information available was from very recent sites and information on more mature sites was very rarely found. In many cases, information was obtained only after several weeks of enquiry and at times the information was not supplied at all.

8.4 Main Findings Relating to Filter Drains and Infiltration Trenches

The extremely diverse nature of the systems examined made generalisation difficult. However, a number of points may be made.

Bad practice/ design

- Many systems had been put into service before construction was terminated. Systems had obviously quickly silted up and now do not operate properly. Only detailed investigations can reveal the extent of malfunction and this is an inherent problem of this type of system.

- Some of the more mature sites were designed with low confidence in their functionality and this lead to wrong design. For example, throttles were not installed due to a lack of confidence in the ability of the throttle to operate effectively in the long term, or for fear of blockage. The result has been a number of installations where the storage volume cannot be utilised effectively. **See figure 8.2.**

- Some systems were installed in locations with extremely low permeability rates and these systems merely act as large storage tanks. This is not necessarily a problem where the filter is able to drain down properly. However, at least two were below the water table and could not empty between events. The most that can be expected from these is the removal of coarse sediment. **See figure 8.3**

- One trench was located at the low point of a landscape planted area with high sediment erosion and this led to a rapid silt-up of the trench.

- Trapped gully pots were installed at a number of sites alongside highways, but cleaning was found to be problematic principally due to bad detailing. Cleaning is undertaken very infrequently (the average appeared to be once per 2 years) leading to blockages of the gully outflow into the filter drains. **See figure 8.2.**

- Cleaning techniques were unsuitable for trapped gully pots. This included high pressure flushing of the outlet resulting in mobilising of accumulated particles and extremely high turbidity readings at the system outlet after cleansing (found at Lang Stracht).

- Offlet kerbs are a common detail and these were found to be blocked at several locations. Broken offlet kerbs were observed at two locations.

- Road sweeping is considered to be unsuitable for roads with offlet kerbs. During road sweeping fine particles are pushed into the offlet kerb where they accumulate and compact, which quickly leads to blockages. **See figure 8.9.**

- One commonly used detail has been to terminate the outlet from trapped gullies in the filter media. Logically the trap should retain both suspended and floating matter. However, this detail has been found to block relatively quickly, particularly with leaves and is no longer used. At Lang Stracht in Aberdeen, all 40 gully outlets became blocked within three years.

Good Practice/ Design

- A number of designs appropriate to soils of low permeability have been found.
- Linear filter drains receiving water over the road edge is used frequently on motorways and trunk roads. This detail is being used on access routes into housing developments and industrial/ commercial areas but is not appropriate for higher density developments.
- A number of designs for end of pipe filter drains have been developed for use in soils of low permeability which include the facility for jetting. Flow monitoring shows good flow attenuation. **See figure 8.6 and Data Summary Sheets 11 & 12.**
- Many infiltration trenches use the upper soil layer for disposal of water and it may become waterlogged at times, although no examples were found where this created problems.
- All filter drains and infiltration trenches should have a sediment sump at the inlet. This sump must be in an easily accessible location for suction equipment.
- Most of the more recent systems have been sized to incorporate the treatment volume Vt, and incorporate flow control devices to throttle the flowrate and ensure that the storage volume is used.

	Location	To Watercourse? Sewer?	Do drawings match construction ?	Reason for not working		Does the SUD system remove pollutants?	Does the SUD system reduce flows?
				Maintenance?	Design?		
1	Queens Gate	W/Course	Yes	Fully blocked	No problem	No	No
2	Glencarse	W/Course	No	No problem	Uncertain	Uncertain	Probably
3	Broxden	W/Course	Yes	No problem	Inappropriate	Yes	Yes
4	Spine Road	W/Course	Yes	Standing water	No Throttle	Yes	Yes
5	Woodend	W/Course	Yes	Catchpit full	No problem	No	No
6	Walkerdam	W/Course	Yes	Nearly blocked	No problem	No	Yes
7	Westhill Old	W/Course	No Records	Nearly blocked	No throttle	No	No
8	Westhill New	W/Course	No	No problem	No problem	Yes	Yes
9	Hatton	W/Course	Yes	Catchpit full	No problem	Yes	Yes
10	Lang Stracht	Sewer	Yes	Gullies blocked	No problem	No	Yes
11	NoSWA Car Park	Sewer	No Records	No problem	No problem	Yes	Yes
12	Kirkhill	W/Course	Yes	No Data	No Data	No Data	No Data
13	Findochty	Sewer	Yes	No Data	No Data	No Data	No Data
14	Great North Road	No Data	No Records	No Data	No Data	No Data	Probably
15	Pitreavie	No Data	No Records	No Data	No Data	No Data	No Data

Table 8.1 Overview of Filter Drain Performance

Table 8.1 presents a subjective overview of fifteen of the systems examined. Assumptions on performance have been made following site inspections and interpretation of details. ‘Sewer’ indicates either combined or surface water sewer.

Typical Locations and Details of Filter Drains

The site at Lang Stracht, Aberdeen

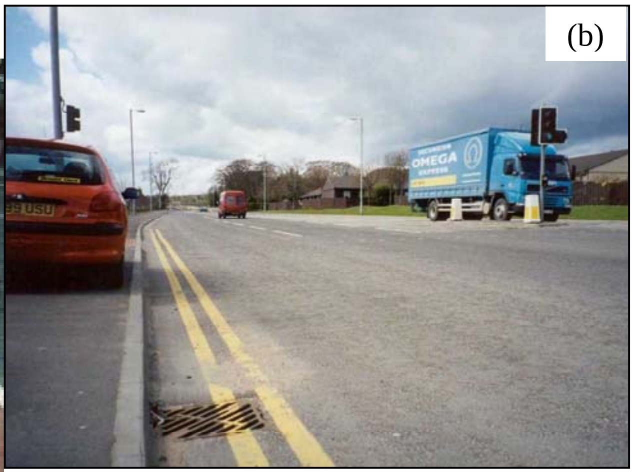


Figure 8.1 Lang Stracht Filter Drain Site – 750m long draining all of the highway and parts of some side streets.

This site has been studied in detail for two reasons. Firstly it is in a relatively dense urban area where the Local Authority and Water Authority both have interest in the system, and secondly because the Council specifically requested that studies should be undertaken since problems had occurred on some sections of the road reconstruction. Flow and load studies have been undertaken, and, of the 25 gullies which convey runoff through which runoff enters the filter material, 10 were found to be blocked resulting in overpassing of flow as illustrated in figure 8.1 (a). See also site summary 10 in Appendix D.

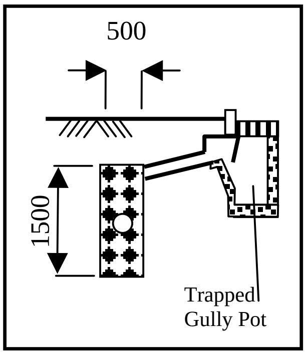


Figure 8.2 Gully Pot Detail

The gully pot detail used at Lang Stracht is shown in figure 8.2. This detail is quite acceptable in concept, but, on inspection after two years of operation, the connection between the gully outlet and the filter media had become blocked by leaves. A very inexpensive change to this detail so that it can be jetted would make this system perform satisfactorily.

Jetting of filter drains is problematic since a significant amount of pollutants are released. Jetting is necessary to maintain the hydraulic performance of the system and is a process which remove leaves and paper in addition to the sediments which constitute the contaminants requiring to be removed. The water used for jetting should be prevented from being discharged to the environment, but the Lang Stracht study also demonstrates that there may be continued carry through of contaminants for a period after jetting and caution should be taken in undertaking the jetting process. Further research in this field would be useful.

Figure 8.3: Example of a Filter Drain

One common filter drain arrangement at the lowest point of a surface water system is illustrated in figure 8.3. It is at the edge of a medium sized development of 30 houses on a relatively cramped site. The SUD system adopted at this site is an arrangement of twin 400mm perforated pipes and was installed at an early stage of the implementation of the SUDS policy in Scotland. The installation has been conceived in the belief that there may be some exfiltration through the perforations, but clearly this would be difficult since the stream (by the trees in figure 8.3) is only slightly below ground level. In addition, soil conditions were such that there is little potential for infiltration. As a result, this system merely acts as a large diameter sewer in which some settlement of coarse solids may occur. Typical general details of this type of arrangement are illustrated in figure 8.4.

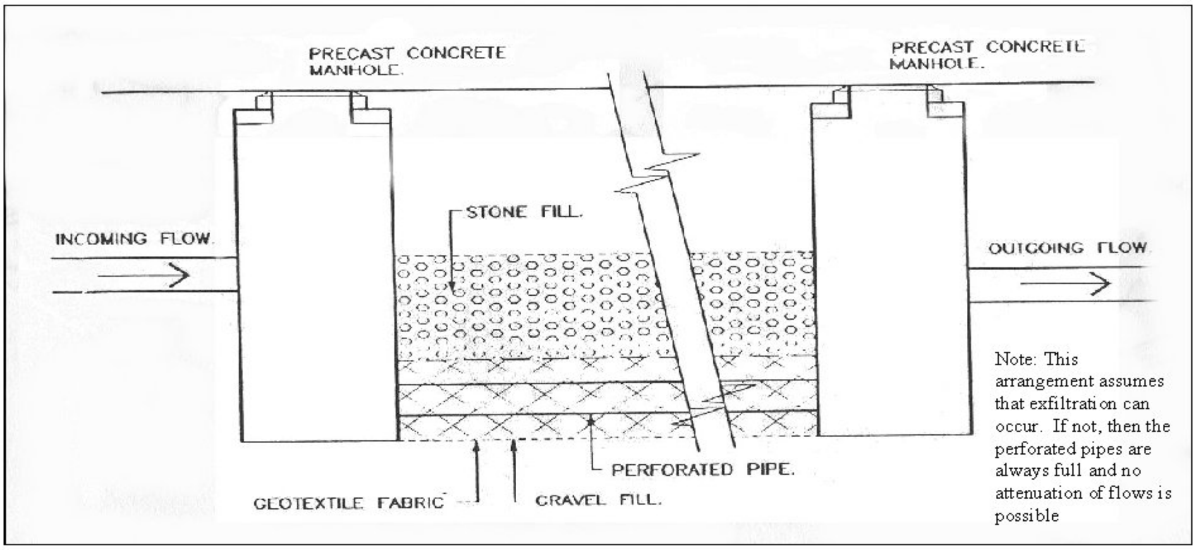


Figure 8.4: Commonly used Filter Drain Detail – But cannot perform as designed unless groundwater table is below manhole bases and the outlet pipe has a throttle.

An alternative, and more successful soakaway system arrangement is illustrated in figure 8.5. This is also located downstream from a conventionally drained suburban development (of around 24 houses) where the outlet is to a very small watercourse. In this case there is a reasonable chance of longer term acceptable performance, firstly because the SUD system was incorporated into the plans earlier and this ensured the system was shallow and not below the water table, but also since there are three flow routes from the inlet manhole, should the inlets become blocked. The inlet detail is also illustrated in figure 8.8.

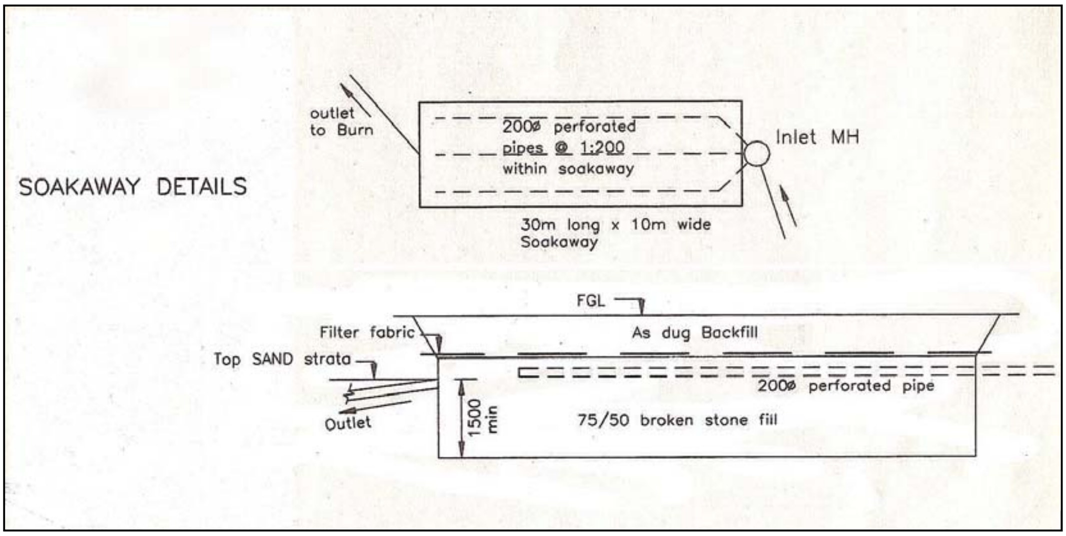


Figure 8.5: Shallow Soakaway Arrangement – Relies on being above water table

Another effective solution to this common end-of-pipe SUD system is illustrated in figure 8.6 which shows a filter drain/ filter bed at the end of a pipe from a development of fifteen houses. Water quality issues are addressed by the flow having to filter between the inlet and outlet pipes. The inlet is protected by a sump which traps large debris, and there is an overflow which might be monitored if the system malfunctions, although there is a strong preference that this should be deleted so that, when blocked, the system will back up and flood, thus causing nuisance which will then be rectified. Both perforated pipes run the full length of the filter and are capped, the upper pipe at the downstream end and the lower pipe upstream. The caps are removed for maintenance. A drawback of the arrangement shown is that it does require a greater difference in elevation to operate correctly.

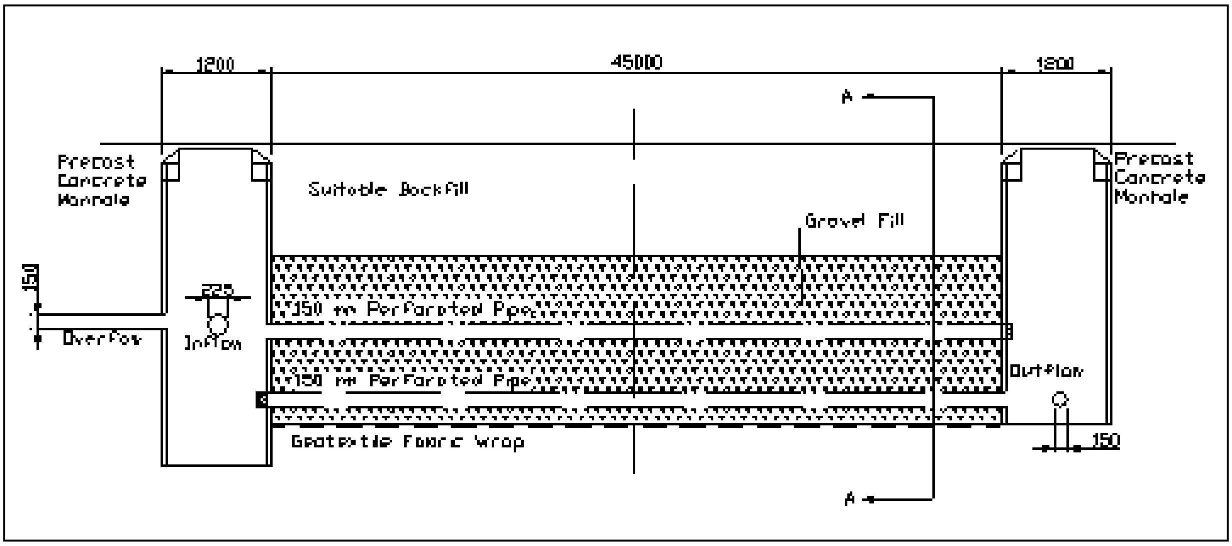


Figure 8.6: Filter Drain/ Filter Bed

Figure 8.7: Blocked Perforated pipe at Inlet to Filter Drain/ Filter Bed

Figure 8.7 illustrates the inlet to a filter drain perforated pipe and the field notes are reproduced here for interest; '*Despite (or it could be argued because of) the design shown in figure 8.6, the inlet sump was filled with sediments and organic matter, and the inlet was partially blocked as shown in figure 5.6. There was also an accumulation of fine particles in the sediment trap at the outlet of the trench resulting in highly turbid outflow when slightly disturbed (see figure 8.12).*' This example clearly shows the importance of maintenance and good design to ensure performance between maintenance activities.

8.5 Blockages to Filter Drains and Other Underground SUDS

The location illustrated in figure 8.2 is one example where the soakaway was connected prior to completion of construction and this led to the subsequent silting-up of the sediment trap and filter drain which was approximately 50% full of gravel and boulders. Further examples of blockages which were relatively commonly observed are illustrated in figure 8.8, but a more extreme example of this problem is shown in figure 8.9 where the inlet to the trench is completely blocked and all flow bypasses the treatment device.

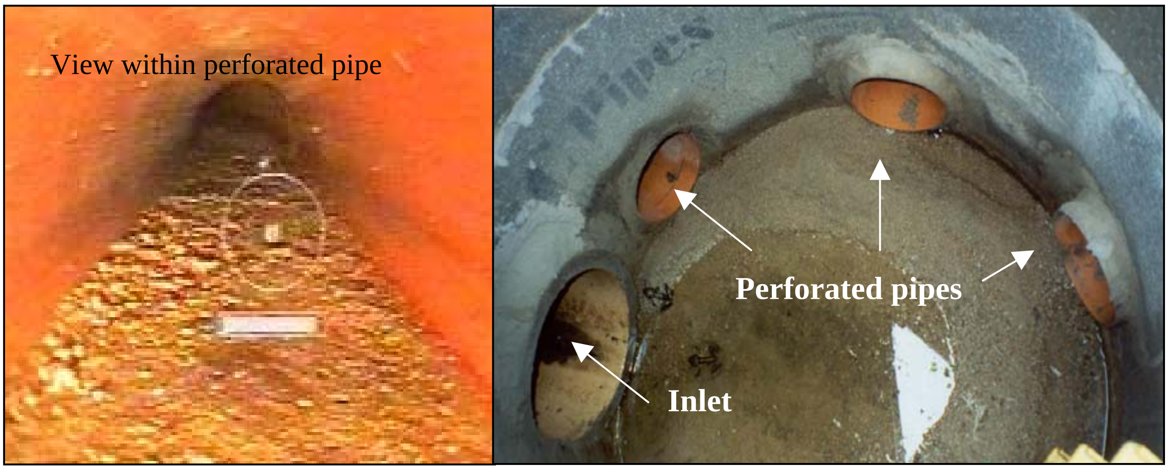


Figure 8.8: Observation of construction impact

Figure 8.9 illustrates the complete failure of this below ground SUDS installation. It should be noted that the concept is quite valid. The trench inlet has been set at a lower level than the bypass so that low flows (with associated pollutant levels) will pass through the trench and have the opportunity to be filtered and to exfiltrate. The bypass will come into operation at higher flows. Unfortunately, construction sediment has completely blocked the trench. This example clearly illustrates unacceptable SUDS performance resulting from poor construction practice. However, it would be acceptable according to traditional drainage criteria since the total capacity to convey storm flows is unaffected, and surface flooding would be prevented except under extreme flows since the bypass continues to operate. This is an example of hidden SUDS failure resulting from ingress of construction debris which would not be problematic with a surface based system since blockages would be unlikely to occur, and the debris would be visible.

Figure 8.9: Completely blocked Inlet

8.6 Filter Drains alongside Car Parks and Roads

A further commonly used technique is the french drain installed in car parking areas and roadsides such as those illustrated in figures 8.10 and 8.11. In the car park shown in figure 8.10, lateral inlets lead directly to the free draining gravel strip and allow hydraulic connection to a perforated pipe or French drain below. It will be noted there has been some accumulation of leaves at the lateral inlets. Although blockages were not complete, this is a very new installation and the installation may become problematic in future.

Figure 8.10: Car Park Inlet using lateral inlets

Figure 8.11: Blocked Roadside Lateral Inlets

8.7 Discussion

This appraisal of in-ground SUDS revealed a range of different operational and maintenance problems many of which have been due to poor design or practice causing their questionable performance as SUDS systems. Several examples have been outlined where lack of maintenance has led to system failure despite good design and construction. Some examples were given where systems have been installed at locations which proved to be unsuitable for the design and concept of the SUDS used. Most problematic were locations of low soil infiltration and with a high sediment inflow from brown field sites.

Figure 8.12: Highly turbid outflow from trench

Unfortunately, once a site has been approved this poor performance may lead to low level degradation of receiving waters quality. The nature of the problem means that it may not be possible for the environmental regulator or water undertaker to identify its location sufficiently closely to enable a solution to be found.

This examination has shown clearly that the two principal causes of failure (as SUDS) were;

- Poor design concept & detailing,
- Poor pollution control practice during the construction phase, and;
- The lack of post construction performance checks.

There was evidence that more recent designs were likely to have better environmental performance and post construction inspection and frequent corrective action remains essential for the long term performance of filter drains and infiltration trenches.

9. POROUS PAVING DETAILS

9.1 Overview

The use of porous paving has become widespread in Scotland since the introduction of the SUDS policy by SEPA in 1997. Pervious pavements were developed as source control systems to attenuate flows and provide a measure of pollution control in urban areas while at the same time permitting a relatively intensive land use. Adoption of porous block systems has become rapid, starting in specific areas such as the South Gyle development to the east of Edinburgh, a very large development on the Water of Leith catchment which is very prone to flooding. By mid 2003, porous paving had become very widely adopted for car parking areas both for new houses and for retail developments. Many house builders now use porous block systems as standard for driveways, and Tesco specify this type of system for car parking at all new stores in Scotland.

Two field studies of ‘live’ in-situ porous pavements used as car parks in Edinburgh constructed in 1997 and 1999 have been undertaken. Both car parks were constructed using Formpave blocks and are constructed in locations were exfiltration is either insignificant or not possible. A further small scale study was undertaken at a purpose built pilot installation at Dundee airport to examine the removal of heavy metals. All studies have shown significant retention of flows and localisation of heavy metals in soluble form.

The porous paving concept is a system in which the block forms an upper wearing surface and this is underlain by sand and gravel layer. The system has underdrains which have hydraulic controls to release the water at a desired controlled rate. When used as a car park, water (rainfall), and any contamination it contains, enters from above and moves vertically into the system. Frequently, roof drainage is also connected directly into the system, using it as below ground storage. A report by Pratt et Al (2001), published as CIRIA Report 582, provides engineering details.

Figure 9.1 Porous paving good & bad practice

a) Porous parking with standard access roads.

b) Soil and sand erosion from unprotected cut slope. Even the filter trench was overwhelmed.

There are a number of concerns about the performance of porous block systems in the medium to long term. These can be summarised as:

- Blocking of the gaps between the blocks by clays and other minerals, thus preventing vertical flow of water. This is closely linked to system specification and maintenance.
- Hydrological and water quality performance.
- Potential for ingress of contaminants to groundwater.
- Structural viability of the systems under wheel loading.

9.2 Blockage

Operation of the porous block system assumes that a proportion of the inter-block gaps remain open to permit the downward movement of water. Only a relatively small proportion of the gaps need to remain open for the system to operate since the primary area of operation is below the surface. However, significant areas of blockage are unsightly and car drivers and passengers may be unhappy to find semi-permanent pools of water on the car park surface. The principal risks of blockage arise from:

- Material falling from vehicles
- Soil and vegetable matter washed from adjacent landscaped areas.

Material falling from vehicles is removed by vacuuming periodically, generally on an as-required basis. Areas of car parks with a greater ‘turnover ‘ of vehicles will block more quickly than locations where vehicles remain all day. It has been noted that the NATS car park in Edinburgh (see Data sheet 6) has never been cleaned in its six years showing no evidence of blocking, and the hydrological performance has not suffered.

Soil and vegetation wash off is prevented by good landscaping practice which must compatible with low transport of fine material, and by good construction detailing. Landscape architects and contractors should realise that a relatively small investment in erosion prevention might avoid a greater cost in porous paving maintenance. Typical points of detail might be:

- Slopes higher than the paving area (i.e. slopes which have been cut) should be protected to prevent soil washing off; slopes below (i.e. embankments) are unlikely to impact on the paving.
- A cut off drain at the base of the cut (i.e. between the slope and the start of the parking) might assist in preventing high soil moisture which weakens and makes soils more easily eroded. This will assist in avoiding easy mobilisation of soils.
- Use rapid, growing low vegetation to stabilise soil quickly.
- Avoid rotovating vulnerable cut slopes. This will loosen the soil so that it might be washed down on to the car park during heavy rainfall.
- Use a surface dressing on cut slopes – wood bark or similar.

9.3 Hydrological and Water Quality Performance

Hydrological, hydraulic and water quality parameters have all been measured in the monitoring programme. The hydrological monitoring produced consistent data on flow attenuation, water retention/ disposal and a comparison with runoff from an impermeable car park. Analysis of both spot and event based samples shows good outflow quality, and results from heavy metals analyses shows very favourable removal rates and comparison with drinking water standards. A limited amount of hydrocarbons data confirmed that some residue from oils and fuels may not be retained by the pavement structure.

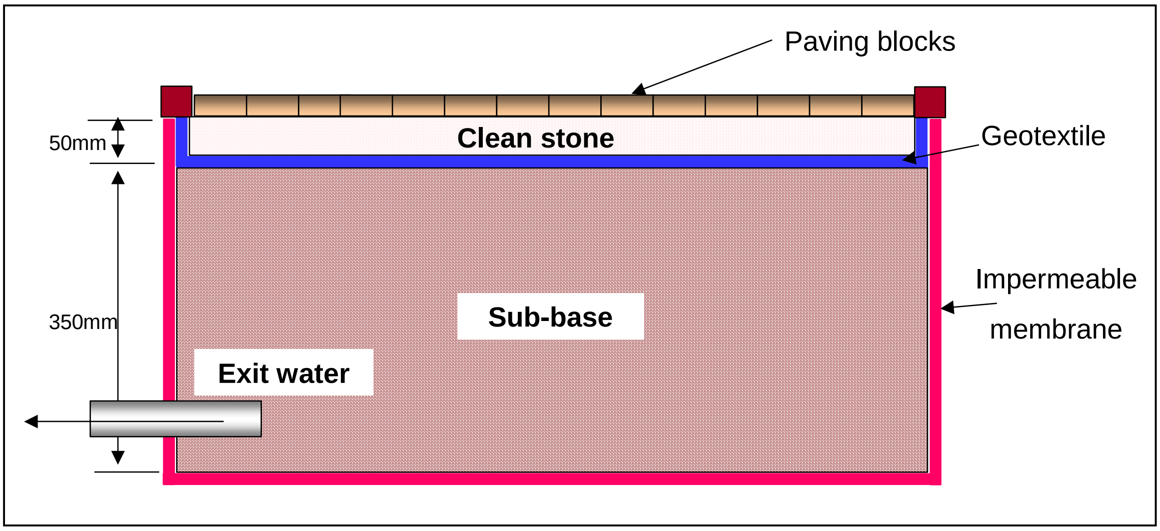


Figure 9.1 Cross-section of a typical modular block tanked system (Formpave®, 2000). (Not to scale)

The results from a trial site investigating heavy metals removal are very encouraging, and show consistently high rates of metal removal (typically > 95%) for nickel, copper, cadmium and lead. This was an accelerated study using higher concentrations of metals than are normally found in the environment. However, the equivalent of four years of contamination were passed over the pilot system and high removal rates were recorded for the full period. The results for zinc were more variable - ranging from 0 - 95 %. This may have resulted from interaction with clay particles which are a major scavenger of metal cations due to their high surface area and surface charge.

It was also noted at the trial site that, even with a section of porous paving 2 m^2 in plan, the applied water could still be detected draining from the system after 2 days.

For further information on the performance of porous pavement systems, the reader should return to section 3 and to datasheets 6 and 7.

9.4 The potential for contaminants reaching groundwater

Fears are expressed over the potential for the escape of contaminants to groundwater. Observations have shown that these concerns are either relatively unfounded, or may be avoided by:

- The risks of contamination may be lowered. Observational data shows that most car parking areas have relatively low levels of contamination and present little risk unless by exceptional accidental causes. See table 3.3 for further details.
- Lining of the base and sides of the car parking area to prevent hydraulic connection with the ground. The study at RBS in South Gyle, Edinburgh (data sheet 7) showed high attenuation of flows, significant initial runoff losses, and a reduction of total percentage runoff on a lined system. In short, the lining does not disrupt the system's hydrological performance.
- Retention of pollutants within the system is good. All studies have shown low concentrations of a range of contaminants in the outflow from porous paving systems.
- Porous paving systems localise contamination, enabling easy and inexpensive remediation. Should unacceptable levels of contamination become apparent, areas of blocks and sand bedding may be removed to a disposal site or cleaned.

9.5 Structural Viability

This report is not concerned with the design or construction detailing of systems except in as much as the observations made may impact on the hydrological or water quality performance. However, it is clear that porous block systems are not able to carry the loadings from heavy goods vehicles or buses which should be prevented from gaining access. Problems are caused by wheel turn under heavy loading when the blocks are regularly rotated and pressed down into the sand bedding. Additionally, in heavily trafficked car parks, the system will be damaged by excessive wheel loadings.

The response by developers has been:

- To prevent heavy goods vehicles and buses from accessing porous block paving systems.
- To specify car parking with 'adoptable' standard access roads for heavy use, only the actual car parking bays being of porous construction.
- Use porous construction for the full car park only for used car parks where the turnover of vehicles is less frequent, and for office parking.

A small number of car parks were observed to have failed structurally. It is suspected that this was due to poor construction and did not have an effect on their environmental performance.

10. SEDIMENTATION AND SEDIMENT QUALITY IN PONDS

This section has been written by Kate Heal and Susan Drain of the School of GeoSciences, University of Edinburgh, Darwin Building, Mayfield Road, Edinburgh EH9 3JU. The full text is referenced in the references section

10.1 Introduction

Sedimentation and sediment quality in SUDS is of concern for a number of reasons. Sediment accumulation will reduce the storage volume over time, decreasing the effectiveness of the SUDS in flow attenuation. The SUDS performance in improving water quality will also be adversely affected due to the reduced residence time as storage volume is infilled with sediment. Furthermore, where unlined SUDS overlie permeable geology, contaminants accumulated in sediment may leach into aquifers. This is of particular concern in areas such as south-east England where groundwater is an important source of potable water. Due to the above concerns, removal of accumulated sediments is likely to be required from SUDS retention basins and wetlands as part of long-term maintenance. To estimate the costs of sediment removal and disposal, assessments of the frequency of sediment removal, sediment volumes and sediment quality are required.

Results are presented for a four-year survey of sedimentation and sediment quality in four SUDS (three retention basins and one wetland) in Scotland. To assess the extent of contamination of SUDS sediments, metal concentrations measured in the SUDS sediments are compared with sediment standards and other aquatic sediments. Finally recommendations are made for SUDS sediment disposal, based on these studies.

10.2 Sedimentation Accumulation In Suds

10.2.1 Methods

Since 1999, annual surveys of sediment depth have been conducted in four SUDS which are part of the stormwater management facilities at Duloch Park, a 5 km^2 new residential, light retail and industrial development in Dunfermline, Central Scotland (Roesner *et al.*, 2001). The SUDS surveyed were all planted in 1998 and comprise three retention basins (Halbeath Pond, Linburn Pond and Pond 7) and a wetland. Once a year sediment depths are measured from sediment cores collected with an aquatic sediment corer from 30-40 locations, regularly spaced along two-three transect lines in each SUDS.

10.2.2 Results

The pattern of sedimentation varies spatially within each SUDS, depending on design. For example, in Linburn Pond (Fig. 10.1) the largest sediment depths occur in the primary basin close to the main inlet, with less sedimentation in the secondary basin. Preliminary estimates of sediment accumulation rates and frequency of removal have been made for the Halbeath and Linburn retention basins (Table 10.1). The time for each basin to infill with sediment was simply obtained by dividing the water storage volume of each SUDS by the annual wet sediment input volume, although accumulated sediment will require removal before the volume is totally infilled.

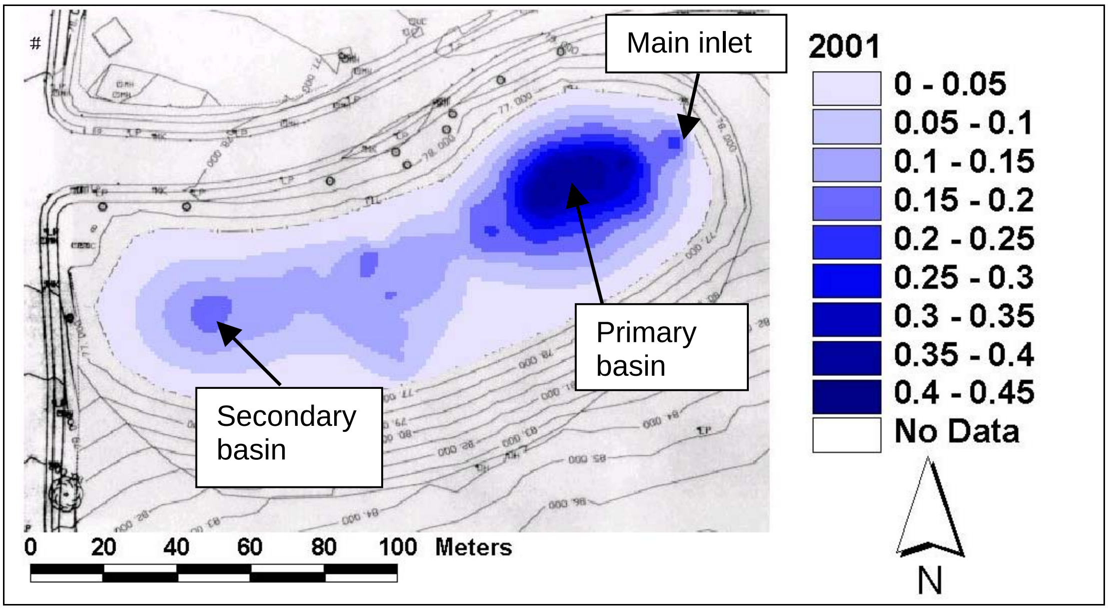


Figure 10.1. Interpolated sediment depth (m) in Linburn Pond, July 2001

Table 10.1. Characteristics and sedimentation estimates for two retention basins. Values are means of 1999-2002. Minimum and maximum values for 1999-2002 are shown in brackets.

	Halbeath	Linburn
Water storage volume (m^3)	4600	15495
Catchment area (ha)	13.5	67.5
% Catchment area developed	70	10
Annual wet sediment input (m^3)	16.2 (-131, 183)	50.7 (-275, 501)
Annual mass of sediment input (t dry weight)	51 (-186, 377)	126 (-236, 597)
Annual sediment washoff from catchment into basin (t ha^{-1} dry weight)	3.8 (-14, 28)	1.9 (-3.5, 8.8)
Time for basin to infill with sediment (to nearest 5 years)	285 (0, 25)	305 (0, 30)

Table 10.1 shows that there is considerable inter-annual variability in sedimentation estimates for each SUDS and in some years sediment appears to be lost from the basins. This may be due to sediment compaction over time, sampling artefacts and/or inter-annual variability in rainfall and washoff of sediment from the catchment. A higher mean annual rate of sediment washoff occurs into the Halbeath basin than the Linburn basin due to the greater development of the Halbeath catchment and the lack of upstream sedimentation facilities in the Halbeath catchment. In the Linburn catchment, sedimentation has been observed in the six detention basins upstream of the retention basin, thereby reducing the sediment input to the retention basin.

10.3 Sediment Quality

Results

Sediment quality was spatially variable within each SUDS, as shown in Fig. 10.2 for nickel concentrations in Halbeath Pond sediment. The highest nickel concentrations occur in sediment deposited near the inlet to Halbeath Pond, probably due to transport attached to particulates. Chromium and nickel concentrations increased in sediment in all basins from 1999/2000 to 2001/2002 (Fig. 10.3). These increases are statistically significant between years and are probably caused by increasing traffic as site development has progressed. Chromium and nickel are often elevated in highway drainage due to corrosion of metal plating and wear of bearings and other moving parts in engines (Makepeace *et al.*, 1995).

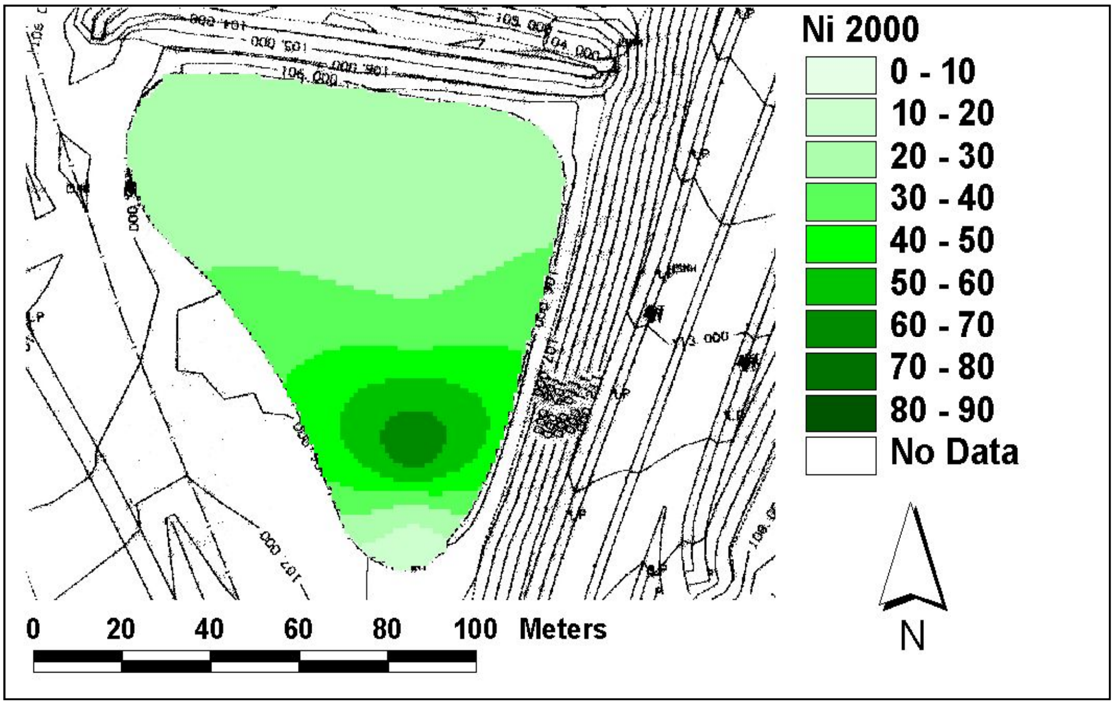


Figure 10.2 Nickel conc'ns (mg kg^{-1} dry weight) in sediment, Halbeath Pond, July 2000

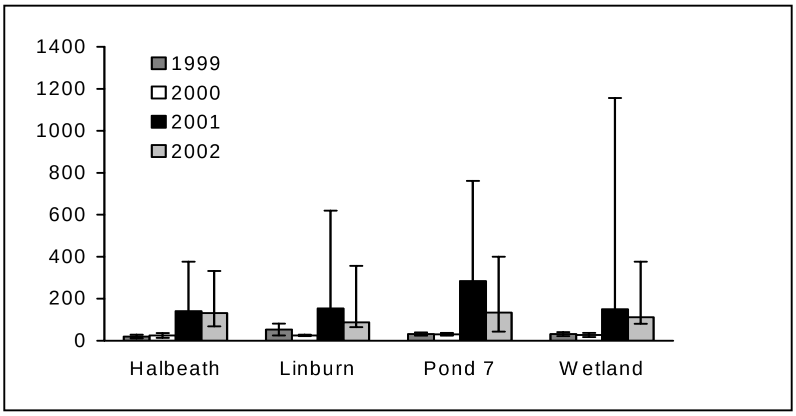


Figure 10.3 Mean sediment chromium concentrations in four SUDS, Dunfermline, Scotland 1999-2002. Error bars are ± 1 standard deviation.

10.4 Assessment Of Contamination In Suds Sediments

10.4.1 Comparison of SUDS sediment results with sediment quality standards

The concentrations of various parameters measured in the sediment samples from the Duloch Park SUDS were compared with three different standards to assess

- whether the sediments are contaminated compared with other aquatic sediments,
- whether the sediments are toxic to aquatic life within the SUDS and,
- if the sediments pose a risk after removal from the SUDS.

Mean metal concentrations in sediment for each SUDS were compared with the Swedish Environmental Protection Agency's classification of aquatic sediment quality (Swedish EPA, 1991) to assess whether the SUDS sediments have higher levels of metals than background concentrations. All SUDS sediments contained low or very low cadmium and zinc concentrations and low concentrations of lead and copper. All sites have moderate-high sediment chromium and nickel concentrations.

10.4.2 Comparison of SUDS sediment quality data with other aquatic sediments

In a wider, literature-based, study the quality of SUDS sediments was compared with other aquatic sediments to assess the extent of contamination of SUDS sediments (Heal and Drain, 2003).

Through literature searches, a total of 396 datapoints were suitable for analysis and were divided into six categories: SUDS (21 datapoints), Uncontrolled (58 datapoints), Contaminated (12 datapoints), Gully Pot (72 datapoints), Dunfermline (198 datapoints) and Background (35 datapoints). SUDS contains sediment data from SUDS sites other than Dunfermline, whilst Uncontrolled contains data from a wide variety of other watercourses (rivers, estuaries, wetlands, canals). Contaminated contains data for sediment/soil mixture at sites which are known to receive contaminated sediment/soil, e.g., sites for the disposal of dredged sediment. The Gully Pot category contains data for gully pot sediment in the UK from the survey by Pratt *et al.* (1987). The Dunfermline category contains the results of the SUDS sediment surveys reported above. Background contains data from sites identified as unpolluted and assumed to be representative of 'natural' background metal concentrations.

Data analysis focussed on Cd, Cr, Cu, Ni, Pb and Zn since these are the most commonly measured metals in aquatic sediments, especially in SUDS retention basins and wetlands, and are also the metals of greatest concern for biological impacts. The data were analysed by principal components analysis (PCA) to identify the similarity of SUDS sediments to other aquatic sediments utilising all the metal data. The causes of any patterns identified in the dataset by PCA may not have any physical basis, but the technique is the most appropriate for identifying patterns in large multivariate datasets, as in this study. In PCA the interrelationships within the dataset are reduced to a number of principal components (PCs).

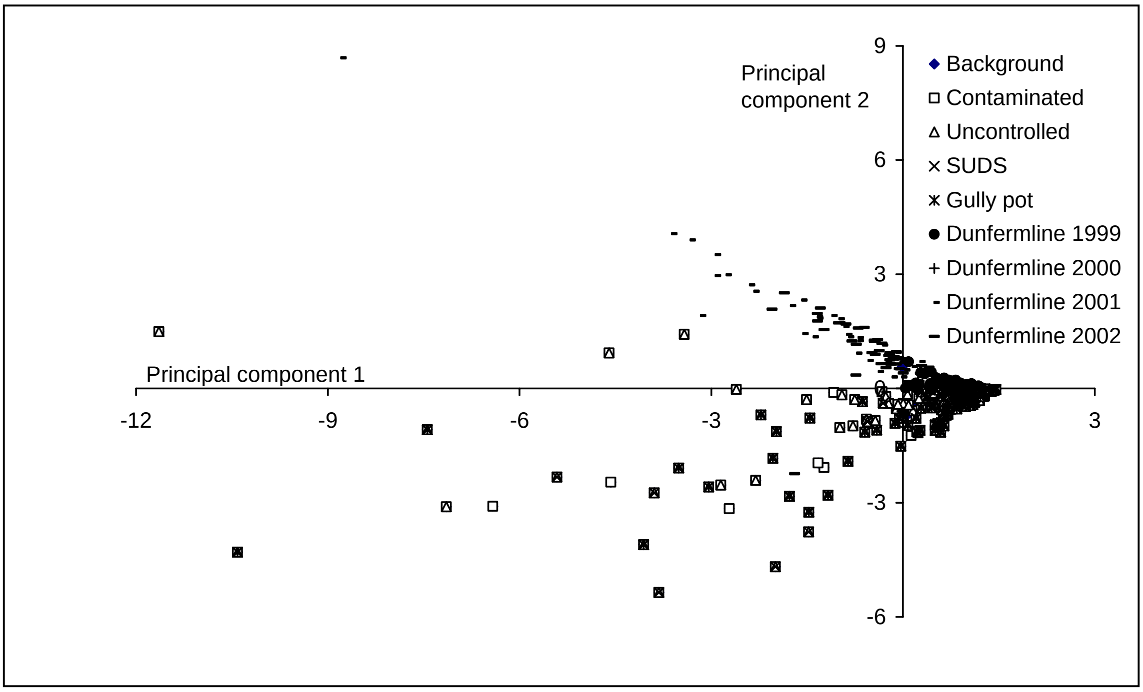


Figure 10.4 Plot of scores for principal component 2 against principal component 1 from PCA of the aquatic sediment database

Some distinct trends in the dataset are apparent in the plot of PC 2 scores against PC1 scores (Fig. 10.4). There is a trend from least contaminated samples near the origin to most contaminated furthest from the origin. The background sediment samples plot at the origin, indicating, as expected, that these samples did not have high scores for any metals on PC1 and PC2. Most samples from the controlled category and Dunfermline sites in 1999 and 2000 are clustered near the origin and the background samples, showing that the metal content of many SUDS sediments is indistinguishable from background sediment quality. However, samples from the Dunfermline SUDS sites in 2001 and 2002 plot away from the origin in the upper left hand sector of the graph, indicating that they are more contaminated than other SUDS sites, but have a different metal composition compared to sediments in the contaminated and gully pot categories that plot in the bottom left hand sector of the plot.

10.5 Conclusions From Sediment Survey

The sediment survey of the Dunfermline SUDS shows that sedimentation rates vary between years, probably due to changes in site development and storm flows. The SUDS management train appears to be effective in trapping sediment in detention basins upstream of retention basins, thereby reducing the costs of sediment removal from retention basins. Sediment quality varies spatially in the Dunfermline SUDS, with the highest contaminant concentrations occurring near the inlets. Metal concentrations in SUDS sediment increased as the Dunfermline site developed, probably due to increased traffic. Mean metal concentrations of sediment from the Dunfermline SUDS complied with different sediment quality standards, although “hotspots” of contamination occur within each SUDS.

11. AQUATIC AND RIPARIAN VEGETATION IN SUDS PONDS

This section has been written by Lars Behrendt and it has been prepared from his PhD thesis. His supervisor was Dr Nigel Willby of Stirling University

11.1 Introduction and aims of Vegetation Survey

Lars Behrendt carried out a survey of aquatic and riparian vegetation in 25 retention ponds within central Scotland covering a variety of pond ages and designs and with reference to specific site conditions such as pond substrate and water chemistry. This project also included a pilot study on metal storage in tissue of selected emergent plants at a small number of sites with contrasting pollutant burdens.

The underlying themes of this research have been;

- To evaluate pond design, test the effectiveness with which different species establish naturally or from introductions and assess how SUDS contribute to local biodiversity planning.
- To assess the relative merits of native and introduced exotic species in SUDS in terms of their implications for other trophic levels, wider ecosystem processes such as litter decomposition, nutrient cycling and immobilisation of contaminants.

11.2 Botanical survey of SUDS ponds

Twenty five ponds in Fife, West Lothian, Stirling and Clackmannan were considered in this study. Ponds were of a variety of age and design and were constructed specifically as retention basins or fulfilled the basic functions of such ponds in terms of contaminant removal and flow attenuation even if not specifically intended for these purposes. Plants were recorded in multiple 20m transects arranged around the perimeter of each pond and data on selected environmental variables (including shape complexity, substrate, shading, use by waterfowl, bank slope, naturalness of the surrounding vegetation, catchment characteristics).

A total of 66 wetland and aquatic plant species were recorded with emergent species accounting for 70% of the total. Of this total, 30% were non-native species, either invasive (e.g. New Zealand swamp stonecrop, *Crassula helmsii*, or Nuttalls pondweed, *Elodea nuttallii*) or planted for ornamental purposes (e.g. various south American arrowhead species, *Sagittaria* or Bog Arum, *Calla palustris*). A further 12% of species that were native to the UK had almost certainly been introduced in most cases, often well outside their native range, e.g. Hampshire Purslane, *Ludwigia palustris* or Flowering Rush, *Butomus umbellatus*). Native species were typical of lowland nutrient-rich ponds, the most widespread species being Branched Bur reed, *Sparganium erectum*, Water Forget-me-not, *Myosotis scorpioides*, Greater Willowherb, *Epilobium hirsutum* and Creeping Bent, *Agrostis stolonifera*. Several regionally or locally uncommon species were also recorded including Needle Spike Rush, *Eleocharis acicularis*, Mares tail, *Hippuris vulgaris* and Horned Pondweed, *Zannichellia palustris*.

Total species richness per site ranged from 5-24 species with an overall mean of 17 species. However, the number of naturally colonising native species ranged from 3-20 with a mean of 11 reflecting the high incidence of introduced species at most sites. This level of native species richness is not atypical of small natural waterbodies or mature ponds in central Scotland although the numbers of aquatic (i.e. submerged or floating-leaved) species in

SUDS ponds is generally rather small. This species richness is however, well below the numbers associated with high quality lowland ponds, mainly in southern Britain, or canal sites of equivalent size.

Interpreting the influence of environmental variables, such as those associated with pond design, is naturally difficult when a large proportion of the species pool is introduced anyway. Multivariate analyses confirmed statistically the importance of shape complexity, the coarseness of marginal sediment and the bank slope. It is well known that the species richness and overall botanical value of ponds increases as more complex shorelines provide greater habitat heterogeneity and fluctuating water depths lead to exposure of fine sediment, often subject to poaching by livestock or wildfowl. There are widely available guidelines on good practice in pond design and management but obviously when dealing with operational water bodies in a suburban environment it is not possible to incorporate certain features that would be seen as desirable purely from a conservation standpoint. In all cases lined or over engineered shorelines should be avoided and a gentle slope that provides ample shallow water habitat will be beneficial to both a range of water plants and other aquatic biota, such as amphibians. The practice of lining ponds with shingle greatly impedes colonisation by water plants and provides a substrate for extensive growth of filamentous alage.

The major practical implications of this study relate to the widespread practice of introducing vegetation to ponds for landscaping purposes. Quite clearly numerous wetland and aquatic species can and do colonise shallow water bodies very rapidly and the choice of any species to plant should take this into account and consider the composition of the regional species pool. In many instances landscapers have introduced non-native species or native species way outside their natural range when there is an ample supply of native species that, given permission, could be transplanted easily in small quantities from local ponds and canals. The choice of ornamental species is often bizarre and inappropriate to local climate and growing conditions. Some of the species introduced, such as Skunk Cabbage *Lysichiton americanum*, are of dubious ornamental value, and more importantly in many cases have been outcompeted over two or three seasons by native vegetation and are thus largely a waste of money.

The ecological consequences of non-invasive ornamental plants are probably relatively limited and it is unlikely that these species will unduly constrain the conservation value of ponds. From a conservation perspective it is of much greater concern that the highly invasive *Crassula helmsii* has become established in several parts of the DEX complex following landscaping. There is well publicised information on the problems posed by this species and its threats to native flora and it is more likely to have been introduced inadvertently as a contaminant of other nursery produced plants. Nevertheless, a significant northward extension of the range of this plant to a position from where it may subsequently colonise high quality natural water bodies will not be welcomed by conservationists.

The experience of conducting botanical surveys of SUDS ponds in Central Scotland quickly reveals that there is a need for much greater dialogue between developers, landscapers and ecologists. Even the choice of native species for deliberate introduction indicates some curious decisions. For example, Common Reed, *Phragmites australis*, has been planted around many ponds to form an impenetrable screen and thereby deter children. Reed can penetrate to much greater water depths (1.5m) than most emergent species and forms particularly recalcitrant litter so will encroach into the centre of ponds and lead to a more rapid loss of volume. Such problems would be much less severe with the use of other emergent species such as Branched Bur Reed, which additionally would allow direct viewing of the pond by the public (compare Halbeath and Stenton ponds).

11.3 Heavy metal burdens in sediment and vegetation in SUDS ponds

A pilot investigation was carried out of the concentrations of lead, zinc, copper and nickel in four ponds at the DEX site (Masterton, Linburn, Duloch Grange and Halbeath). The work was carried out in conjunction with Dr Carol Salt in the Department of Environmental Science. The primary aim was to relate differences in metal burden to catchment characteristics, compare storage in sediment and plant tissue and in different plant species and to determine if existing concentrations reach levels likely to cause phytotoxicity. This investigation was also stimulated by an interest in the potential role of emergent vegetation in phytoremediation. Thus immobilisation of metals in plant tissue with subsequent harvesting may be one environmentally sustainable method for removing metals and meeting targets for sediment metal concentrations.

Surface sediment was collected from shallow water at five representative locations in each pond. Correction was not made for differences in bulk density between sites since these were very minor and all samples comprised fine mineral sediment. At each location a sample of the vegetative biomass of the emergent plants Marsh Marigold (*Caltha palustris*) and Common Reed (*Phragmites australis*) was also collected. Consideration of metals within plant tissues was restricted to these two species which were both abundant and widespread, and common to all four ponds. The average biomass of these two species at the ponds studied was c.250 and 900 gm^{-2} respectively. Therefore areal concentrations (mgm^{-2}) of metals for the two species are equivalent to approx. 25% or 90% of their foliar concentrations (mgkg^{-1}). Values presented are based on digestion of dried material and are corrected for under recovery relative to standard reference material.

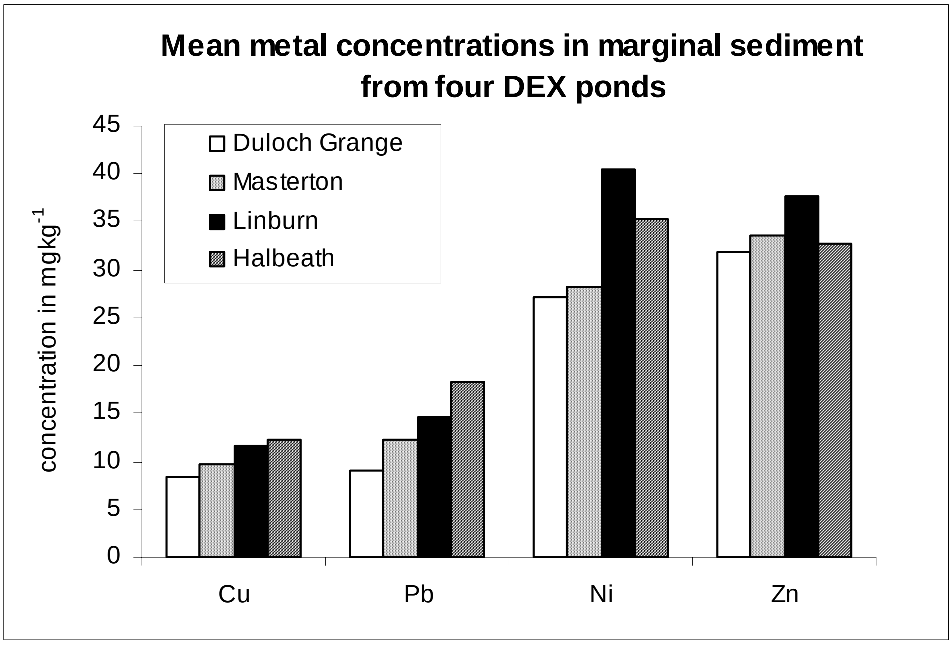


Figure 11.1 Mean Metal Concentrations in Marginal Sediment

Sediment concentrations of metals from individual ponds were highly variable and in the case of zinc showed no discernible difference between ponds. In the case of lead, copper and nickel concentrations were clearly higher in the two ponds (Halbeath and Linburn) with more urbanised catchments. In terms of sediment metal concentrations values for copper and zinc barely or never exceed the background level and are generally at least an order of magnitude below UK ICRCL trigger values. Although low and of no biological concern, lead levels are substantially above background concentrations, especially in the case of Halbeath. The source of this contamination is unclear but may relate to reactivation of historic contamination during the construction phase.

Only the results for nickel present any cause for concern since these are well in excess of the background and currently average (32mgkg^{-1}) almost 50% of both the UK ICRCL trigger value and the severe effect level (70-75mgkg^{-1}) of the Ontario Provincial Sediment Quality Guidelines. These results are somewhat higher than those recorded in previous years by other researchers and may be a particular feature of marginal sediments but closer monitoring of the accumulation rate of nickel in different ponds may still be prudent.

In terms of tissue metal concentrations there was no evidence of the gradient of concentrations across sites that was observed for sediment concentrations. Indeed tissue and sediment concentrations were very poorly correlated. Lead was generally undetectable in tissue samples. Zinc concentrations on a foliar basis were similar between species while *Caltha* tended to accumulate both copper and nickel to a higher level than *Phragmites*. However, given the differential in standing crop between these species (3-4 times higher in *Phragmites*) any advantages of *Caltha* for metal stripping would be considered very marginal.

On an areal basis removal of zinc by *Phragmites* would clearly be superior. The benefits of *Phragmites* in phytoremediation are enhanced further given its large depth tolerance and consequently much higher coverage at all sites (>10 times higher than *Caltha*). Both species showed slight evidence of zinc accumulation on an individual sample basis, while accumulation of copper by *Caltha* was observed in a quarter of the samples taken.

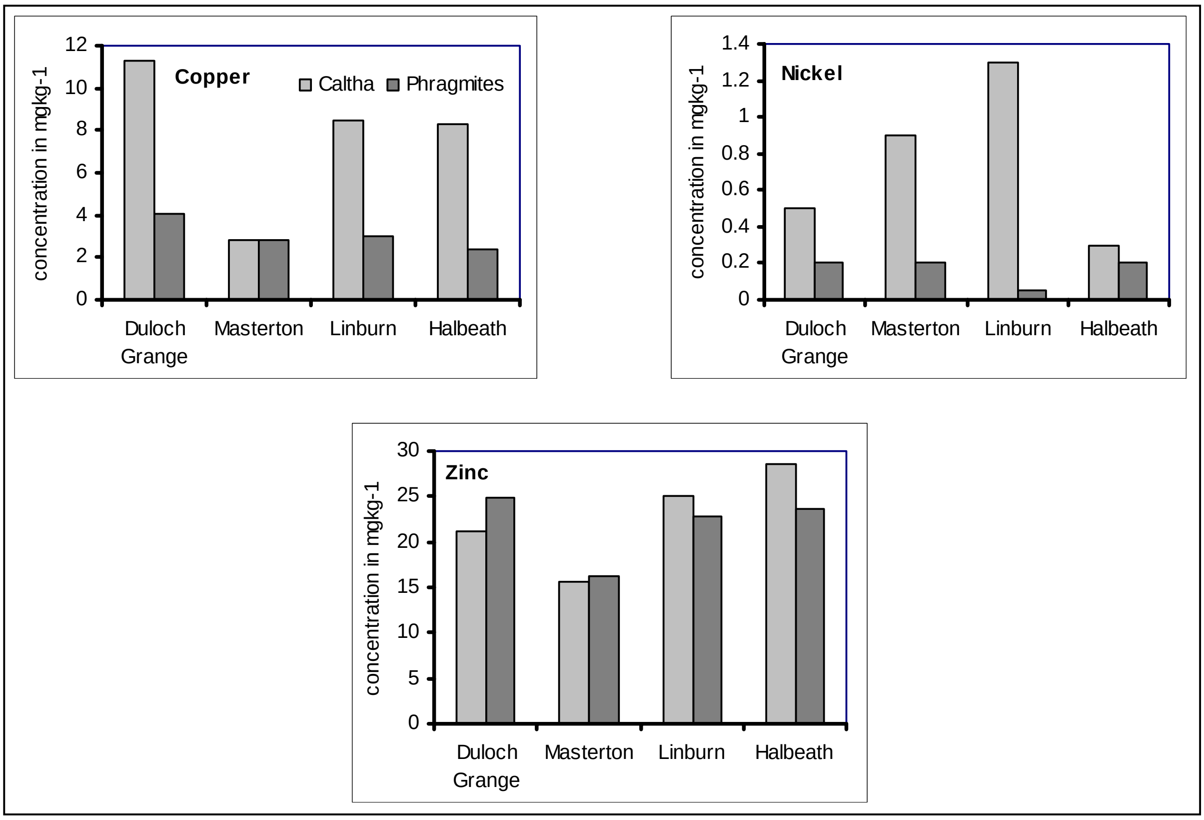


Figure 11.2 Heavy Metals Accumulations in Vegetation

In all cases even the maximum concentrations observed are well below the reported toxicity thresholds for plants (Cu: 20-30 mgkg^{-1}; Zn: 100-300 mgkg^{-1}; Ni: 10-50 mgkg^{-1}) although it is conceivable that other wetland species could potentially experience retarded growth on thebasis of bioavailable copper concentrations.

Although sediment depth was not determined in different ponds it is easy to see from even a crude estimate of 50cm sediment depth that by far the bulk of metal storage within ponds occurs within the sediment. The efficacy of harvesting of the above–ground biomass of reed in reducing the annual build up of contaminants in the sediment would depend on the ease of decomposition and fate of plant tissue relative to the sedimentation rate and external inputs. On the basis of existing metal concentrations in sediment and plant tissue relative to sediment quality guidelines and critical toxicity concentrations for plants there would seem little justification for plant harvesting or for concern over effects of metal contaminants on plant growth. However, this situation may change appreciably with continued urbanisation of catchments; a consideration of annual metal accumulation rates due to sedimentation versus storage in plant tissue would allow a more critical assessment.

However, currently reduction in pond performance due to loss of volume caused by sediment accumulation should be a more immediate concern than contaminant build up. In terms of the value of different species as phytoaccumulators comparisons will be made in future of metal concentrations in soil and tissue of large emergent species (e.g. *Glyceria maxima*, *Typha latifolia*) at other sites to determine if there are advantages in manipulating the choice of plant species. Sampling will also be extended to encompass submerged species since these are known to have higher metal uptake rates and biomass turnover.

Acknowledgements

Lars Behrendt was hosted by Stirling University under the SOCRATES scheme.

12. SUDS MAINTENANCE AND COSTS

12.1 General Comments

Surprisingly little maintenance has been carried out on most of the SUDS systems monitored and virtually all that has been undertaken has been trimming of the vegetation in ponds, detention basins and swales to maintain a pleasant appearance. A number of incidences requiring major attention have been noted and these are discussed in the text. However, many can be put down to construction deficiencies and not to design or poor concept. Only the occasional example of a cross connection leading to foul sewage in ponds was found.

Most of the systems examined have been relatively new and observations have been made during the first five years of their lives. At this time, routine maintenance can be confused with 'bedding in' of the new works. Little evidence was found that any maintenance of filter drain assets had been undertaken, although it is suspected that serious problems affecting their performance as SUDS components may be developing, and this was discussed in section 5. In general, no maintenance had been carried out at the porous paving installations. This is probably not an issue at the low density car parking sites, but may become problematic in time at more heavily used supermarket sites. The roadside detention basins (small swales) were found to deliver excellent performance in spite of very high loads of suspended solids. Furthermore, the performance was good despite the appearance of some being poor due to debris being deposited in them and the slightly haphazard development of 'native' vegetation since no grass seed had been sown.

The impression has been gained, supported by monitoring, that all of the above ground SUDS which have been monitored in detail have performed satisfactorily and will continue to do so provided that maintenance is undertaken. There is evidence of poor performance of some of the filter drains monitored.

12.2 Minor Maintenance in General

<u>Vegetation removal</u>

No maintenance driven specifically by water quality/ treatment issues has been carried out on any of the ponds. Activities have focussed on amenity, safety and rectifying post-construction snagging issues and have included grass cutting, litter picking, planting replacement and fence installation. Herbicide is applied at the margins of some ponds partly to encourage the planted species to develop strongly and partly to ensure protection and inspection of the underlying water retention structure. Straw bales have been placed in some ponds to control blue-green algae and this has been driven purely by the desire to preserve a 'park like' appearance.

<u>Litter Removal</u>

Most litter has originated from local construction activities and has been primarily wind blown packaging and construction materials. Specific maintenance has required (the attempted) removal of polythene sheet from a hydrobrake at a detention basin outlet. This type of debris results from construction and commercial activities on adjacent sites. It has been observed that once the house building phase of a development has been completed, the need for litter removal reduces markedly.

Minor Repairs

Inlets to swales & detention basins often become blocked and require minor clearing. Wave action in ponds has caused minor damage to banking. The bases of some swales and detention basins have become waterlogged. Figure 12.1 illustrates typical maintenance activity to remove blockages, correct local waterlogging and improve the local amenity, while figure 12.2 illustrates the nature of the debris which must be removed from minor above ground channels.

Figure 12.1 Debris in runoff channel Figure 12.2 Maintenance of detention basin base

An example of minor 'beautification' was noted at the Linburn detention basin in DEX. This basin has a very high profile due to its location close to facilities used to launch the SUDS policy in Scotland and because the main developer wanted to retain an attractive appearance at the entrance to the development. The floor of the basin was badly levelled in comparison with the outlet and it became muddy except in the very driest of periods. Local residents were vociferous in objecting about the unsightly basin and additional material was added to its base to improve the drainage. By late 2002, this facility had taken on a mature appearance and impromptu goalposts had been set up in the grassed area Figure 12.3 shows an overall view of this detention basin.

Figure 12.3 Linburn Detention Basin

12.3 Major Maintenance Requirements

A number of systems, or components of systems have required major attention in the study period. In a number of instances this has been due to exceptional factors such as lack of design knowledge, or late consideration of SUDS in the planning of the development. Others are effectively part of the construction stage, but the issues surrounding SUDS maintenance are relatively unknown. The following examples are included here to give the types of problems which have occurred due consideration.

- Erosion at a conveyance swale in Ardler Dundee occurred due to detailing of the geotextile. This is illustrated in figure 12.4. The swale was formed in earth which was seeded in autumn. Very heavy rainfall occurred before the grass roots had developed and the geotextile did not permit ingress of flow into the gravel bed. The result was high flows on the surface and there was severe erosion/ deposition of the growing medium and some gravel bed material. This swale was designed to convey the low flow from a small watercourse in a gravel trench below the swale and detailing of the geotextile component prevented the high flow from using the gravel trench resulting in excessive above ground flow and erosion.

Figure 12.4 Conveyance swale, Ardler Dundee during and after heavy rainfall

Significant remedial work was required involving excavation and partial removal of the geotextile. However, its cost was offset by the need to create a new access road at the upper end of the problem section. This problem was principally due to lack of 'joined up thinking' of the need for the SUDS philosophy and the traditional French drain and the geotextile is effectively not needed since in this case, the cause of failure was by flow out of the gravel material. After remeditation, the swale had the very pleasant appearance shown in figure 12.5.

Figure 12.5 Ardler Conveyance Swale after remediation

- <u>One section of DEX Pond 6</u> (the cascade of three ponds illustrated in figure 4.3) does not retain water to their full depth, although the remaining two sections are satisfactory. The wet summer of 2002 produced improved vegetation growth. At the time of writing, the developers were seeking a solution to remedy the problem which might require some form of reconstruction.
- <u>DEX detention basin at Pond 6</u>. This is a completely unrelated problem at the same location. The building contractor filled in the pond with rubble and this rendered completely inoperative the treatment train for this section of the DEX development. The maintenance required was to return the detention basin to its design state by excavating the infill material.
- <u>Emmock swale</u>. Difficulties were experienced at this site (the contractor went bankrupt) and the final landscaping was not completed. This resulted in a very unsightly facility which subsequently had to be remediated. However, it must be pointed out that the performance of the section of this swale which was monitored was excellent (Macdonald 2003). Data sheet 13 gives information on this site.
- <u>Tesco filter drain</u>. This section of drain was constructed to protect a porous paving car park from groundwater flow and sediment washoff. The principle was that the gravel top to the drain (see figure 6.1b) would trap any material washed off the slope and the drain material could be replaced without causing a problem to the car park. Slope protection was poor and sediment from the top of the slope was washed onto the surface of the drain and it had to be scraped off and replaced. Furthermore, a considerable section of the porous block paving had to be replaced due to blockage of the gaps between the blocks.

12.4 Maintenance of Detention Basins

Sediment in detention basins is likely to become a severe problem with their increased use in treatment trains as a result of construction stage runoff. Improved construction stage control is required if detention basins are to be viable in the longer term. Most sediment deposited is primarily construction runoff, high in sand and minerals, but low in soluble solids content and does not present a particular pollution hazard. Two remediation strategies are proposed, both predicated by the assumption that construction practices are unlikely to change significantly, and sediment washoff will remain a problem. The possible strategies are as follows:

1. Post-development rehabilitation of detention basins is likely to be essential once the building stage of developments has been completed. Rehabilitation will comprise moving the sediment from the basin base to the sides, clearing of dry weather flow channels and inspection of all upstream and downstream pipework.
2. The second strategy requires that the detention basin should incorporate a temporary volume which will be filled by the end of the construction stage. Once this volume has been filled, the required treatment volume will remain. At present there is no way of predicting the volume of sediment which might be washed into a basin. The basin must continue to function when this sediment volume is nearly filled and this will require appropriate inlet and outlet designs.

<u>Sediment Removal</u>

Most of the detention basins monitored have collected sediment at a greater rate than might have been expected. This is their prime function (in controlling pollution) and they permit sediment to deposit very efficiently. In many cases the sediment has been due to construction activities on the contributing catchment, but this is not always the case. Three categories have been identified:

- Basins adjacent to active construction sites;
- Where there has been erosion (for example from an unconsolidated slope or a field);
- During normal operation after construction has been completed.

Each of these situations requires a different solution, if only because control will be different in each case.

Detention Basin Detailing for Sediment

The observations made at detention facilities have led to the recommendations below:

- Inlet detailing – sediment accumulates close to inlet structures causing partial blockage of inlet pipes. This can be compensated for by a greater drop at the inlet. Access to the inlet area is critical to facilitate removal of sediment.
- The concept of the sacrificial detention basin built with a zone for sediment accumulation This would merely need to be 'raked' to form a smooth surface for growing and pollutant entrapment. The construction sediment is not contaminated and enables rapid growth of good grass.
- There is evidence of hydrocarbon accumulation at some highway detention basins. It is highly likely that the hydrocarbons are being trapped as at one location there is no evidence of their being carried into the basin downstream.
- It may be possible to avoid the use of retention ponds altogether since the detention basins are removing a significant proportion of the pollutant loading. Provided extended detention basins are specified, there should be sufficient pollutant removal, although data have not been gathered to demonstrate this conclusively.
- Sacrificial detention basins have been used at a number of locations. In at least one example where this has been done, the development of the permanent facility has been excellent.

Figure 12.6 Swale/ detention basin at Murieston, Livingston overwhelmed by construction stage runoff

12.5 Maintenance of Ponds

Sediment accumulation

Where protected by detention basins, there is no evidence of reduction of volume due to sediment deposition and current estimates are for an effectively infinite life. Some ponds in Telford were noted to have filled up excessively and yachting now abandoned, reducing amenity value. The following ponds serve housing areas. Appearance is important for the public to believe that ponds are acceptable.

Stenton pond (Glenrothes) – little or no maintenance has been necessary in spite of significant foul sewage ingress. Macro algae accumulates over large areas of the pond in summer, but there is no evidence of problem sediments. The pond margins are well kept parkland without fencing allowing easy public access.

Linburn Pond (Dex) – There has been very rapid growth of very dense marginal vegetation. To achieve this required monthly trimming and annual replacement of dead plants.

Clayland pond (M8 motorway) - Sediment qualities are not a problem.

Inlets

In contrast to the outlet structures which tend to be designed with care, several pond inlets were found to have problems. The principal cause was lack of detailing for erosion protection causing minor slope erosion in a number of places.

Outlets

No maintenance of pond outlets was believed to have occurred after cessation of construction maintenance periods. In general, recent ponds (post 1997), designed as SUDS components have outlets which are below ground and effectively vandal proof. A wide variety of arrangements can be found, but all tend to be robust and not easily damaged. Ponds tend to have the advantage that flowrates are larger and the control structures less likely to block with debris. No examples were found where the outlet structure was operating incorrectly.

The outlets of earlier ponds are simpler, open structures which can become covered in vegetation, but otherwise are likely to remain operating with virtually zero maintenance.

12.6 Whole Life Costing

At least four studies have been undertaken into the costs of constructing and operating SUDS since 2001. Unfortunately, the funders are reluctant to permit free dissemination of the key findings of these projects. The whole life cost (WLC) methodology is not new, the WLC process and constituent computations are well documented and it has been applied to a wide range of areas, but not yet to SUDS systems. The principal generic barriers to the application of WLC analysis were identified and these are particularly problematic in the context of SUDS systems. These are:

- The lack of a standard approach to the definition of boundaries in WLC analysis.
- Requirement to combine costs from traditionally separate capital and (operational) maintenance budgets.
- Uncertainties in predicting future maintenance costs.
- Lack of consistent historical data and the problem of extrapolating historic data into the future.

Maintenance data are very scarce and no historic component failure data are available. There is a need to consider qualitative data collection and costing based on subjective probabilities. Consequently, a probabilistic WLC model is required. Table 12.1 presents a summary of the cost categories used in WLC as applied to SUDS.

Table 12.1 Cost Categories included in WLC models for SUDS

Capital Costs	Design fees Planning fees Construction costs Adoption and inspection costs Loss of marketable land
Maintenance Costs	Litter removal Debris removal Fence repair Silt removal Grass cutting Vegetation replacement planting/ improving plant stock Vegetation removal Component replacement and renovation
Operational Costs	Ongoing inspection costs Evacuation of catch pits Removal and restoration costs
Intangible Benefits (Costs)	Amenity enhancement (or amenity loss) Biodiversity and habitat enhancement Impact on downstream hydrology morphology and water quality

12.7 Gathering Whole Life Cost Data

Meetings were held with a number of stakeholders to determine the key drivers on the costs of SUDS. The results of these interviews are summarised in table 12.2.

Table 12.2 Whole Life Cost Data Collection Interviews

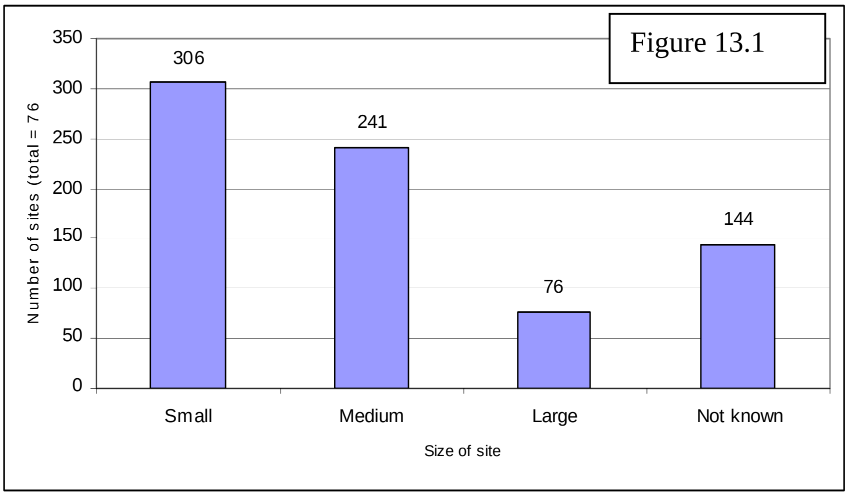
Interviewee	Summary of Information Collected
Local Authority Leisure & Recreation Department Official	In most SUDS sites in the area developers are still responsible for the maintenance. Local Authority does not have real maintenance costs for these sites. For a number of locations the maintenance responsibility the onus is on the residents. This is written in to the deeds of the properties but on most occasions not really considered by the purchaser.
Operations Engineer 1, Water Authority (WA)	Water Authority favour the concept of maintenance responsibility above ground lying with Local Authority and below ground with WA. WA opinion that the maintenance cost are not a problem for the council because the types of system like swales do not really have any different maintenance requirements than any other area of communal grass the council are required to upkeep.
Operations Engineer 2, Water Authority (WA)	Opinion that many newly constructed systems were damaged by developer during construction of the development and not working when passed on to Council/WA. Performance must be checked before adoption. SW charge 8% of the capital cost of the scheme to check and verify design on plans. This includes the cost of inspecting the work. Due to manpower limitations not every development systems gets checked thoroughly. Likely to do a yearly inspection to assess the performance of the suds. Likely replacement age for swales - 15yrs, infiltration system - 10yrs
Environment Regulator Official	The maintenance of systems and the relationship with failure was discussed. Porous pavements for example will have to be maintained to perform. Developer maintenance agreements need to be drawn up (now available from CIRIA). Failure age estimates porous paving which is looked after 15yrs, not looked after 5 years. Swales surface might need replacing after 10yrs
Engineering Project Manager, Major house builder	SUDS system design fee more expensive They preferred underground infiltration because less space is lost. Also if they are required to put in something "undesirable" they may have trouble selling houses near it costing money due to slower returns on investment. Land take cost could be the value of one plot for some designs. Could be estimated by the profit they would make on one house. This figure was not given but could be the difference between developing or not. Opinion that SUDS systems were more cost effective on large developments. Replacement for a soakaway estimated as every 10 years.

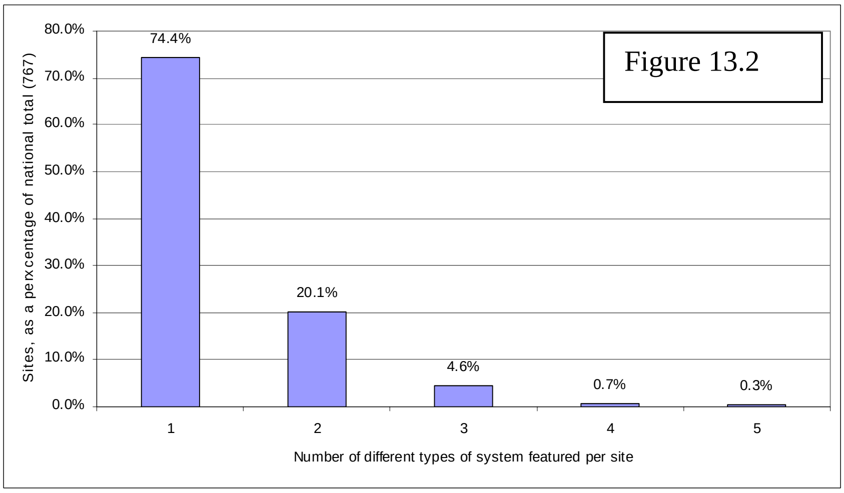
One study (Dundee) gathered information from 5 sites – two swales and three detention basins. The results of this exercise are being incorporated into the whole life costing model under development for the UK water industry.

13. THE SCOTTISH SUDS DATABASE

A database of SUDS sites* in Scotland was developed early on in the SUDS monitoring programme and this has now been developed to such an extent that a separate SNIFFER report has been written. The database contains information relating to 3716 systems on 676 sites in Scotland. Key information is given in figures 13.1 and 13.2. Figure 13.1 shows the sizes of sites on which SUDS have been developed. Small sites predominate, probably reflecting the nature of the building and construction industry in Scotland, but there are a significant number of large sites drained by SUDS. The information in figure 13.2 shows that 75% of all sites are drained by one type of SUDS, and only a few have more than one type. This is interpreted as demonstrating that there has been little effort to implement the stormwater hierarchy, since that would require at least two types of system on each site.

Interpretation of the information in the database is ongoing, and a range of specific outcomes are planned using this information.





Further key issues from the database analysis include:

- Below ground systems predominate in Scotland.
- Whether a separate database of monitoring results would be desirable.
- Would a form of pollution weighting for different contributing areas assist in understanding the issues surrounding the types of systems which have been implemented?
- The incorporation of treatment volume information into database analysis.
- The relative importance of ponds and in-ground systems.

*SNIFFER Report No SR(02)09 *Scotland and Northern Ireland Forum for Environmental Research, Edinburgh:* Wild, T.C., Jefferies, C., and D'Arcy, B.J. (2002) SUDS in Scotland – the Scottish SUDS database. August 2002.

14. THE SCOTTISH UNIVERSITIES SUDS MONITORING GROUP

University of Abertay Dundee

Urban Water Technology Centre (UWTC), established 1993, aims to provide a service to the water industry (in the UK and elsewhere). It is the only one of its type in Scotland, offering education and research opportunities connected with water and wastewater problems from a very strong consultancy base. A wide range of clients have approached the Centre for advice and assistance including water companies and authorities, local authorities, manufacturers and private sector companies involved in the construction and civil engineering industry. In the many projects carried out to date (from Orkney to the North and Lancashire to the South, with many in between), the Centre has been highly successful due to its combination of academic skills with commercial expertise.

The UWTC Team include: **Prof. Chris Jefferies** (head of centre and co-ordinator of the programme). Chris's interests lie in the overall performance of SUDS, **Dr David Blackwood** leads in the estimation of the whole life costs of SUDS.

Fieldwork Capability. The centre operates a dedicated field support vehicle and a wide range of field equipment including 28+ Montec in-sewer flow survey monitors; 15 Epic portable water samplers; 4 water quality sondes, 10 rain-gauges, 12 Isodaq loggers with sensors for depth, temperature and other parameters, 10 tipping bucket flow meters, 2 sigma (bubble) flow loggers. Established field sites include: ponds, car parks, swales and filter drains. The Centre also has access to well-equipped laboratories and workshops.

Edinburgh University

Edinburgh University has collaborated on many SUDS projects with the University of Abertay and has been on board the monitoring programme since its inception. Prime research contributions are the assessment of sediment rates and sediment quality in SUDS and the effect on maintenance regimes.

Dr Kate Heal (water resource management specialist) research areas include: fate of contaminants in SUDS (water, vegetation, sediment), management of SUDS, environmental costs and benefits of SUDS, **Dr Jill Lancaster,**

Fieldwork Capability. The Institute of Ecology and Resource Management has a well-equipped environmental chemistry laboratory (analysis of nutrients and metals in soils, sediment and vegetation), supported by a full-time technician. Analytical instruments include: FAAS, GFAAS, HPLC (Dionex), flow injection analyser and segmented flow analyser. Sediment coring equipment includes soil augers, and aquatic sediment samplers which can collect undisturbed samples from several metres of water in SUDS ponds. There is also access to well-maintained boats for aquatic sediment sampling. Facilities are available in heated and unheated greenhouses and in field plots for testing the suitability of different plant species for sediment entrapment and contaminant removal within SUDS Systems.

Heriot – Watt University

Heriot-Watt University campus provides an ideal site for studying SUDS design and performance with relation specifically to small watercourses and "retention ponds" that receive runoff from roads, car parks, playing fields, agricultural land, and buildings. In addition the university has access to unique facilities for studying the source removal of pollutants from conventional drainage systems.

The Heriot-Watt University Team include: **Dr Steve Grigson** (environmental chemistry specialist, 20 years), **Dr Steve Wallis** (computational hydraulics specialist, ADZ & DISCUS transport model development), **Dr Derek Fordyce** (pavement technology specialist, developed joint patent – in relation to cleaning road water runoff, patents pending in road water runoff attenuation), **Professor Gareth Pender** (surface runoff modelling specialist, responsible for many research projects – to a total of £1.5M - in his area including the prediction of sediment & pollution transport).

Fieldwork Capability. HWU has a fully equipped environmental chemistry laboratory with a full time instrument technician funded from research and consultancy income. Equipment includes: tandem mass spectrometer with gc and hplc interfaces; gc with ECD; ion chromatography system; Microtox toxicity testing system. Also available are two weather stations monitoring: rainfall, windspeed/direction, temperature, humidity, soil temperature and solar radiation. Full scale laboratory-based double gully pot testing facility, on-site double gully pots installed in housing developments within the Edinburgh area and prototype equipment for removing pollutants from single gully pots.

Aberdeen University

Aberdeen University is responsible for establishing the "Aberdeen Urban Experimental Catchment" (AUEC), which currently runs a number of projects and has a large potential for future studies on urban runoff. The **Aberdeen University Team** include: **Dr Dubravka Pokrajac** (groundwater and soil water hydraulics expert, with particular interests in modelling reactive contaminant migration in sub-surface zones, considerable experience in development of numerical models - FEM, FD, MOC, and transport processes in sub-surface model incorporated into GROW software package, currently co-ordinates tests on infiltration system installed at AUEC); **Dr Jorg Feldmann** (environmental analytical chemistry specialist, main research interests involve metal speciation through various media, manages £20K+ of research grants, 4 PhD students and one part-time technician).

Fieldwork Capability. AU has the above AUEC where a site has been modified to enable a soakaway to be continuously monitored regarding: rainfall intensity, runoff quantity and quality. Access to a fluids laboratory containing the following equipment: several flumes, Malvern particle sizer (Mastersizer MS1005) used for quick particle analysis, LDA for velocity measurements at fixed locations, PIV for full flow field measurement. Access is also available to a fully equipped environmental chemistry laboratory.

Stirling University

The Stirling University Team include: **Dr Nigel Willby** (freshwater ecology specialist with 10 years research experience, NERCF, contribution will focus on identifying strategies that will optimise the value of SUDS both in terms of local biodiversity planning and potential for pollutant storage in plant tissue).

Fieldwork Capability. The Stirling team are well equipped for the collection of general hydrological data in the field and have access to laboratories with facilities for the analysis of soil, sediment, water and vegetation. General facilities, equipment and departmental competences include: geographical information systems (IDRISI, ArcView, ArcInfo), remote sensing image analysis, Coulter counter, anion chromatography, AAS, soil thin section laboratory, light microscopy, ammonium & phosphate by colormetric auto-analysis, gamma spectrometry, auto water samplers, Guelph permeameter, stage recorders, portable theta probes for soil moisture determination, rapid in-situ gamma ray spectrometry.

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