Lamb Drove Sustainable Drainage Systems (SuDS) Monitoring Project

Final Report

Cambridgeshire County Council

March 2012
Final Report
9S7422

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LIST OF ABBREVIATIONS

BOD	Biological Oxygen Demand
CEH	Centre for Ecology and Hydrology
CIRIA	Construction Industry Research and Information Association
COD	Chemical Oxygen Demand
Defra	Department for Environment, Food and Rural Affairs
DEX	Dunfermline Eastern Expansion
EMC	Event-Mean Concentration
ERDF	European Regional Development Fund
FLOWS	Floodplain Land use Optimising Workable Sustainability
PAH	Polyaromatic Hydrocarbon
MAVIS	Modular Analysis of Vegetation Information System
SuDS	Sustainable Drainage Systems
TSS	Total Suspended Solids

1 INTRODUCTION AND BACKGROUND

1.1 Background

The Lamb Drove Sustainable Drainage Systems (SuDS) Showcase project that was completed in 2006, demonstrates sustainable water management techniques in a residential development. The SuDS Showcase project was part of the FLOWS (Living with Flood Risk in a Changing Climate) programme funded by the European Regional Development Fund (ERDF) through the INTERREG IIIB North Sea Region programme. Through this, SuDS and property flood-proofing measures were retro-fitted into the design of the Lamb Drove development site in Cambourne, Cambridgeshire including the following SuDS features:

- Water butts;
- Permeable pavement;
- Green roof;
- Swales;
- Filter strips;
- Under-drained swales;
- Detention basins; and
- A retention pond.

The main aim of the Showcase project was to reduce the impact of development on flood risk and reduce the vulnerability of new developments to flooding. The Lamb Drove site was developed and is managed by Cambridge Housing Society.

1.2 Introduction

Following on from the completion of the Lamb Drove SuDS Showcase project Cambridgeshire County Council commissioned Royal Haskoning to undertake the Lamb Drove SuDS Monitoring project between 2008 and 2011. The Monitoring project aimed to assess and compare the performance of a range of SuDS features with that of pipe drainage system. It compared two similarly sized sites within Cambourne - Lamb Drove (known as the Study Site) with its range of SuDS measures with that of Friar Way (known as the Control Site) with pipe drainage.

Funding support for the first two years of monitoring was provided by Defra, Cambridgeshire Horizons and the Environment Agency. Funding for the final year of monitoring was provided by Defra.

The Cambridge Housing Society has worked in partnership with Cambridgeshire County Council and Royal Haskoning through the whole monitoring project. The final year of monitoring built on the successes of the initial two year programme increasing the number of observations and specifically targeting the performance of the permeable pavement SuDS measure.

1.3 Purpose of the Report

This report documents the three years of monitoring. Appendix A shows the project plan for the monitoring project, outlining the key outputs for the study. This is separated into the programme for the first two years and the twelve month extension.

It focuses mainly on water flows and water quality although the project also covered a wider range of issues such as biodiversity and residents' views on the impact of SuDS on them and the community.

The purpose of this report is to document the key findings from the monitoring project,

1.4 Project Objective

The objective of this project is to carry out monitoring to identify any significant trends in flow volumes, water quality and environmental aspects, across the Study Site and between the Study Site and Control Site.

The monitoring focussed on the assessment of the following performance indicators:

A. Effectiveness of flow and volume attenuation (i.e. reduction in flow rates and volumes);
B. Effectiveness of water quality control (i.e. reduction in pollutant load to the receiving waters for key target pollutants – e.g. Total Phosphorus (TP), Total Nitrogen (TN), Total Suspended Sediment (TSS));
C. Environmental benefits – e.g. habitat (plants and macro-invertebrate counts in receiving waters) and amenity;
D. Maintenance costs and frequency;
E. Robustness and operation;
F. Whole-life costs; and
G. Residents' feedback on aesthetic appeal, health and safety and practicality of measures.

These indicators have been monitored over a three year period at the Study Site and the Control Site.

1.5 Site Location

Cambourne is a settlement located approximately 13km west of Cambridge spread over 1030 acres. Cambourne is situated on high ground, the surface water from which contributes ultimately to the Bourn Brook to the south. Historically, Bourn Brook has caused flooding to the nearby villages. In agreement with the Environment Agency, the runoff from the Cambourne development is limited to the greenfield rate (3 l/s/developed hectare) through strategic balancing lakes.

The Study Site is approximately one hectare in size and comprises 35 residential dwellings owned and managed by Cambridge Housing Society. It slopes from the west to lower ground in the east, and is bounded by a public footpath (a greenway) to the north and a "proposed" golf course to the east.

The Control Site at Friar Way has 29 residential dwellings within a total area of 0.8 ha. It generally falls from east to west towards the adjoining greenway and has a shallower slope than the Study Site. The location of the Study Site and the Control Site are shown in Figure 1.1.

The Study Site is constructed on largely impermeable clay which slopes gently from the north-west to the south-east. As a showcase project, it includes a wide range of SuDS features linked together as a management train to form the SuDS system. The main elements comprise permeable pavement on the road surfaces (part), an internal system of swales and detention basins and a more substantial receptor arrangement of swales and detention basins incorporated in the open space bounding the development on two sides. Other features include filter strips, water butts to the front and rear of every home and a small demonstration green roof.

The Control Site is drained using a pipe system which channels water directly into the strategic balancing lakes that serve the whole of Cambourne. The lakes are designed to store water from the Cambourne development, discharging it at the greenfield rate and removing pollutants prior to reaching the local watercourse known as the Bourne Brook.

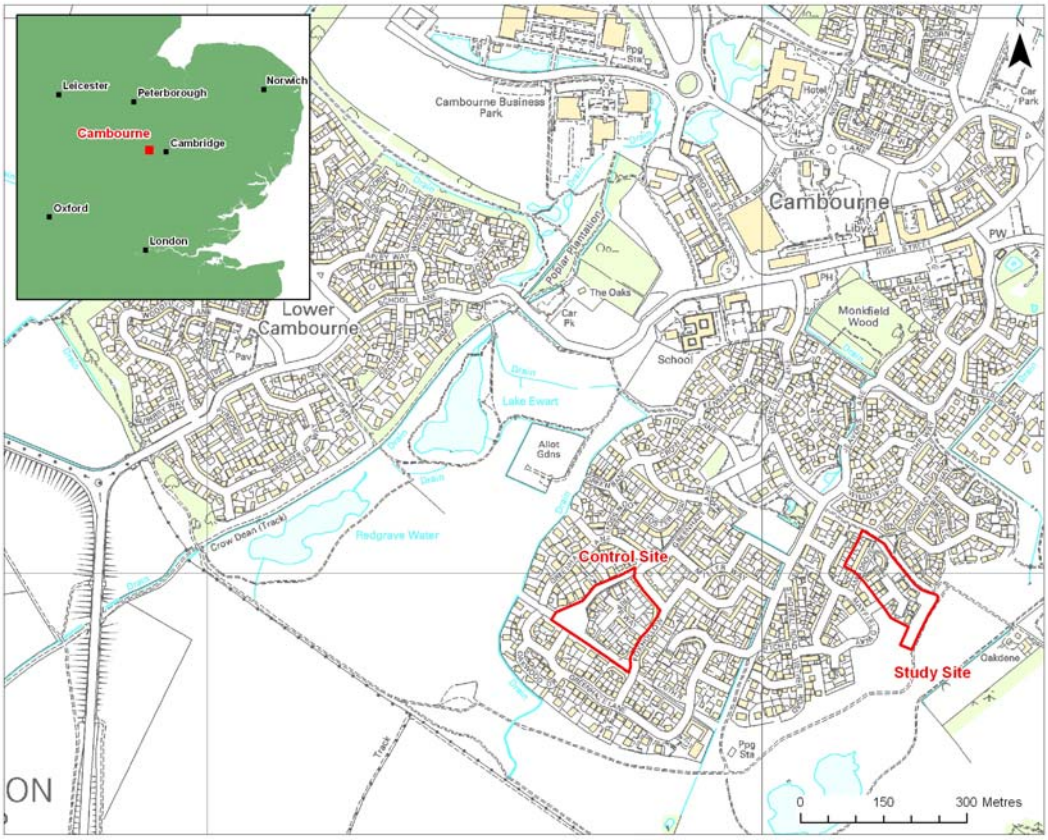

Figure 1.1: Study Area – Study Site and Control Site

2 METHODOLOGY

The methodology for monitoring and assessing the performance indicators is outlined in this section.

2.1 Flow Monitoring

The discharge of water from the Study Site was monitored by a system of automated flow measurement instruments at eight monitoring locations across the site (Figure 2.1).

Figure 2.1: Monitoring locations at the Study Site

The flow measurement instruments were supplied by RS Hydro and consist of eight v-notch weir control structures constructed to BS 3680 with a standard ¼ vee (28°) notch (Figure 2.2). Within each chamber is a water pressure monitoring device, with an attached data logger that continuously records the water level flowing through the weir (Figure 2.1; Monitoring Locations 1 to 8). These have been downloaded on a quarterly basis as part of the monitoring regime.

Figure 2.2: V-notch weir control structure at the Study Site

The water level data has been converted to discharge (m^3/s and l/s/ha) using the standard equations from BS 1438 that replaced BS 3680 in 2008. The full sampling results are shown in Appendix B.

In addition, at the end of the Study Site an automatic flow monitoring system has recorded the discharge leaving the site and sent this back to a website to allow continuous monitoring of the site (Figure 2.1; Site 9). An identical system has also been in place at the surface water drainage outfall of the Control Site located within a manhole access point (Figure 2.3).

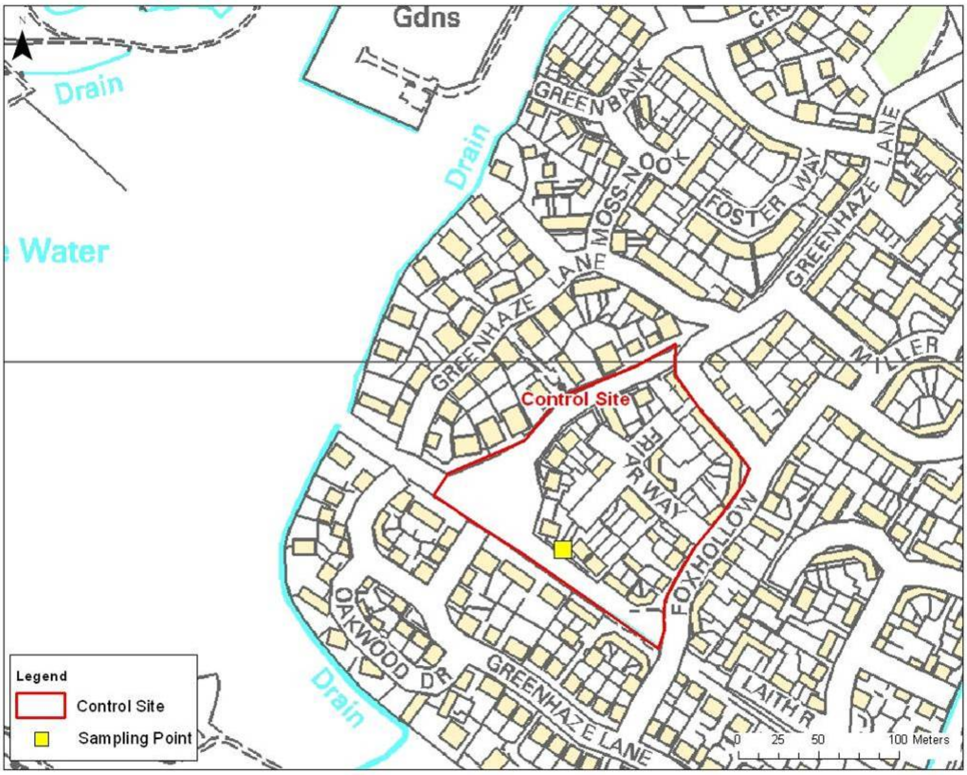

Figure 2.3: Control Site and sampling point

To fully appreciate the results from the Study Site it is necessary to understand the characteristics of the catchments area upstream of each of the monitoring locations. Table 2.1 documents the SuDS features upstream of each monitoring location and an estimate of its catchment area.

Table 2.1: Catchment characteristics for the monitoring locations at the Study Site

Monitoring Location	Catchment Area (m^2)	SuDS Features Upstream
1	4,200	• 400m^2 of permeable pavement • 1 detention basin • 10m of under-drained swale • 33 water butts • 27m^2 green roof
2	1,000	• 9 water butts
3	5,400	• 400m^2 of permeable pavement • 2 detention basins • 10m of under-drained swale • 50m of swales • 27m^2 green roof • 33 water butts
4	6,000	• 400m^2 of permeable pavement • 2 detention basins • 10m of under-drained swale • 90m of swales • 27m^2 green roof • 37 water butts
5	2,800	• 30m of under-drained swale • 250m^2 of permeable pavement

Monitoring Location	Catchment Area (m^2)	SuDS Features Upstream
		• 17 water butts
6	9,300	• 650m^2 of permeable pavement • 3 detention basins • 40m of under-drained swale • 90m of swale • 27m^2 green roof • 54 water butts
7	600	• 17m of under-drained swale • 8 water butts
8	10,100	• 650m^2 of permeable pavement • 3 detention basins • 57m of under-drained swale • 120m of swale • 27m^2 green roof • 62 water butts
9	10,600	• 650m^2 of permeable pavement • 3 detention basins • 57m of under-drained swale • 140m of swale • 27m^2 green roof • 62 water butts • 1 retention pond

2.2 Rainfall

Continuous rainfall data has being collected using two tipping bucket rain gauges with data loggers located within the Cambourne development site. These have been downloaded on a quarterly basis as part of the monitoring regime. Figure 2.4 shows the location of these gauges. In addition data has been obtained from Anglian Water Services Ltd for a gauge installed in Great Cambourne between January 2011 and August 2011.

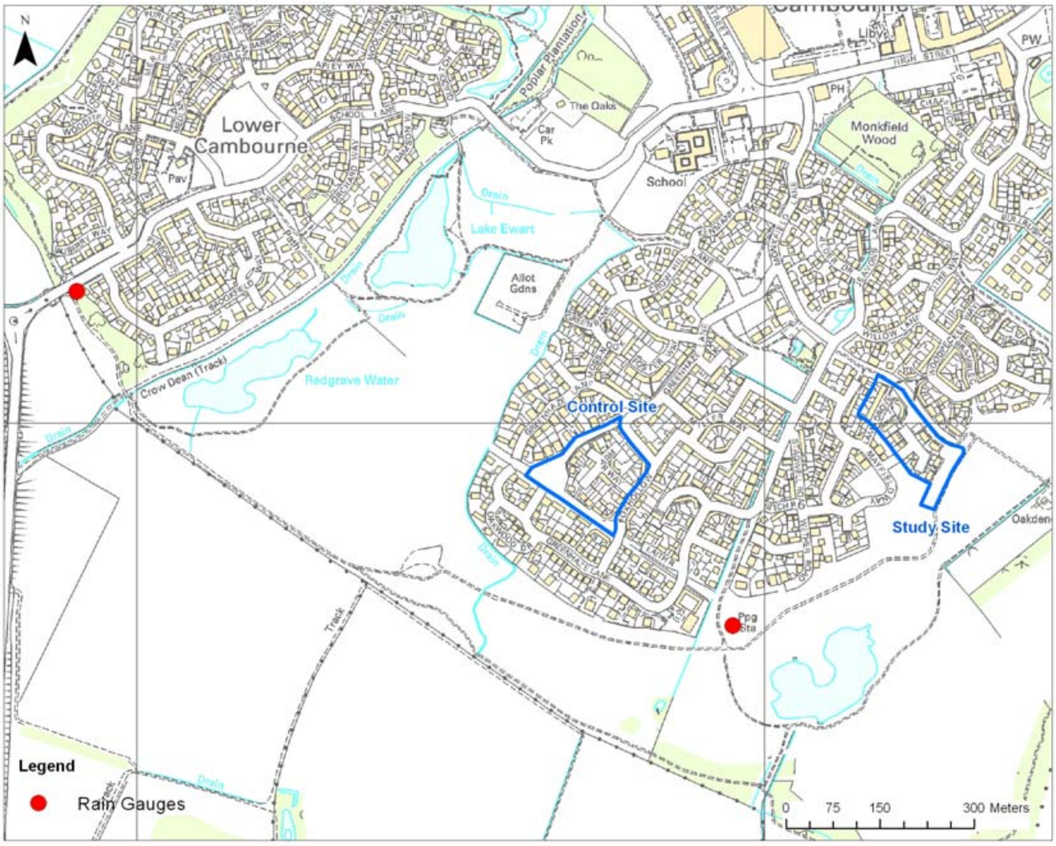

Figure 2.4: Location of Rain Gauges at Cambourne

2.3 Water Quality

Measurement of water quality sampling has been carried out at the eight v-notch weir control structure locations within the Study Site (Figure 2.1) and at the Control Site at the sampling point for flow monitoring (Figure 2.3). Quarterly samples have been collected and taken to the Anglian Water Services Ltd laboratory at Huntingdon for chemical analyses for concentrations of the parameters listed in Table 2.2. The full sampling results are shown in Appendix C.

Table 2.2: Water quality parameters

Water Quality Parameter	Unit
Total Suspended Solids	mg/l
Total Phosphorus	mg/l
Total Carbon	mg/l
Total Organic Carbon	mg/l
Total Nitrogen	mg/l
Total pH	pH
Ammonia-Nitrogen	mg/l
Biological Oxygen Demand	mg/l
Chemical Oxygen Demand	mg/l
Total Chromium	mg/l
Total Copper	mg/l
Total Zinc	mg/l
Total Lead	mg/l
Benzo(ghi)perylene	µg/l
Benzo(a)pyrene	µg/l

Benzo(b)fluoranthene	µg/l
Benzo(k)fluoranthene	µg/l
Indeno(1,2,3-CD)pyrene	µg/l

Due to the fact that water drains through the Control Site quickly following rainfall events, only six samples have been collected.

At Monitoring Location 2 no sample has been collected for a similar reason. The upstream catchment primarily comprises roofs and impermeable road/car parking surfaces. Therefore water drains past this point rapidly following rainfall and on no occasion has there been sufficient water for samples to be taken.

Table 2.3 indicates the number of samples obtained from each Monitoring Location and must be taken into account when considering the significance of the results.

Table 2.3: Number of water quality samples obtained from the Study Site and the Control Site

Monitoring Location	Number of Samples
1	10 (3 partial samples with only results for metals and phosphorous)
2	0
3	12 (2 partial samples where no results for hydrocarbons)
4	10 (1 partial sample where no results for hydrocarbons)
5	12 (1 partial sample where no results for hydrocarbons)
6	10 (1 partial sample where no results for pH, BOS, COD, ammonia and suspended sediments)
7	12
8	11 (1 partial sample with only results for metals and phosphorous)
Control Site	6

2.4 Environmental Benefit

The environmental benefit of the SuDS scheme has been assessed through habitat surveys. Extended Phase 1 Habitat Surveys were conducted in October 2007, May 2010 and June 2011. MAVIS analysis (Modular Analysis of Vegetation Information System) (CEH, 2000) and the DAFOR scale have been used to classify the vegetation present at both sites. The main aim of these surveys was to compare the impact of the SuDS scheme and the pipe drainage system on the types, quantities and diversities of both habitats and species present. A summary of the results can be found in Section 4.4.

2.5 Permeable Pavement Performance

The permeable pavement at the Study Site has not undergone the recommended maintenance since its installation. There has been biannual manual sweeping of the pavement since 2009 in March and November, however the recommended suction cleaning has not been undertaken.

Cranfield University was commissioned to assess the hydrological performance of the permeable pavement at the Study Site and the impacts of this reduced maintenance. Infiltration capacity testing was undertaken during June and July 2011 and compared to the recorded rainfall events and rainfall intensities estimated to have a 1% and 2% chance of occurrence once every year, to assess the performance of the pavement. Manual cleaning of the pavement was also undertaken to investigate the impact of maintenance upon performance. Figure 2.5 shows the locations of the infiltration testing measurement points. The results of this analysis are summarised in Section 4.5.

Figure 2.5: The infiltration measurement points on the permeable pavement

3 MAINTENANCE REGIME

To fully understand the results of the monitoring programme it is important to have a clear record of the maintenance carried out at the Study Site. The maintenance of the Study Site is the responsibility of Cambridge Housing Society and is carried out by their sub-contractor, Fordham Landscapes. The maintenance regime originally designed by Royal Haskoning (2006) includes details on levels of vegetation cutting, litter removal, and maintenance at the inlet and outlet structures (Appendix G).

During the first year of monitoring there were some issues with the maintenance not being carried out in accordance with the original maintenance schedule for the Study Site. To help address these issues Cambridgeshire County Council met with Cambridge Housing Society to clarify the maintenance schedule in March 2009 (Appendix G). Following on from this there was a site visit on 30th July 2009 with Royal Haskoning, Cambridgeshire County Council, Cambridge Housing Society and Fordham Landscapes present to explain the details of the required maintenance regime. The main focus of the visit was to establish what maintenance had been occurring and to educate the contractor so that they were able to follow the schedule correctly. Therefore the Study Site has been subject to differing maintenance regimes.

The main aspects of the maintenance that have a direct impact upon the performance of the SuDS concern vegetation cutting, clearance of litter and maintenance of the permeable pavement areas.

3.1 Pre Site Visit on 30th July 2009

Observations made during the monitoring visits revealed that on one occasion the vegetation in the base of the swales and detention basins was cut back significantly at the start of the growing season in contradiction to the maintenance schedule. Since that time these SuDS features were not cut at all allowing high wetland vegetation to colonise the sites where the ground is regularly saturated.

The remainder of the grassed areas on the site had been cut to a standard height of 50mm on a monthly basis. This includes the banks of the swales and detention basins, as well as the level areas of grass around the site between the SuDS features. At this point, the permeable pavement had received no maintenance since its installation in January 2006.

Another point to note is that the retention pond at the end of the SuDS management train had been filled with sediment from an unknown source, potentially the adjacent building site which had remained in an uncompleted state and which is likely to have affected the performance of this feature.

3.2 Post Site Visit on 30th July 2009

At the site visit changes to the previous maintenance regime were discussed and the following actions were agreed:

- Any litter on the site to be removed by the maintenance contractor during each visit;
- The swales and basins to be cut to a minimum length of 100mm;
- The tall vegetation in the bottom of the basins and swales to be cut to 100mm once annually in the autumn (October) and the cut vegetation to be removed from site;
- All other grass to be cut to the standard length of 50mm;
- The building waste in the pond at the bottom of the site was to be removed by hand using spades, to ensure vegetation is retained; and
- The approach for maintenance of the permeable pavement was confirmed by Royal Haskoning and communicated to Cambridge Housing Society.

Further monitoring showed that the vegetation cutting regime had changed in accordance with the maintenance schedule.

The permeable pavement has undergone some maintenance since the site visit in 2009. The pavement has been manually swept twice a year in March and November. However the recommended suction cleaning had not been carried out. The reduced maintenance regime was the trigger for the specific investigations by Cranfield University. This is discussed in full in their report (Appendix I).

During 2011 the Bovis Homes construction site adjacent to the pond and final swale at the downstream end of the site has been re-activated following several years of little activity. Figure 3.1 shows the downstream end of the Study Site during 2011; this shows that the retention pond has been surrounded on three sides by the site car park, access road and eastern boundary of the construction site. This has prevented access to the pond for any maintenance and is likely to have acted as a sediment source. Cambridgeshire Housing Society has stated that their contractor has not been able to access the pond to carry out maintenance since 2009.

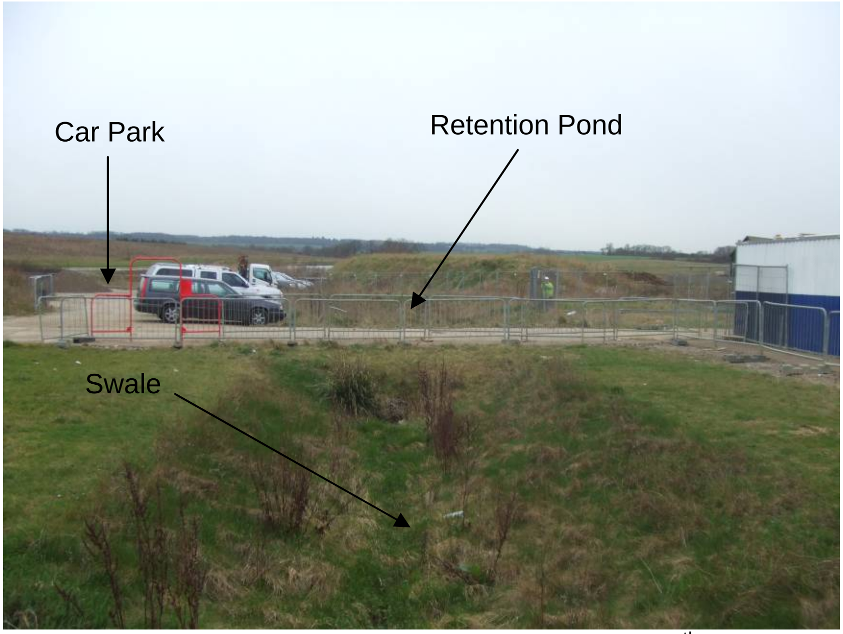

Figure 3.1: (a): Downstream end of the Study Site on 18th March 2011

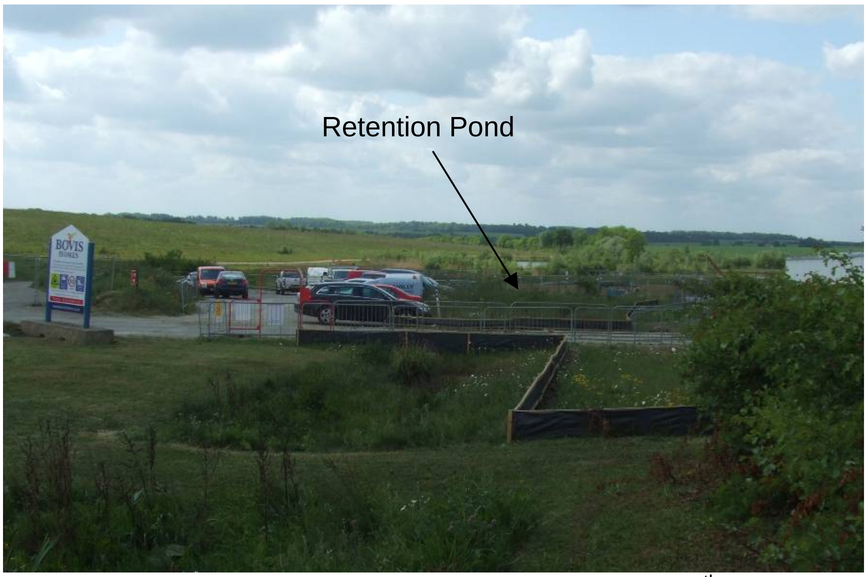

Figure 3.1 (b): Downstream end of the Study Site on 19th May 2011

Figure 3.1 (c): Downstream end of the Study Site on 4th November 2011

3.3 Whole Life Costs

Whole life costs are the total costs of the system throughout its entire life, primarily the capital costs for construction and then the on-going costs of maintenance.

3.3.1 Capital Costs

The capital costs of the scheme were £5,646 per property compared to an estimated cost for a traditional pipe drainage system of £5,960 per property. Therefore the SuDS system was £314 per property cheaper than the alternative pipe drainage system that would have been required for the Study Site.

3.3.2 Maintenance Costs

The overall cost to maintain the SuDS scheme at the Study Site is currently £1,340 per year, which equates to a total of 56 manpower hours. This includes maintenance associated with the following activities:

- Litter removal;
- Swales vegetation cutting;
- Filter strip vegetation cutting;
- Under-drained swales;
- Detention basins (vegetation cutting);
- Retention pond (vegetation cutting); and
- Permeable pavement (manual sweeping).

Most of the SuDS maintenance are carried out as part of the overall site maintenance. The costs are based on specific site visits to carry out the maintenance of the SuDS features. The permeable pavement has not undergone the recommended maintenance since its installation; this is due to the road not yet being adopted by Cambridgeshire County Council.

In contrast, maintenance costs associated with conventional pipe drainage systems would include, but is not limited to, the following activities:

- Cleaning and emptying of gully pots, silt traps and manholes;
- Jetting and cleaning sewers;
- Road sweeping;
- Litter removal; and
- Road verge landscape management.

Cost comparisons between conventional drainage systems and SuDS made by Dunfermline Eastern Expansion (DEX) (Duffy *et al.* 2008) with data collected relating to maintenance activities carried out over a five year period concluded that on average, the annual cost of maintaining SuDS is approximately 20-25% lower for SuDS, and whole-life maintenance costs of SuDS within the catchment were half that of the conventional alternative. This considered a range of SuDS features including detention basins, swales and permeable pavement. In addition DEX is located on low permeability clay soils similar to Cambourne and therefore as with the Study Site infiltration methods were not used, increasing the relevance of this comparison (CIRIA 2001).

As part of the justification for the Flood and Water Management Act, Defra considered the costs of maintenance for SuDS and conventional pipe drainage (Defra 2009). A value of £40 per property per year was taken for pipe drainage. Adjusted to present day prices a pipe drainage system at the Study Site would cost about £1,400 per year to maintain based upon 35 properties. Therefore at £1340/annum, the SuDS drainage system at the Study Site is has been cheaper to maintain than the corresponding estimated cost of a conventional pipe drainage system.

4 RESULTS AND ANALYSIS

4.1 Rainfall

Throughout the monitoring period the two rain gauges located within the Cambourne development have experienced issues which have led to gaps in the record.

The gauge at Great Cambourne recorded very little rainfall between August 2008 and March 2009, and between August 2009 and October 2009 in comparison to the gauge at Lower Cambourne. The flow monitoring equipment also suggests that there was more rainfall than was recorded by the Great Cambourne gauge. The Lower Cambourne gauge did not record data from February 2010 until July 2010. Finally the gauge at Great Cambourne was removed in July 2011 to allow for the adoption of the Jeavons Lane Pumping Station by Anglian Water Services Ltd.

Therefore the data from the two gauges has been combined to provide a reliable dataset which was used to analyse the relationship between rainfall and discharge. In addition data has been obtained from Anglian Water Services Ltd for a gauge installed in Great Cambourne between January 2011 and August 2011. This has been used to validate the data from the study gauges for this period.

The average monthly rainfall recorded is shown in Figure 4.1. The average annual rainfall recorded between August 2008 and October 2011 was 528mm, with the most rainfall being recorded in August, with significant amounts also falling in November and

February. The average annual rainfall is in line with the average observed at Cambridge between 1971 and 2000 of 553.5mm (Met Office 2011).

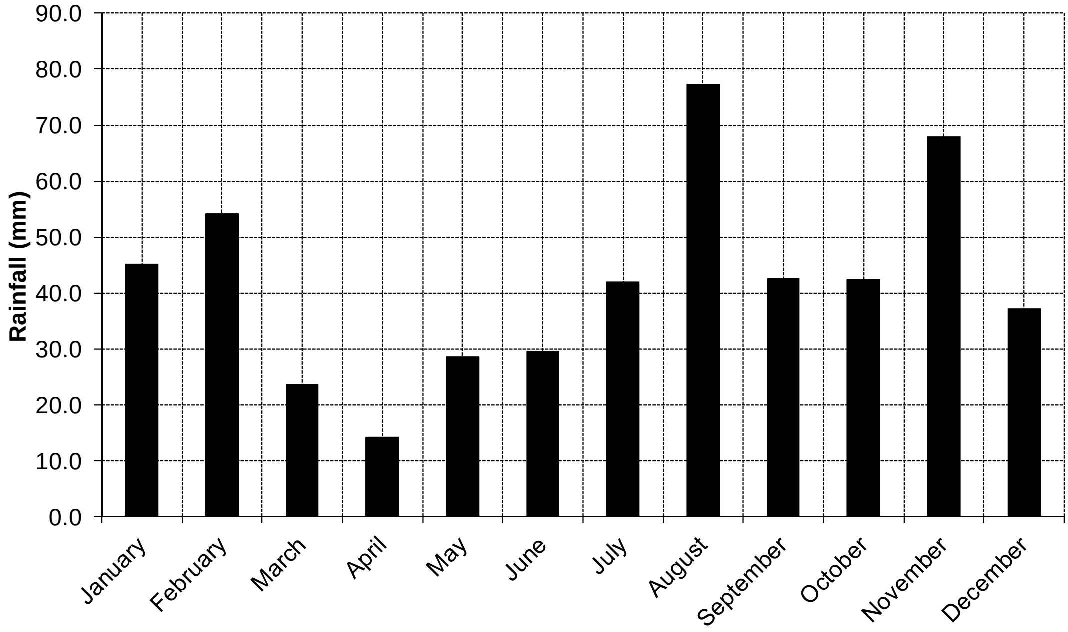

Figure 4.1: Average monthly rainfall recorded at the Cambourne gauges

4.2 Discharge

To analyse the discharge of water through the Study Site several representative rainfall events have been analysed as well as assessing the maximum recorded discharge at the various recording points within the Study Site.

The full record of discharge at each of the locations is included in Appendix B. This illustrates that while overall the peaks in discharge occur within a consistent range at each site there have been some anomalies suggesting significantly higher discharges.

4.2.1 Comparison with Control Site

To assess the effectiveness of the Study Site in attenuating flows following a rainfall event, the discharge recorded by the automatic systems at Monitoring Location 9 at the Study Site and at the Control Site were analysed for an event on the 13th and 14th December 2008 (Figure 4.2a) and 29th September 2010 (Figure 4.2b).

In December 2008 the discharge at the Control Site responded quickly to the rainfall and the peaks in discharge mirror those in the intensity of the rainfall. There are two distinct peaks in discharge at 20:15 and 22:00 on the 13th December reflecting the peaks in rainfall. In contrast the discharge at the Study Site occurs much later and is far lower than the Control Site. The only peak in discharge at the Study Site occurred at 00:00 on the 14th December and is likely to be the result of all the preceding rainfall.

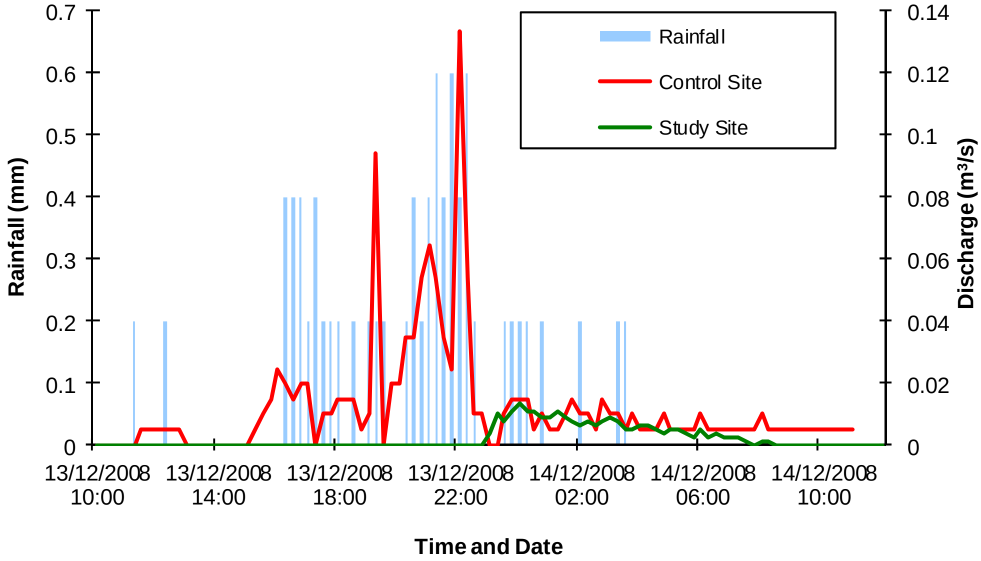

Figure 4.2a: Comparison of Discharge at the Study Site and the Control Site on the 13th and 14th December 2008

The event in September 2010 displays a similar pattern in terms of the Control Site reflecting the rainfall pattern. However, the Study Site responded more quickly to the rainfall on this occasion. The discharge from the Control Site as before is far higher than that at the Study Site.

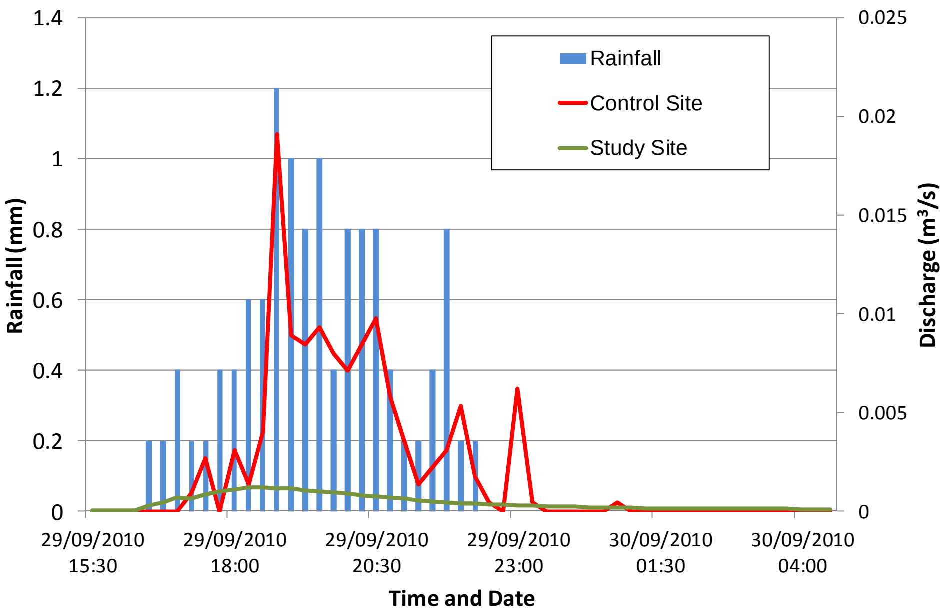

Figure 4.2b: Comparison of Discharge at the Study Site and the Control Site on the 29th of September 2010

These events indicate how the impermeable surfaces and pipe drainage at the Control Site facilitate rapid transfer of water through the system. In contrast, the SuDS system attenuates discharge from the Study Site and delays the time at which the peak discharge occurs. The SuDS system increases the time between the peak in rainfall and the peak in discharge from the Study Site, and the peak in discharge is far reduced in comparison to that of the Control Site.

4.2.2 Analysis of Discharge within the Study Site

To assess how the different elements of the SuDS system at the Study Site are performing, the discharge recordings for the eight Monitoring Locations as shown in Figure 2.1 have been assessed.

Table 4.1 shows the maximum recorded discharge at the eight Monitoring Locations from the 1st September 2008 to the 30th October 2011.

These results reflect the location of the various Monitoring Locations, particularly the SuDS treatment chains that precede them and their respective catchment areas.

Table 4.1: Maximum recorded discharge at the Study Site

Study Site Monitoring Location	Maximum Discharge (m^3/s)
1	0.006
2	0.009
3	0.017
4	0.005
5	0.015
6	0.018
7	0.002
8	0.003

Table 4.2 shows the maximum recorded discharge per hectare at the eight Monitoring Locations from the 1st September 2008 to the 30th October 2011 based on the catchment areas displayed in Table 2.1. This illustrates the influence of the various SuDS features on discharge through the Study Site.

Table 4.2: Maximum recorded discharge at the Study Site

Study Site Monitoring Location	Maximum Discharge (l/s/ha)
1	14.0
2	95.0
3	31.2
4	8.4
5	54.1
6	19.8
7	31.9
8	3.1

The highest recorded discharge per hectare by a considerable margin is that at Monitoring Location 2. This can be accounted for by the fact that it is fed directly by a sub-catchment with no permeable surfaces and only 9 water butts to attenuate flows (See Figure 2.1). This increases the rate of overland flow and hence the highest recording at Monitoring Location 2 compared to other Monitoring Locations.

The lowest discharge per hectare is at Monitoring Location 8 illustrating the attenuation provided by the whole treatment train except for the final swale and retention pond. The design criterion for Cambourne is to achieve a discharge rate of 3l/s/ha. At Monitoring

Locations 8 the SuDS features have almost achieved this within the monitoring period without the attenuation provided by the final two features (a swale and the retention pond).

To investigate how the SuDS system delays the transfer of water from the Study Site as well as attenuating the discharge five events were analysed (26th May 2009, 7th June 2009, 5th November 2009, 21st March 2010 and 16th July 2011). Figure 4.3(a), 4.3(b), 4.3(c), 4.3(d) and 4.3(e) show discharge and rainfall at various Monitoring Locations in the Study Site for these events.

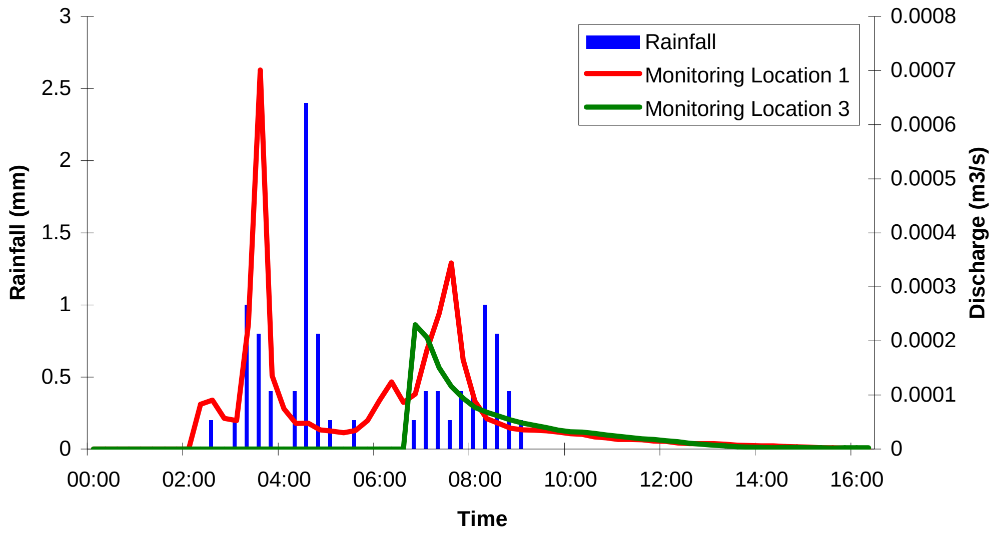

Figure 4.3(a): Rainfall and discharge at the Study Site on the 26th May 2009

Figure 4.3(a) shows how Monitoring Location 1 at the beginning of the system responds quickly to rainfall with the two peaks in discharge reflecting the peaks in rainfall. Monitoring Location 3 responded far slower in this event with a noticeable reduction in discharge. Monitoring Locations 4 and 8 did not register any discharge for this event.

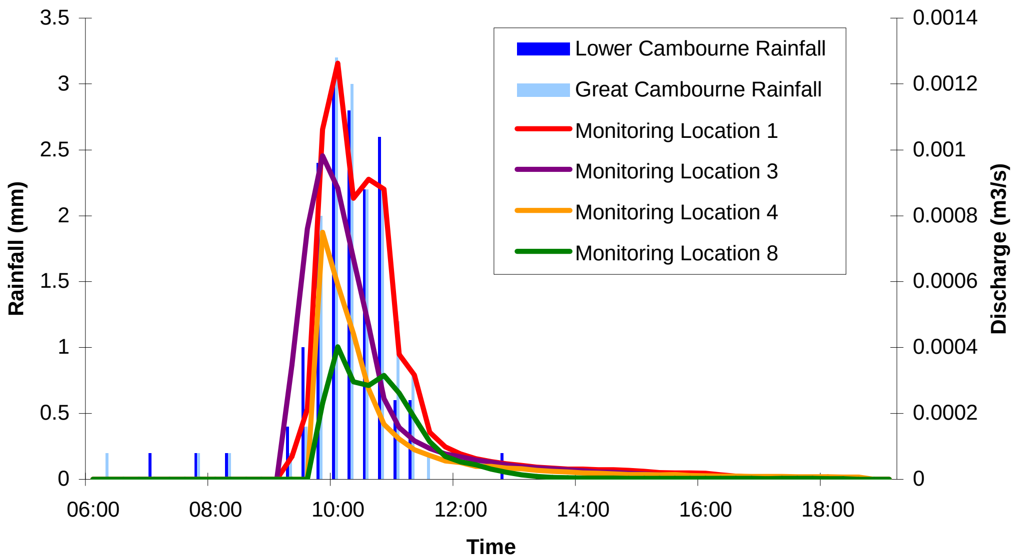

Figure 4.3(b): Rainfall and discharge at the Study Site on the 7th June 2009

Figure 4.3(b) shows how the system responded to a more intense rainfall event. The peak discharge recorded reduced through the site as more of the SuDS features within the treatment train were utilised, with Monitoring Location 1 recording far greater peak discharge than Monitoring Location 8. However, there was no significant delay in the timing of peak discharge between the sites and the discharge closely followed the pattern of rainfall.

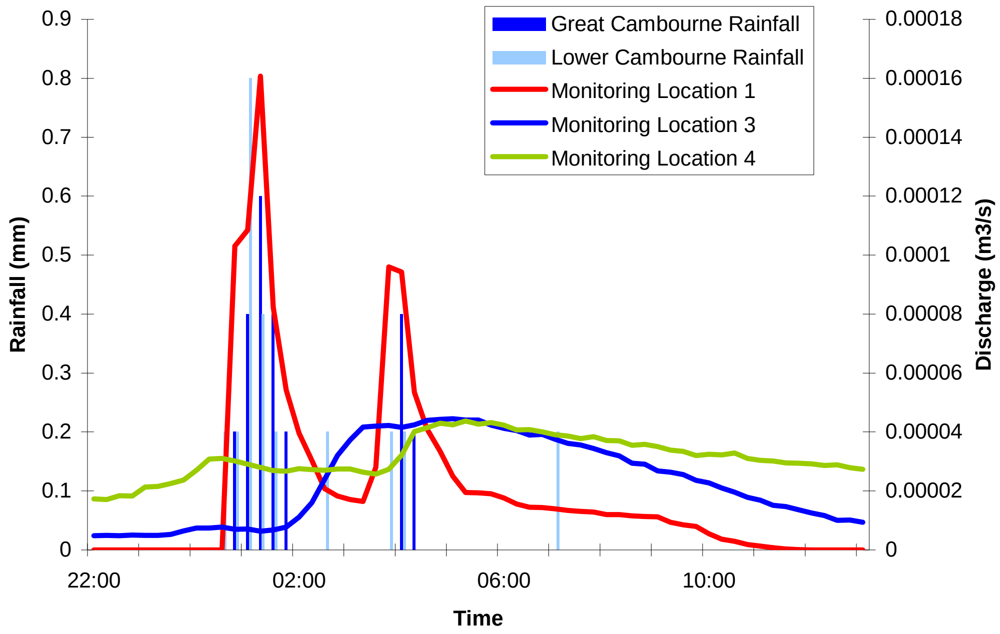

Figure 4.3(c): Rainfall and discharge at the Study Site on the 5th November 2009

Figure 4.3(c) once again shows that peak flow at Monitoring Location 1 closely follows the peak of the rainfall event, compared to Monitoring Locations 3 and 4 which observed reduced trends and greater lag times between peak rainfall and peak flows.

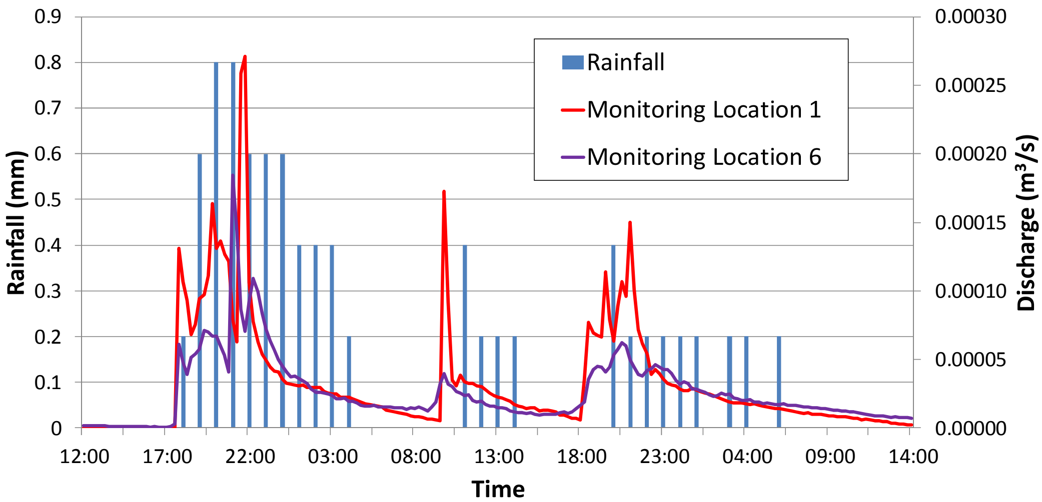

Figure 4.3(d): Discharge at the Study Site on the 19th – 21st March 2010

Figure 4.3(d) once again illustrates the effects of the SuDS system, by not only delaying the transfer of water through the system but also reducing flow volumes.

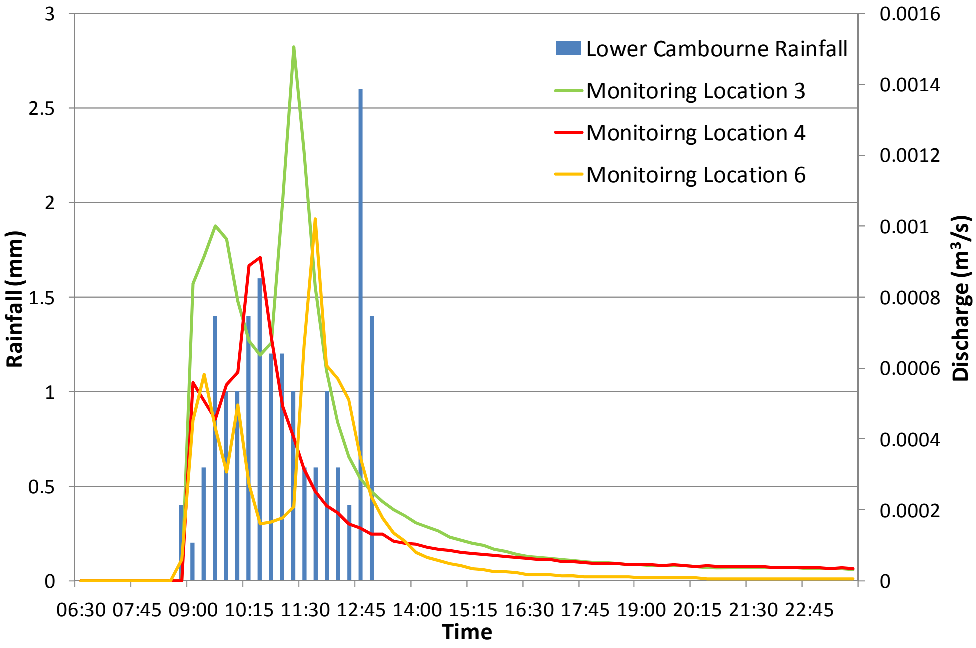

Figure 4.3(e): Discharge at the Study Site on the 16st July 2011

Figure 4.3(e) once again illustrates the effects of the SuDS system, by delaying the transfer of water through the system and reducing the impact of a rainfall event. The increased maximum discharge at monitoring location 6 in comparison to monitoring location 4 is likely to be caused by the additional that occurs upstream of monitoring location 6.

4.3 Water Quality

This section assesses significant water quality trends of the Study Site compared to that observed at the Control Site. It also draws on the water quality trends observed throughout the Study Site.

The water quality results reflect the conditions at the site on the day of the monitoring visits. Therefore, the statistical validity of the conclusions is limited as they are based on a maximum of twelve samples at any one Monitoring Location. They are also affected by the weather conditions leading up to and on the day of the visits.

4.3.1 Comparison of Study Site and Control Site

To compare the effectiveness of the SuDS measures at improving water quality the results from Monitoring Location 8 at the Study Site have been compared to those obtained from the Control Site.

Polycyclic aromatic hydrocarbons (PAH) are of concern in surface water runoff as they disrupt biological cell function and are known to be carcinogenic (Ellis and Chatfield, 2000). Five different PAH have been tested for in the water quality samples taken from the Study Site and Control Site which include Benzo(a)pyrene, Benzo(ghi)perelyene, Benzo(b)fluoranthene, Benzo(k)fluoranthene and Indeno(1,2,3-CD)pyrene. Figure 4.4 shows the concentrations of PAH at the two sites and as expected the results show that there are significantly higher concentrations at the Control Site in comparison to the Study Site. The primary source of hydrocarbons in such residential environments is parked vehicles, at the Control Site these are washed directly off the parking areas and into the surface water drainage system. At the Study Site they are retained within the SuDS features, where they naturally biodegrade.

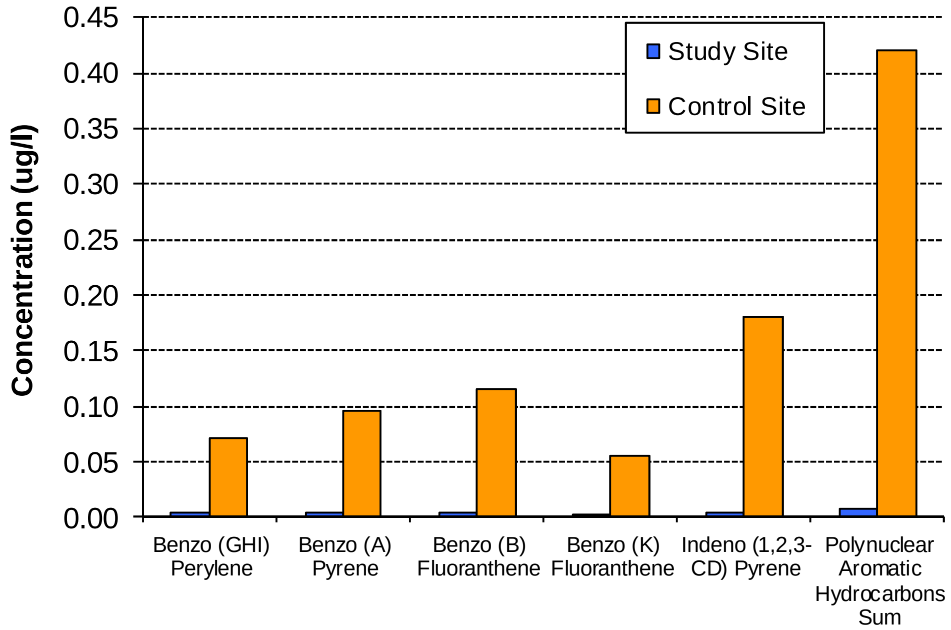

Figure 4.4: Comparison of hydrocarbon concentrations at the Study Site and Control Site (2008 – 2011)

Heavy metal concentrations in runoff are of concern as they can become toxic to aquatic species. At the Study Site and Control Site the concentration of Copper, Zinc, Lead and Chromium have been measured. Research suggests that there are a variety of sources of these metals in the residential environment including corrosion of parked vehicles, roof runoff and atmospheric deposition (Wilson *et al.* 2004). Figure 4.5 shows the concentration of heavy metals at the two sites; in all cases these are higher at the Control Site. The removal of heavy metals by SuDS systems occurs through adsorption of the pollutants onto the soil within the SuDS features. While at the Control Site the metals are washed directly off the parking areas and into the surface water drainage system.

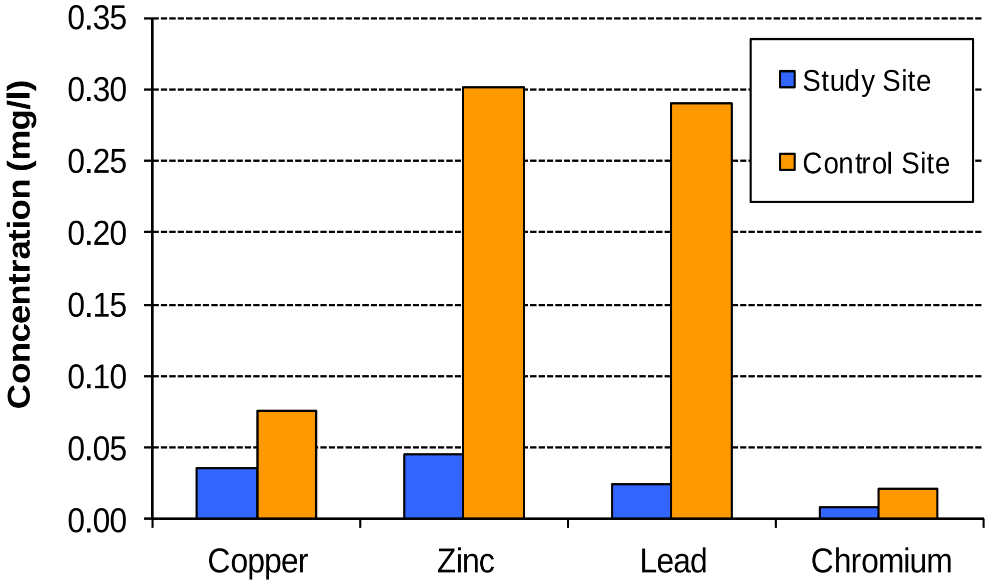

Figure 4.5: Comparison of heavy metal concentrations at the Study Site and Control Site (2008 – 2011)

Four other indicators that show higher levels at the Control Site in comparison to the Study Site are Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Organic Carbon and Suspended Solids (Figure 4.5).

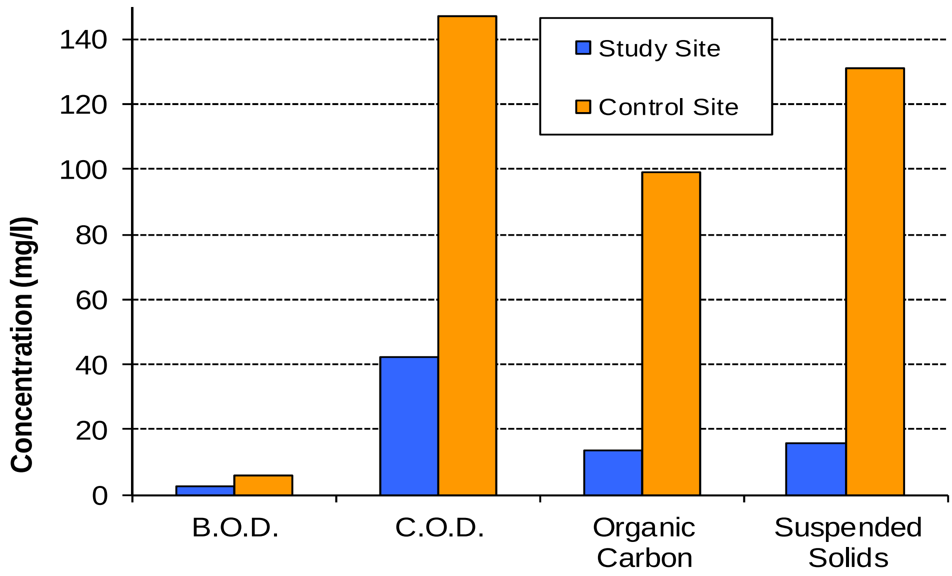

Figure 4.6: Comparison of BOD, COD, organic carbon and suspended solids at the Study Site and Control Site (2008 – 2011)

4.3.2 Comparison within the Study Site

To analyse the distribution of pollution across the Study Site the water quality samples have been analysed for significant trends. It should be noted that due to a lack of water for sampling, no samples have been recorded from Monitoring Location 2. This can be accounted for by the limited permeability of the sub-catchment. In contrast, the majority of flows, from this sub-catchment during rainfall events, flow overland and flush straight through to downstream Monitoring Locations.

For several of the samples, the results returned values lower than the level detectable by the testing procedures. In these cases it has been assumed that the concentration of the variable was equal to the concentration below which the test cannot detect. Therefore if the limit of detection was 0.07mg/l and the test returned a result of <0.07mg/l then it was assumed to be 0.07mg/l.

Heavy Metals

The average concentration of metals across the Study Site does show some significant trends (Figure 4.7). Mitchell (2001) reported Event-Mean Concentrations (EMC) of a range of pollutants for various land uses.

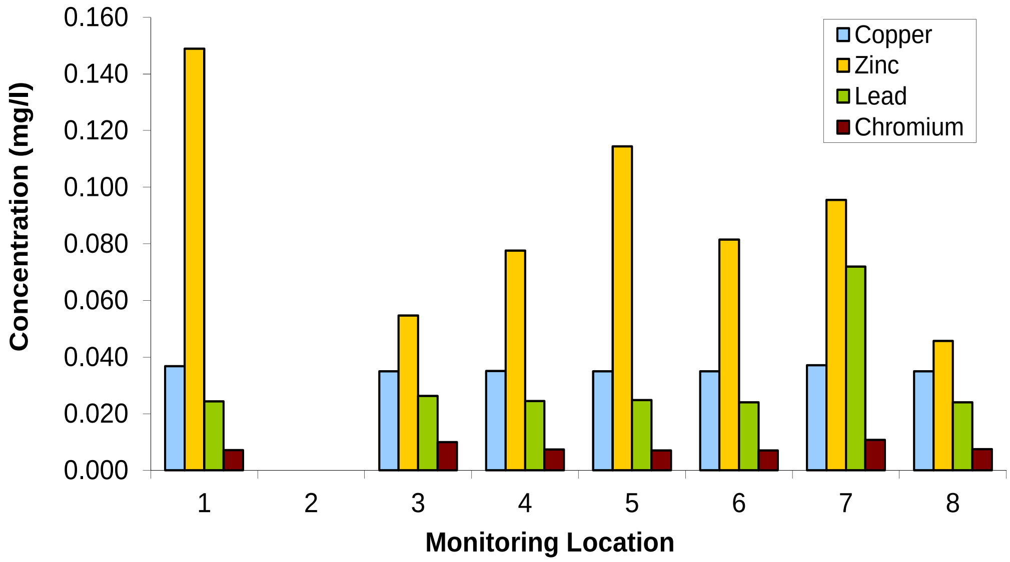

Figure 4.7: Average metal concentrations at the Study Site (2008-2011)

The most significant reduction in metal concentration can be seen in zinc which reduces from an average concentration of 0.15mg/l at Monitoring Location 1 to 0.046mg/l at Monitoring Location 8. Lead is seen in its highest concentration at Monitoring Location 7 (0.72mg/l), which although being located towards the end of the system does have a similar upstream catchment to Monitoring Location 1. The mean concentration for zinc and lead from residential land uses were reported to be 0.297mg/l and 0.141mg/l respectively. These values are higher than all of the samples from the Study Site.

The EMC for chromium is only reported for a generic ‘Urban’ category, which gives 0.007mg/l. Measurable levels of chromium are present at Monitoring Locations 1, 3 and 4; the testing procedure cannot measure levels of chromium below 0.007mg/l and this is the case for all samples from the other Monitoring Locations. Therefore the majority of the Monitoring Locations have levels of chromium below that reported by Mitchell (2001).

There is also a small reduction in copper from Monitoring Locations 1 and 7 to the rest of the Monitoring Locations from 0.037mg/l to 0.035mg/l. For Copper the EMCs are reported as 0.028mg/l for ‘Urban Open’ and 0.051mg/l for ‘Developed Urban’.

Total Suspended Solids

Total suspended solids (TSS) increase turbidity and lower dissolved oxygen levels in water bodies. The main sources of TSS in the residential environment are soil erosion and road surfaces (Wilson *et al.* 2004). The average TSS concentrations across the Study Site (Figure 4.8) are in the general range reported by Mitchell (2001). The EMC for residential land uses is reported to be 85mg/l. Ferrier and Ellis (2000) reported an EMC for TSS of 100mg/l for low density residential land use. All of the Monitoring Locations for the Study Site show concentrations below these levels except for Monitoring Locations 3, 4 and 7, with Monitoring Locations towards the end of the Study Site showing generally reduced concentrations.

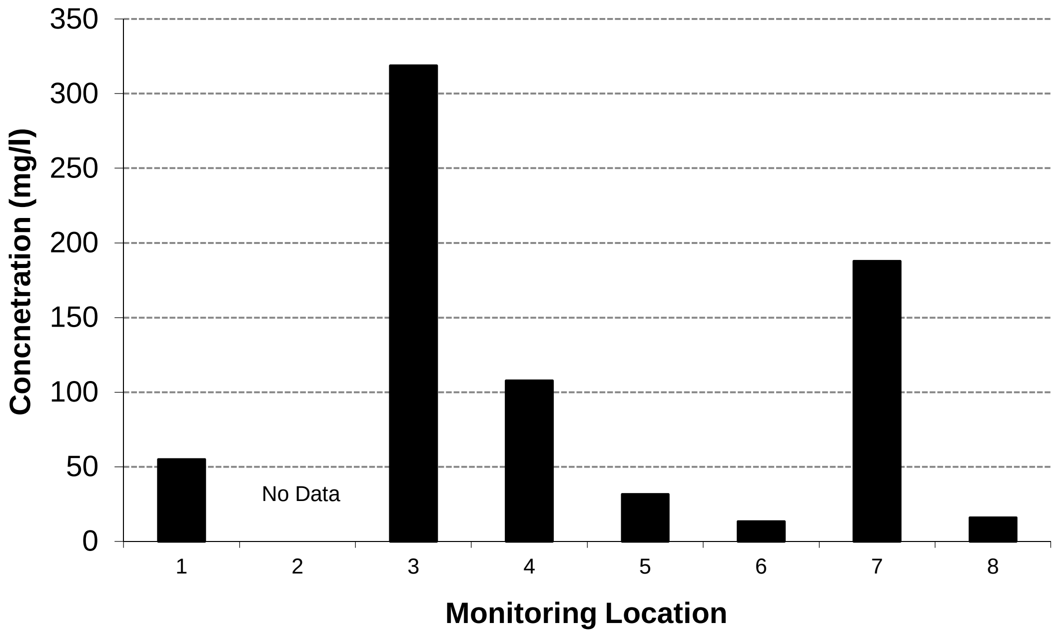

Figure 4.8: Concentration of Total Suspended Solids at the Study Site (2008-2011)

The high levels of TSS at Monitoring Locations 3 and 4 are thought to be the result of additional sediment input from the loose gravel cycleway that runs parallel to the Study Site at these locations. Then interestingly high concentrations are also observed at Monitoring Location 7 when compared to Monitoring Location 6. This can be explained by considering the SuDS features and catchment characteristics upstream of Monitoring Location 7, where water is collected from a series of small under-drained swales, an area of permeable pavement and a large area of impermeable road surface, as opposed to Monitoring Location 6 which receives water from a wide range of SuDS features, including three detention basins upstream.

Hydrocarbons

The concentration of the hydrocarbons tested for at the Study Site (Figure 4.9) follows the pattern observed with the TSS. This is the case as hydrocarbons attach themselves to fine particles through surface adsorption. MacKenzie and Hunter (1979) found that 86% of hydrocarbons were associated with particulates, and Hoffman *et al.* (1982) suggested this figure may be as high as 93%. This recognised correlation between TSS and hydrocarbons that is reflected in the results also explains the ability of SuDS to improve water quality. The SuDS features are designed to trap sediment, therefore the water leaving the SuDS feature should contain less sediment and therefore less hydrocarbon pollution.

The general trend in PAH concentrations can best be explained in the same way as with TSS. Monitoring Locations 3 and 7 give the highest concentrations and this is attributed to their proximity of the cycleway outside the site and the impermeable pathway within the site to Location 3 and the position of Location 7 within the context of the system. Overall the SuDS features appear to be causing a reduction in the concentration of hydrocarbons in discharge through the Study Site.

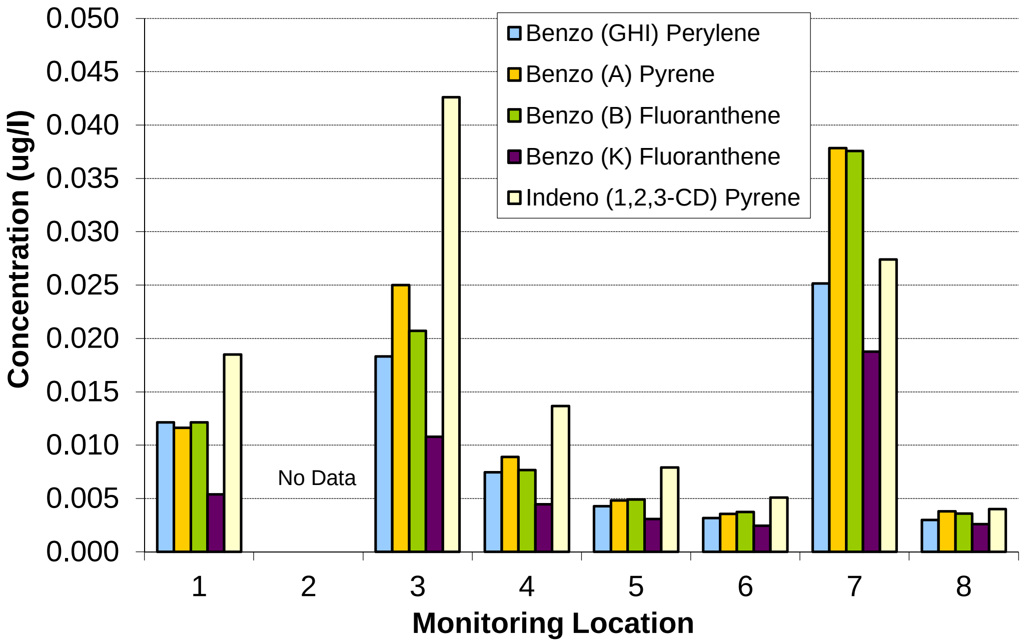

Figure 4.9: Concentration of Polycyclic Aromatic Hydrocarbons at the Study Site (2008-2011)

Phosphorous and Nitrogen

The concentration of phosphorus and nitrogen in surface runoff are important because of their role in aquatic eutrophication of water bodies. Sources of these pollutants in the residential setting include vegetation/landscape maintenance, soil erosion and atmospheric deposition (CIRIA, 2007; Wilson *et al.* 2004).

Over the Study Site the levels of phosphorus fluctuate with the highest value recorded at Monitoring Location 8 (Figure 4.10). Mitchell (2001) reported mean phosphorus EMC for residential runoff of 0.41mg/l. This is similar to the values for the Study Site. It is also apparent that the highest concentrations have been recorded at Monitoring Locations 4, 7 and 8. The overall trend of phosphorus concentrations follows that already discussed for TSS and PAH, apart from the high concentrations at Location 8. The high concentration at Location 8 is in contradiction to the trends shown by the other pollutants and may be due to a point source or a significant input from the catchment that joins the treatment train through Monitoring Location 7.

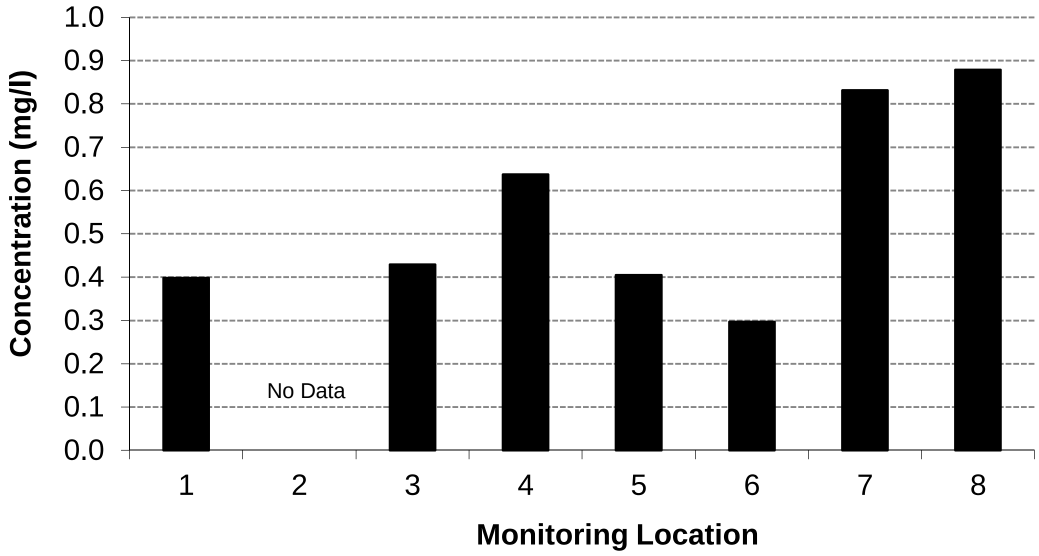

Figure 4.10: Concentration of Phosphorus at the Study Site (2008-2011)

Nitrogen levels rise slightly from Monitoring Location 1 to Monitoring Location 5 before gradually reducing towards the end of the treatment train at Monitoring Location 8 with the exception of Monitoring Location 7 (Figure 4.11). The mean nitrogen EMC reported by Mitchell (2001) was 2.9mg/l; the Monitoring Locations at the Study Site gave concentrations around this value, with an apparent influxes at Monitoring Locations 5 and 7. These are likely to be caused by localised sources of pollution such as the nearby gardens.

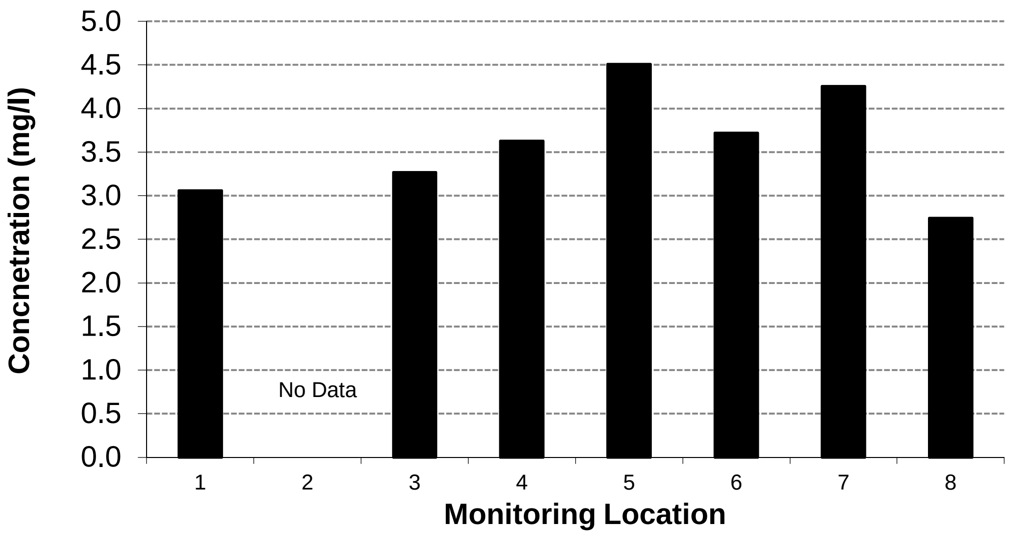

Figure 4.11: Concentration of Nitrogen at the Study Site (2008-2011)

Chemical Oxygen Demand

The Chemical Oxygen Demand (COD) is an indirect measure of the amount of organic compounds in water. Residential EMC values for COD were reported as having a mean value of 80mg/l for residential land uses (Mitchell, 2001). The levels recorded at the Study Site are all below this level except for Monitoring Locations 3 and 7 (Figure 4.12). Monitoring Location 7 may have higher levels than the Monitoring Locations around it due to its catchment characteristics. Overall there is still the general trend of a reduction in concentrations as water flows towards to end of the SuDS treatment train at Monitoring Location 8.

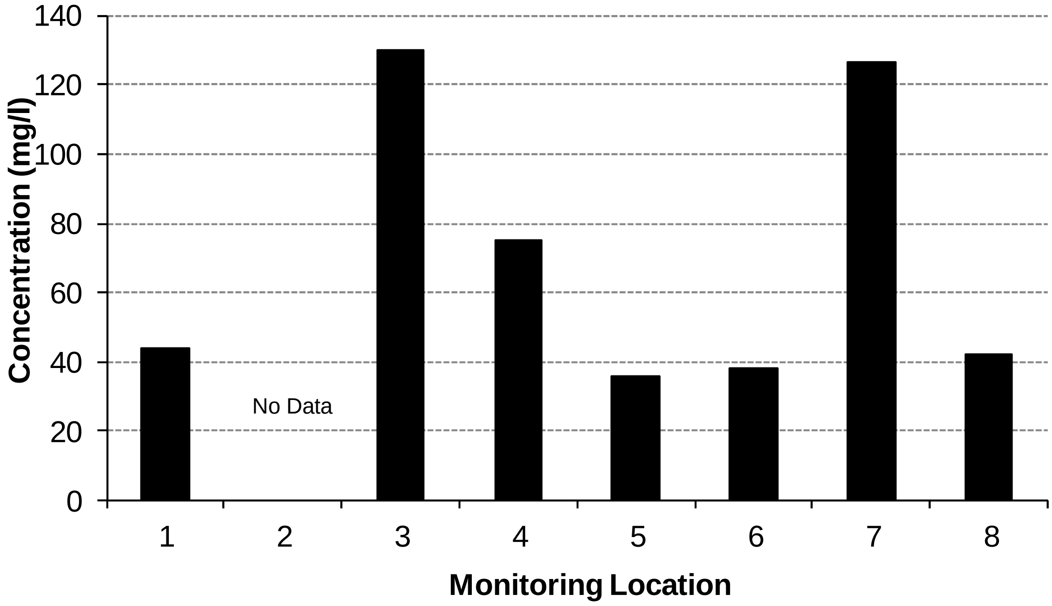

Figure 4.12: Chemical Oxygen Demand in runoff at the Study Site (2008-2011)

Biological Oxygen Demand

The Biological Oxygen Demand (BOD) is a measure of the oxygen consumption of a water sample and high BOD levels of are an indication of poor water quality. This is usually the result of organic matter which removes dissolved oxygen from water bodies (Wilson *et al.* 2004). The results from the Study Site follow the general pattern of many of the other indicators considered; overall there is a general reduction in BOD with peaks at Monitoring Locations 3 and 7 (Figure 4.13). Residential EMC values for BOD were reported as having a mean value of 8.5mg/l for Residential land uses (Mitchell, 2001); all of the Monitoring Locations at the Study Site are below this level with the exception of Monitoring Location 7. The level at the end of the treatment train is only 2.2 mg/l (Monitoring Location 8).

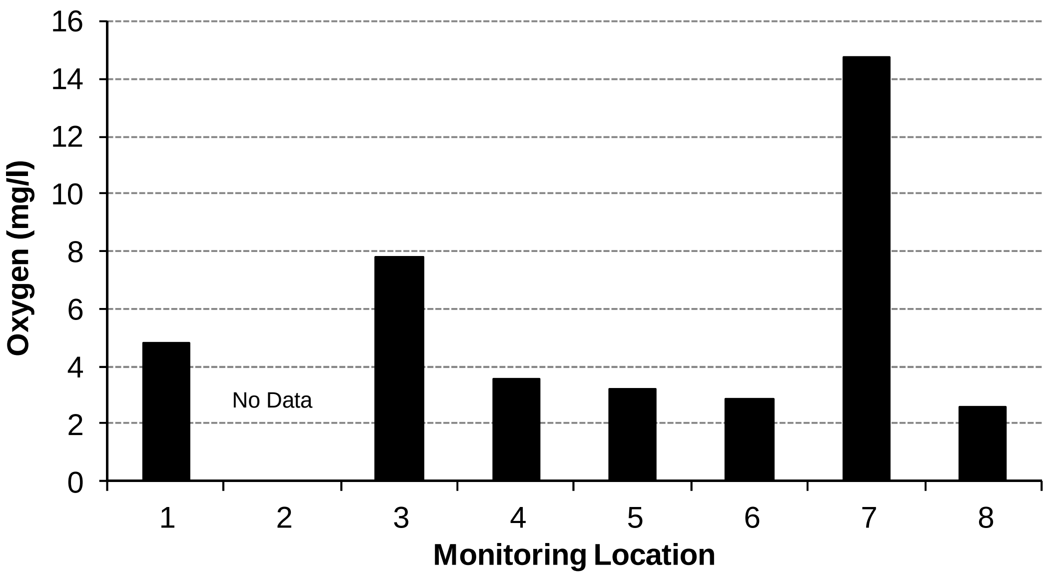

Figure 4.13: Biological Oxygen Demand in runoff at the Study Site (2008-2011)

Ammonia

Ammonia levels are used as an indicator of organic pollution, and can be highly toxic to aquatic fauna (Foy *et al.* 2000). The results from the samples taken from the Study Site show a reduction in the concentration of ammonia through the SuDS system, except for the anomalously high levels at Monitoring Location 7 (Figure 4.14). This is likely to be due to the nature of the catchment for Monitoring Location 7.

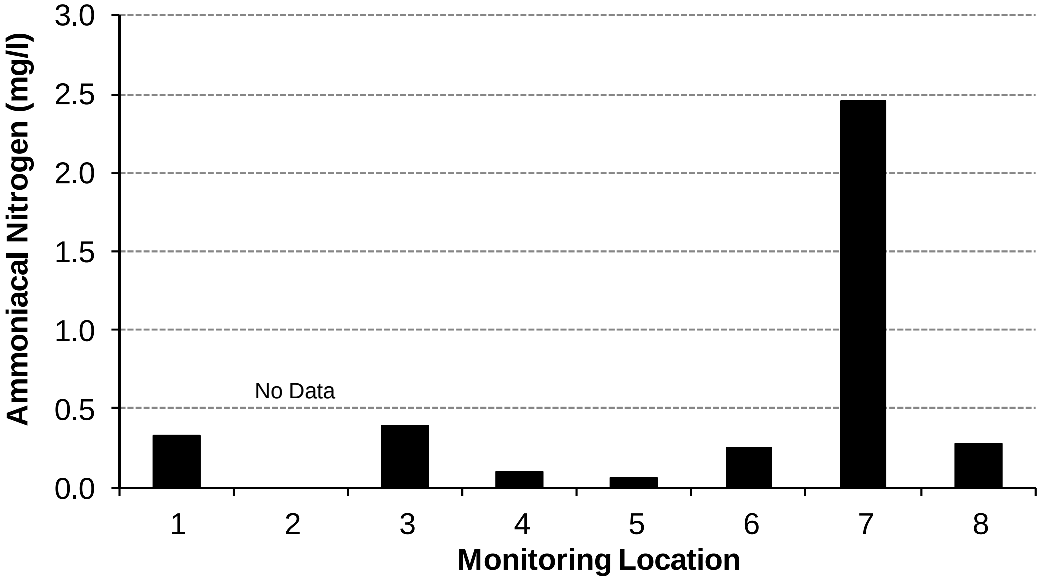

Figure 4.14: Concentration of Ammonia at the Study Site (2008-2011)

Other Parameters

The other parameters of pH and total organic carbon did not show any significant trends through the Study Site.

Overall, in line with the performance indicators outlined in Section 1.2, the SuDS system at the Study Site is acting to improve water quality when compared to the Control Site, and thereby is reducing pollutant loads discharging into the strategic balancing lakes and then ultimately into Bourn Brook.

4.4 Environmental Benefit

The extended Phase 1 Habitat Surveys were carried out in October 2007, May 2010 and June 2011. Since the first survey in 2007, both the Study Site and Control Site have maintained a moderate diversity of plant species which are of limited conservation significance. However, there has been a decline in the total number of plant species recorded the Control Site from 34 plant species in 2007 to 21 species in 2011. This decline has been primarily due to the transition from poor semi-improved grassland to amenity grassland between 2007 and 2011. It is also possible that weather conditions, in particular the dry period before the survey could also have impacted species numbers.

The Study Site has shown a slight increase in numbers, from 30 to 34 species present. Since 2007 there has been an increase in ephemeral/short perennial species such as ox eye daisy and black medick. Yarrow has also increased dramatically on site, especially around the lower swales. In 2011 common mallow was recorded on site after being absent since 2007. The marginal and aquatic plant species first recorded on site have not been seen since 2007 and flag iris and rush species are now the only aquatic plants present on the site.

Although a detailed assessment of invertebrate species was not undertaken, a number were noted at the Study Site during the 2009 and 2011 surveys. A range of butterflies, damselflies, grasshoppers and bumble bees were noted and is evidence of the diversity within the SuDS area and the importance of the habitats present. In addition amphibians have been seen in the swales and basins during the regular monitoring visits, these were not seen during the habitat surveys.

MAVIS analysis (Modular Analysis of Vegetation Information System) (CEH, 2000) analysis has been used to classify the vegetation present at both sites in the previous surveys. In 2007, the Study Site was identified as a mix between ‘rye-grass grassland’ and ‘fertile mixed grassland’. The Study Site was identified as ‘grassy roadsides’ and/or ‘rye grass / clover grassland’. The 2011 MAVIS analysis indicates similar results; the Control Site is still ‘rye grass grassland’. The Study Site is classified as a combination of ‘fertile grassland’ and rye grass/Yorkshire fog grassland’, both of which are common grass types in the UK.

The Study Site although not being a significantly different vegetation classification from the Control Site does show more diversity, which is primarily due to the SuDS features and the associated management regime which has allowed to development of the swales to form stands of vegetation capable of supporting invertebrate life.

The photographic record illustrates the changes that have occurred to both sites between 2007 and 2011. CS and LD refer to Control Site and Study Site respectively.

2007 **2010** **2011**

Control Site

CS2

CS5

2007 **2010** **2011**

CS6

CS7

2007
CS10

2010

2011

2007
Study Site (Lamb Drove)
LD16

2010

2011

2007 **2010** **2011**

LD17

LD19

2007 **2010** **2011**

LD20

LD21

2007
LD22

2010

2011

The Study Site has shown a higher number of species present over the three surveys, than the Control Site. The area is comprised of marshy grassland which is a more species diverse type of grassland than the amenity grassland present elsewhere. Without the planted tree and hedgerow species on the Control Site, the area would have much lower species diversity. However, the planting of these features within the Control Site does improve its diversity and in the long term should offer habitat for birds, small animals and invertebrates.

Overall, the Study Site represents a more natural management regime and this is represented in the range of species present on the site and the similarity of parts of the site with the adjacent watercourse. In the long term the diversity of the site is likely to improve and the swales could support a variety of animal species.

Interestingly, the results of the residents' survey, outlined in Section 4.6 and Appendix H, show that the residents of the Study Site have a high regard for the aesthetics and visual appearance of the open spaces achieved through SuDS, as illustrated in Figure 4.16. This advocates the recent government drive to promote the positive benefits of integrating SuDS within open spaces and the move towards multifunctional land management for the benefit of communities such as improved quality of life.

Overall, it is apparent that the SuDS measures implemented at the Study Site have resulted in increased habitat diversity and visual amenity when compared to the Control Site. The surveys are reported in full in Appendices D, E and F.

4.5 Permeable Pavement Performance

Infiltration capacity testing was undertaken during June and July 2011 at ten locations across the pavement and compared to the recorded rainfall events. The estimated 1 in 100 years and 1 in 50 year rainfall intensity was used to assess the performance. The rainfall data for Lower Cambourne collected by the main study (Section 2.2) was used to assess rainfall intensity.

Figure 4.15 shows the mean infiltration rate (and confidence interval) for the Study Site. The infiltration rate is high initially as water is drawn into the dry pavement joints by suction as well as gravity, but reaches a more or less constant rate of 200mm/h after approximately 20 minutes.

The permeable pavement at the Study Site has been manually swept twice a year since 2009. In addition part of the pavement may have been mechanically cleaned by a road sweeper in error in 2011 before the study as no cleaning work was scheduled at the time. This is not in-line with the recommendations for suction cleaning and represents a reduced maintenance regime than would be expected. The impact of this cleaning work upon the study results is unknown.

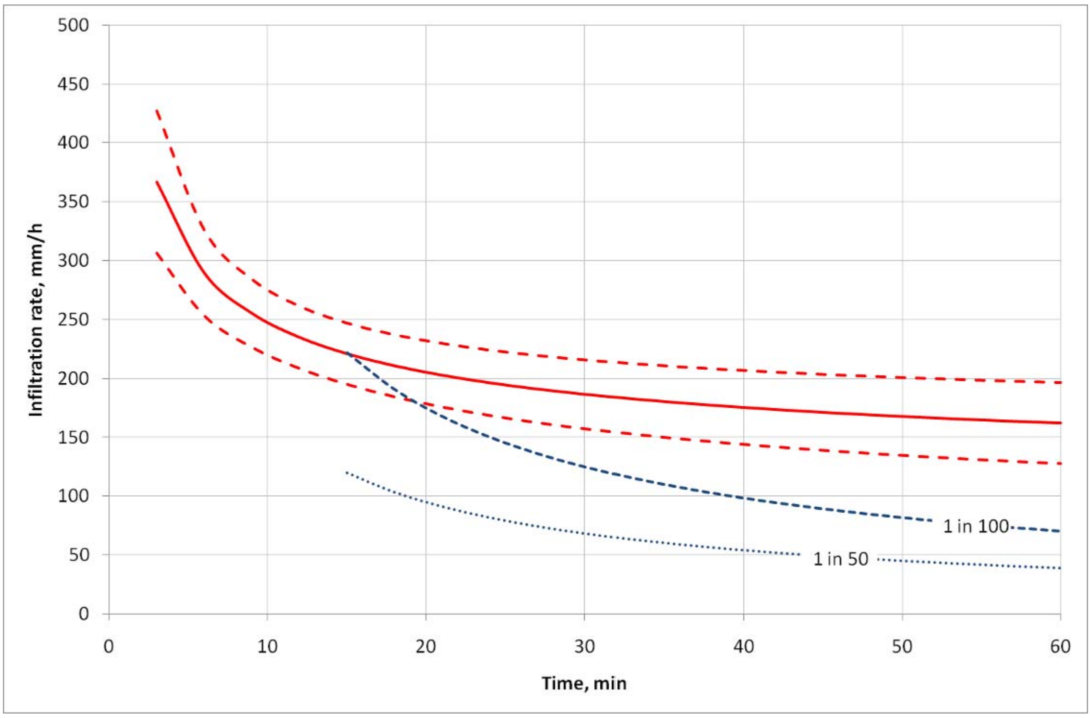

Figure 4.15: Mean infiltration rate, mm/h (and confidence interval) for permeable pavement at the Study Site, compared to 1 in 100 and 1 in 50 year return period rainfall intensities.

The infiltration measurements undertaken after manual cleaning of the pavement showed no significant change in the infiltration rate. This may be due to either the improvised nature of the cleaning or the potential mechanical cleaning that is thought to have occurred in error prior to the investigation.

The highest recorded rainfall intensity over the three year monitoring period was 52.5 mm/h over a duration of 8 minutes (on 7th July 2009) when the peak intensity exceeded 130 mm/h for 2 minutes. However the infiltration rate of the permeable pavement at the Study Site would be expected to be over 300 mm/h after 4 minutes of wetting according to the Figure 4.15. This suggests that the permeable pavement could adequately cope with this highest recorded rainfall intensity.

The infiltration measurements show that, even after 1 hour of wetting, the average infiltration rate of the permeable pavement was 162 mm/h. This considerably exceeds the 50 mm/h rainfall intensity typically used for highway drainage design.

Although the permeable pavement has not been maintained in line with the recommendations for 6 years since installation, it is still functioning well and should be able to deal with all but the most extreme, short duration rainfall events.

4.6 Residents' Feedback

A survey of Lamb Drove/Shepherd Close and Friars Way residents was undertaken in February 2008 and June 2010. In 2008, thirty-six questionnaires were hand delivered with a covering letter explaining the SuDS system and the aim of the monitoring project. Despite a stamped addressed envelope being provided there was a poor response, with only 11% returning their questionnaires. Nevertheless, the low level of returns does at least show that SuDS is not a controversial issue with residents, although the forms did reveal some variety of opinions.

All respondents agreed that the landscape and drainage around their homes were different to other areas of Cambourne, but views were mixed as to whether these were better or worse. With regards to views on the various SuDS features, respondents felt these were either satisfactory or poor. However, it is important to note that these views were canvassed at a time when the maintenance regime was in a state of flux and this may have coloured the nature of the response.

In comparison, the residents survey carried out in 2010 observed a higher success rate in resident response and feedback, with over 44% returning their questionnaires. This can be accounted for by the change in survey methodology, which involved a door to door survey with the added incentive of a prize for participating. It was also decided to include additional questions with the aim of capturing residents' views on the appearance of the area and residents awareness of the SuDS scheme and monitoring.

The main findings from the 2010 survey were residents' feedback on drainage around their homes and noticing that the Study Site was much more aesthetically pleasing when compared to others parts of Cambourne (Figure 4.16).

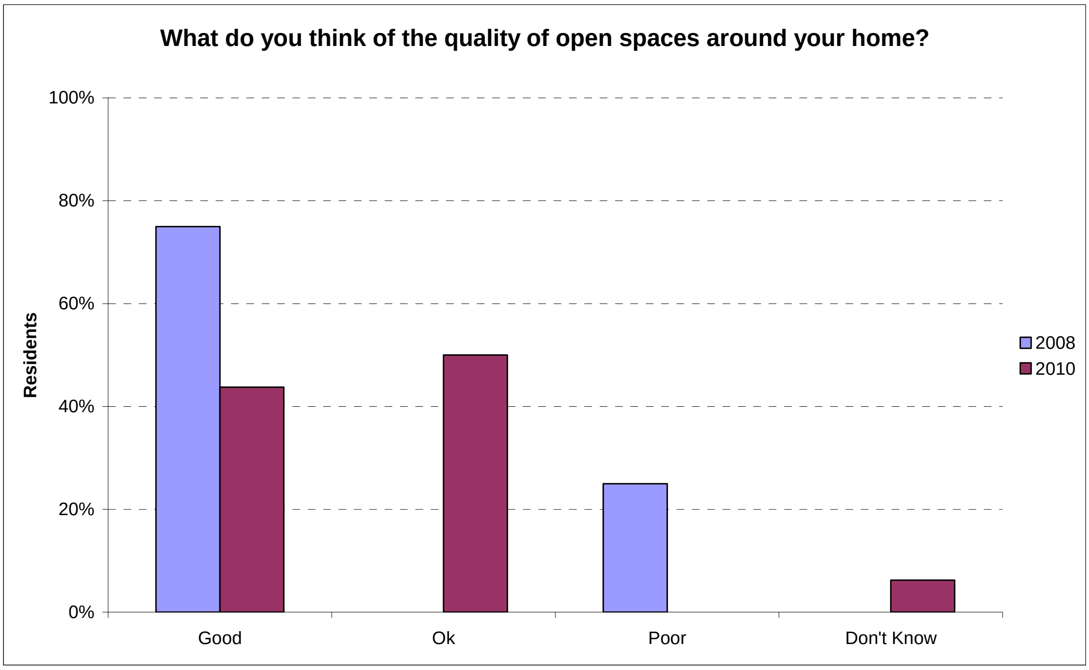

Figure 4.16: Comparison of survey feedback between 2008 and 2010 relating to the quality of open spaces around their home.

The residents also felt that the drainage in the Study Site was much better when compared to other parts, a response which was much more pronounced when compared to the 2008 survey (Figure 4.17).

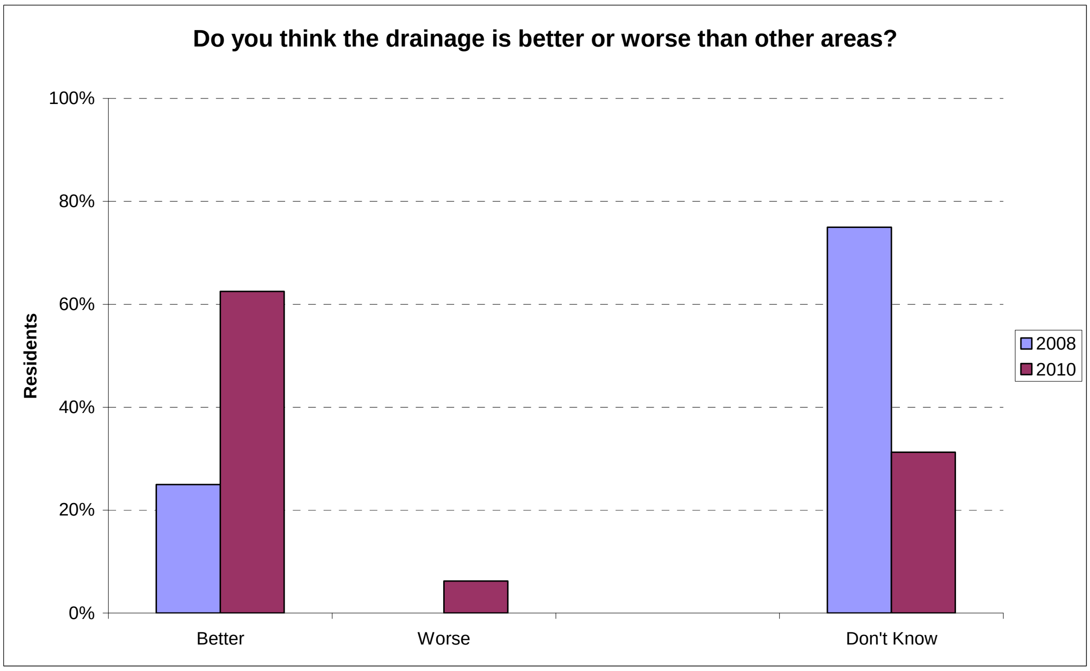

Figure 4.17: Comparison of survey feedback between 2008 and 2009 relating to drainage within the area.

The resident survey report can be found in Appendix H, which provides more detailed information on questions posed and overall results.

4.7 Robustness and Operation

A clear objective of this SuDS scheme was to produce a robust drainage system for the residents of Lamb Drove. Overall the Study Site in comparison to the pipe drainage system at the Control Site is showing excellent results in terms of reduction of flows rates, volumes, enhanced water quality and improvements to the habitat and visual diversity. These are the main benefits as a result of this SuDS scheme, and all achieved despite a reduced maintenance regime as initially intended. For example, the SuDS system is showing excellent results despite the permeable pavement having not been cleaned since installation, due to the road not yet being adopted by the County Council. This illustrates how robust and resilient SuDS are to the lack of maintenance when compared to pipe drainage systems. Also, the visibility of the measures also ensured any issues were easily identified for action and not hidden away in piped systems.

5 KEY FINDINGS

The monitoring results of the SuDS scheme at the Study Site and the pipe drainage system at the Control Site between 2008 and 2011 show marked differences in runoff volumes and peak flows, pollution concentrations, associated maintenance costs and habitat and biodiversity benefits.

In line with the performance indicators of the scheme, as outlined in Section 1.2, the key findings from the study revealed the following:

Indicator A: Reduced flow rates and volumes

The Study Site has attenuated flows more significantly when compared to the Control Site. The Control Site observed larger peak discharges, much quicker, when compared to the Study Site, and readings for the Control Site seem to closely mirror rainfall patterns for that catchment, reflecting the impermeable surfaces and rapid transfer of water through that development. In contrast, the Study Site observed greater periods between peak rainfall and peak discharge events, with peak discharge readings being much lower than that observed in the Control Site, which can be accounted for by the series of SuDS measures delaying the transfer of water through the Study Site, attenuating the flows, as expected, before discharging into the strategic balancing lakes in Cambourne. A particularly unexpected outcome was the extent to which the flow volumes were also significantly reduced. Clearly, the attenuation and storage effects allowed evaporation, evapotranspiration and infiltration (even though the soil has low permeability).

The monitoring programme has clearly shown the successive, improved, attenuation and reduction of both flow and volumes through each stage of the SuDS management train at the Study Site when compared to the Control Site. This is evident throughout the site, from the source to the discharge point.

Monitoring Locations at the latter stages of the SuDS treatment chain have observed reduced discharge when compared to that in the upper phase of the SuDS scheme as would be expected. For example, Monitoring Location 2 has the highest discharge per hectare reflecting the lack of SuDS features upstream of this point attenuating flows. Furthermore, it is also apparent that the sub-catchment characteristics play a vital role in determining the discharge at each Monitoring Location. For example, despite Monitoring Locations 1 and 2 being at the top of individual sub-catchments, Monitoring Location 2 observed greater peak discharges. Reasons for these differences are that Monitoring Location 2 exhibits greater percentage of impermeable surface area within its sub-catchment, whereas Monitoring Location 1 exhibits permeable pavement and a green roof in its sub-catchment assisting in reducing overland flows and the reducing the transfer of water. This illustrates how the treatment train which combines a variety of SuDS measures acts to attenuate flows.

Indicator B: Reduction in pollutant loads to receiving watercourses

Monitoring data over the last three years has shown that the SuDS treatment chain of the Study Site is acting to improve water quality when compared to the Control Site. Results showed that the Study Site observed reductions in concentrations of a variety of pollutants and other indicators.

Significantly higher concentrations of hydrocarbons, heavy metals, COD, Organic Carbon and TSS were observed at the Control Site when compared to the Study Site. This illustrates the impact of the SuDS measures in improving the quality of the water discharged from the Study Site and problems that conventional drainage systems cause.

In addition, marked differences in Total Suspended Solids (TSS) were also observed spatially throughout the SuDS treatment train. For example, Monitoring Locations 3 and 4 revealed high levels of TSS when compared elsewhere within the system, which can be attributed to additional sediment input from a local cycleway, indicating how external factors could induce dramatic changes in pollutants within such a scheme. Similarly, high TSS concentrations were also observed at Monitoring Location 7, which can be accounted for by the reduced retention of water upstream of Monitoring Location 7. Overall however TSS concentrations reduce as water flows through the treatment train towards the outflow from the site. The general trend in hydrocarbon concentrations, Chemical oxygen demand and biological oxygen demand can best be explained in the same way as with TSS.

Indicator C: Environmental Benefit (habitats and amenity)

The Study Site has shown a higher number of species present over the three surveys than the Control Site. The number of species has increased at the Study Site over the monitoring period (30 to 34) while it has decreased at the Control Site (34 to 21).The Study Site is comprised of marshy grassland, a more diverse type of grassland than the amenity grassland present at the Control Site. Although not being a significantly different vegetation classification, the Study Site shows more diversity, which is primarily due to the SuDS features and the associated management regime.

Overall, the Study Site represents a more natural management regime and this is represented in the range of plant, invertebrate and amphibian species present on site. The future implementation of the SuDS management regime will allow the swales to develop, becoming a supportive habitat for faunal species.

Indicators D, E and F: Maintenance Costs, Robustness and Whole life costs

It is apparent that overall the maintenance regime has not required substantial investment or manpower to maintain a functioning SuDS scheme. The total cost is £1,340 per year, equating to approximately 56 manpower hours per year. Overall the maintenance costs associated with the Study Site are lower when compared to costs associated with conventional pipe drainage systems. This is based on comparison with costs for similar SuDS schemes and accepted average costs for conventional pipe drainage. Other studies have indicated that maintenance of SuDS schemes may be 20-25% cheaper than an alternative pipe system, while Lamb Drove is currently 4% per year cheaper to maintain than the accepted average costs for conventional pipe drainage. It is likely that some of the Lamb Drove SuDS maintenance costs would have been carried out anyway (including road sweeping and some of the landscape management, which would suggest the real difference is much more than 4%.

Furthermore, monitoring of the SuDS scheme over the last three years has also indicated how resilient the scheme is. Results showed that despite a reduced maintenance regime to that originally intended at the start of the scheme, the SuDS scheme is still showing excellent results. For example the permeable pavement had no maintenance at all for the first three years and was maintained to a lower standard than the recommended regime for the following two and a half years.

The permeable pavement infiltration study (Section 4.5) specifically illustrates the robustness of the performance of this feature to limited maintenance. The infiltration capacity of the permeable pavement is able to adequately cope with the highest recorded rainfall intensity at the Study Site over the 3 year monitoring period. Despite having not been maintained in line with the recommendations for 6 years since installation, it is still functioning well and should be able to deal with all but the most extreme, short duration rainfall events. This illustrates how robust SuDS are to the lack of maintenance when compared to pipe drainage systems.

The capital costs of the scheme were found to be £314 per property cheaper than the alternative pipe drainage system that would have been required for the Study Site. The maintenance costs as discussed above are also cheaper than those which would be incurred for a pipe system. Therefore it can be concluded that the whole life costs of this SuDS system will be significantly lower than a conventional pipe system.

In addition research has suggested that properties that are located next to SuDS measures incorporating well maintained open space such as ponds, swales and basins may experience increase in their market value due to the aesthetic appeal of the features (HR Wallingford, 2004).

Indicator G: Resident's feedback

It is apparent that the residents of Study Site have a high regard for the aesthetics and visual appearance of the open spaces within the SuDS scheme, something which is a key government driver, moving towards a multifunctional land management scheme for the benefit of communities such as enhanced health and well-being.

The resident surveys found that they regard the open space around their homes more aesthetically pleasing when compared to others parts of Cambourne, with over 90% regarding it as either good or satisfactory.

6 RECOMMENDATIONS

In carrying out the monitoring for the Study Site and Control Site, several recommendations have been identified which could further improve achievement of the objective of the R&D study. These include:

- The results could further be enhanced by undertaking another similar monitoring project in 3 to 5 years as to capture any significant changes in performance of SuDS features. It is felt that this would be beneficial for all aspects of the SuDS system, in particular the water quality and biodiversity elements of the project. The reason for this is because of the lack of knowledge and understanding relating to this area, in particular to provide more seasonal information on how SuDS affect ecology and water quality trends. Also a limited flow monitoring regime to extend the length of the record would allow greater confidence in the results and extreme events to be recorded.

- While the outcomes of this study show clear performance results for some aspects of SuDS, it is only representative of this site. The broader understanding and wider uptake of SuDS will benefit from similar studies being carried out at other sites and the results being collated and compared. This will provide a more comprehensive picture across varying SuDS features, rainfall patterns, locations, site topographies and soil types.

- This monitoring project deals with the performance assessment of SuDS within a new residential development. Similar studies to assess the impact of retrofitting SuDS to existing developments with primarily pipe drainage features would provide performance data to support future decisions on retrofitting SuDS. This is of high importance, given the high number of existing developments or re-developments compared with proposed new developments.

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