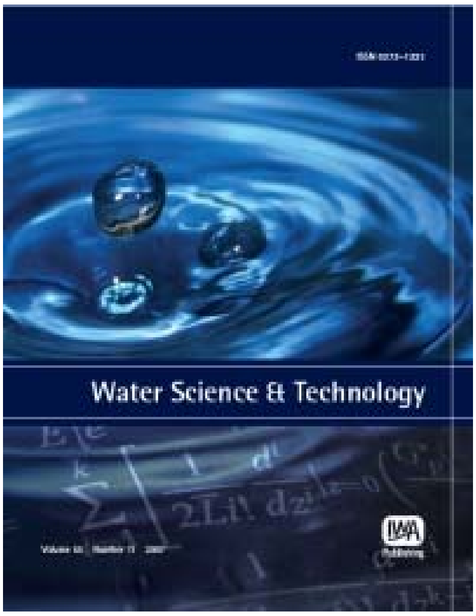
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Medium-term performance and maintenance of SUDS: a case-study of Hopwood Park Motorway Service Area, UK

K. V. Heal, R. Bray, S. A. J. Willingale, M. Briers, F. Napier, C. Jefferies and P. Fogg

ABSTRACT

One of the main barriers to implementing SUDS is concern about performance and maintenance costs since there are few well-documented case-studies. This paper summarizes studies conducted between 2000 and 2008 of the performance and maintenance of four SUDS management trains constructed in 1999 at the Hopwood Park Motorway Service Area, central England. Assessments were made of the wildlife value and sedimentation in the SUDS ponds, the hydraulic performance of the coach park management train, water quality in all management trains, and soil/sediment composition in the grass filter strip, interceptor and ponds. Maintenance procedures and costs were also reviewed. Results demonstrate the benefits of a management train approach over individual SUDS units for flow attenuation, water treatment, spillage containment and maintenance. Peak flows, pond sediment depth and contaminant concentrations in sediment and water decreased through the coach park management train. Of the 2007 annual landscape budget of £15,000 for the whole site, the maintenance costs for SUDS only accounted for £2,500 compared to £4,000 for conventional drainage structures. Furthermore, since sediment has been attenuated in the management trains, the cost of sediment removal after the recommended period of three years was only £554 and, if the design is not compromised, less frequent removal will be required in future.

Key words | maintenance, management train, motorway service area, performance, sediment, SUDS

K. V. Heal (corresponding author)
The University of Edinburgh, School of GeoSciences,
Crew Building, West Mains Road,
Edinburgh EH9 3JN,
UK
E-mail: *k.heal@ed.ac.uk*

R. Bray
Robert Bray Associates Ltd,
Fairfield, Coronation Road, Rodborough, Stroud,
Gloucestershire GL5 3SB,
UK
E-mail: *bob@robertbrayassociates.co.uk*

S. A. J. Willingale
Formerly Swansea University,
Singleton Park, Swansea SA2 8PP,
UK
E-mail: *sophie_willingale@hotmail.com*

M. Briers
Environment Agency,
Phoenix House, Global Avenue, Leeds LS11 8PG,
UK
E-mail: *mike.briers@environment-agency.gov.uk*

F. Napier
Scottish Environment Protection Agency,
Greyhope House, Greyhope Road, Torry,
Aberdeen AB11 9RD,
UK
E-mail: *fiona.napier@sepa.org.uk*

C. Jefferies
University of Abertay Dundee,
Bell Street, Dundee DD1 1HG,
UK
E-mail: *cetcj@tay.ac.uk*

P. Fogg
Cambridge Environmental Assessments, ADAS Gleadthorpe,
Medan Vale, Mansfield,
Nottinghamshire NG20 9PF,
UK
E-mail: *Paul.Fogg@cea-res.co.uk*

INTRODUCTION

Sustainable urban drainage systems (SUDS), that take account of water quantity, quality and amenity, are increasingly a standard component for managing surface water runoff in new developments in many countries. However, the literature contains few reports of integrated studies of their longer-term performance, including flow attenuation, water and sediment quality, ecology, management and maintenance. Although the studies of SUDS

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increased when they were initially introduced within a country/region (e.g. the UK from the mid-1990s to the mid-2000s), once SUDS became more widely accepted there has been less incentive to examine their longer-term performance. Integrated studies of older SUDS are important for optimizing SUDS design, management and performance and for addressing some of the barriers to SUDS implementation, such as maintenance costs, particularly associated with sediment removal and disposal (McKissock *et al.* 2003). Measurements of the accumulation and composition of in situ sediment in SUDS ponds indicate typical sedimentation rates of ~2 cm year^{-1} (Heal *et al.* 2006). However, sedimentation rates may vary considerably and are dependent on pond design and its location within a management train. Guidance on the timing of sediment removal is limited although Bray & HR Wallingford (2004) recommended that sediment removal should be conducted approximately every three years. This paper presents data on the medium-term performance, management and maintenance costs for the SUDS at the Hopwood Park Motorway Service Area (MSA), UK. In particular it focuses on sediment accumulation and composition within different designs of SUDS management trains.

METHODS

Site description

Hopwood Park MSA (56°22′N,1°57′W) is located near Bromsgrove, Worcestershire, central England. It comprises an amenity building with car parking, coach parking, a centrally located fuel filling area and a separate HGV park. The MSA has a total area of 9 ha which drains into the adjacent Wildlife Reserve and Hopwood Stream. The concept of the management train was used to design a variety of SUDS in series to improve the flow and quality of runoff in stages prior to release into the local watercourse and to deal with unforeseen spillage events. The SUDS were designed with the following multiple objectives agreed with the England and Wales Environment Agency to: attenuate the 1 in 25 year storm runoff; provide a greenfield runoff rate of 5 l s^{-1} ha^{-1}; and treat the first 10 mm of storm runoff. The design was undertaken by Robert Bray Associates/Baxter Glayster Consulting Ltd. before the publication of design manuals in the UK (CIRIA 2000*a*,*b*; Woods-Ballard *et al.* 2007) and followed guidance from the Environment Agency and a review of stormwater management manuals from the USA (e.g. Schueler *et al.* 1992; Horner *et al.* 1994). Four management trains were completed in 1999 that receive runoff from: 1) the HGV park; 2) the coach park, fuel filling area, service yard and main access road; 3) the car park; and 4) the amenity building roof (Figure 1).

The former two areas pose a serious pollution risk (Ellis & Revitt 2008) and have extended management trains. Sheet runoff from the HGV park receives treatment in a 10-m wide grass filter strip, followed by a stone-filled and lined infiltration trench, a spillage basin (Pond 1) and a final attenuation pond (Pond 2), with a further grass filter strip and swale for overflow in excess of the 10-mm first flush. Although there is a high kerb by Pond 1 so that spillages would be routed through the grass filter strip, in November 2000 a spillage of ~200 l of diesel in the HGV park was hosed by the fire brigade directly into Pond 1 (C. Angel, *pers. comm.*), bypassing the upstream part of the management train. A gravel filter drain immediately adjacent to the HGV park was designed to trap sediment during construction and to protect the grass filter strip. A different approach was taken to managing drainage from the main access road, fuel filling area and coach park in that runoff is collected via a conventional gully and pipe system and passes through a proprietary silt and oil interceptor prior to discharge to a wetland/pond/wet swale management train (Ponds 3–6). The first basin (Pond 3) has an outlet valve to isolate any spillage event, and a subsidiary basin (Pond 5) receives runoff from the service yard. The car park runoff and amenity building roof water were considered less likely to cause pollution and therefore have shorter treatment systems although the management train concept is applied to provide insurance against unforeseen spillage events. Car park runoff is collected via slotted kerbs into sub-surface, gravel-filled collector trenches that drain to a balancing pond (Pond 7). The amenity building roof water is piped to a balancing pond (Pond 8), with a fountain and planting around the margins, before draining towards the Hopwood Stream. All ponds have artificial membrane liners covered with 30 cm subsoil.

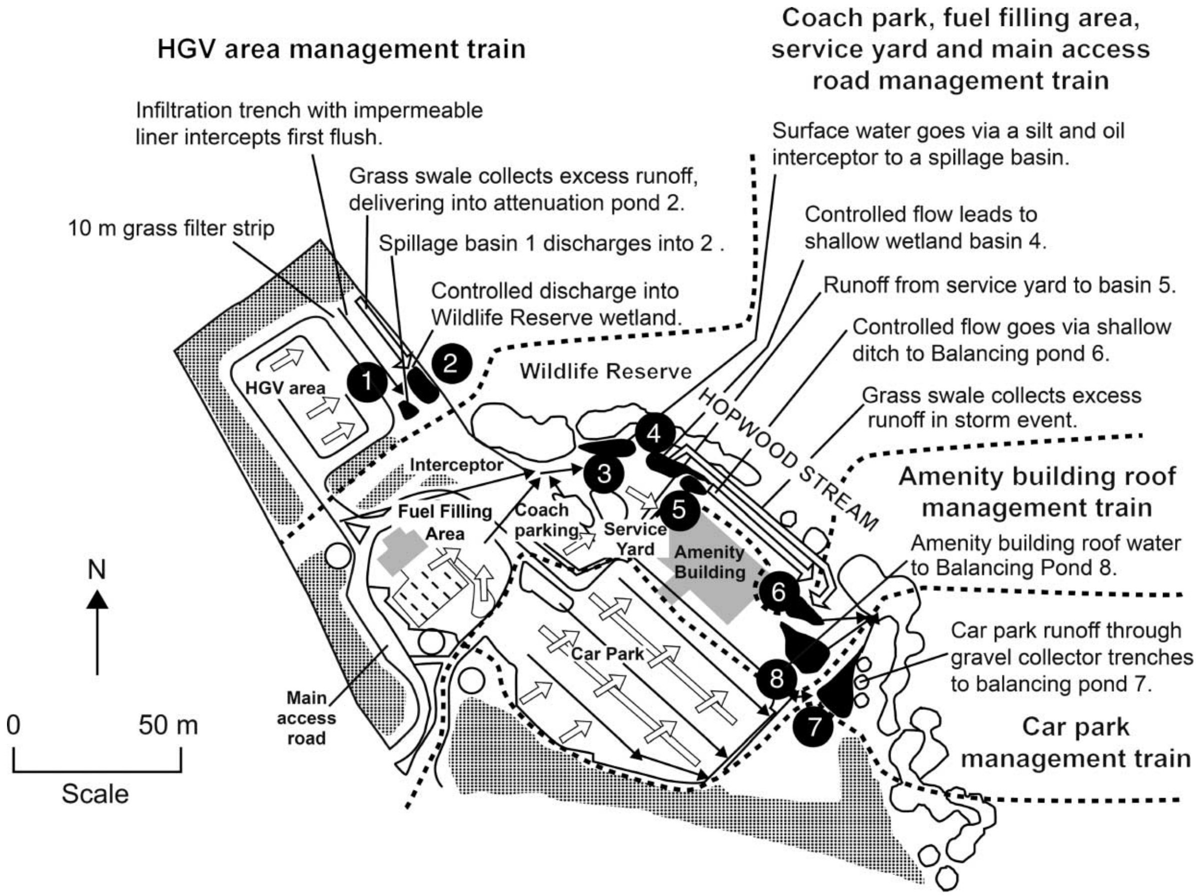

Figure 1 | Layout of Hopwood Park Motorway Service Station Area and SUDS management trains. Numbers indicate ponds referred to in the text. Dotted lines show the boundaries between the different management trains. Hatched areas represent vegetation planting to screen roads.

Construction costs for the SUDS were sought but, since as for most SUDS these mainly comprised earthworks which were an integral part of the site development, the quantity surveyor was unable to extract these from the costs for the overall site. Management and maintenance of the above-ground SUDS comprises litter-picking and cutting of grass and wetland vegetation and has been conducted by contractors, advised by Robert Bray Associates. Contractors visit every two weeks as part of the overall landscape management of the MSA. The conventional drainage components (gullies and pipes) and the proprietary silt and oil interceptor are maintained by separate contractors. The interceptor was not maintained for the first 18 months and became blocked but it is now maintained by a specialist contractor every six months, as specified by the manufacturer. Following the recommendation in Bray & HR Wallingford (2004) that sediment removal should be conducted every three years, in autumn 2003 (actually four years after construction), sediment was removed from Ponds 1–7 in a half-day operation costing £554 (2007 prices).

SUDS assessment

Several studies have been conducted between 2000 and 2008 to assess the costs and performance of the SUDS at Hopwood MSA. The aims, timing and methodology employed by these studies are summarized in Table 1. The results of many of these studies have been reported individually elsewhere but this paper is the first to integrate them, together with new information on maintenance procedures and costs, to provide an overall assessment of the SUDS at Hopwood MSA and to draw conclusions that are relevant to the design and management of SUDS in general.

Table 1 | Summary of studies conducted of SUDS at Hopwood MSA between 2000 and 2008

Assessment	Organisation/Reference	Dates	Methods	Parameters assessed
Water treatment performance	Environment Agency	May 2000–Dec 2005	Water sampled in trains 1–3 on 2–25 occasions (where flowing) close to rainfall events	Water samples analyzed for potentially toxic metals, pH, nutrients, TSS, DOC. A few samples analyzed for hydrocarbons/oils
Biological quality and conservation value	Environment Agency	2000–2001	Macroinvertebrates sampled in Ponds 1–8 and in Hopwood Stream	Identification to species level where possible. Calculation of BMWP score, ASPT, various indices, species rarity
Aquatic plants and invertebrates, biological quality and conservation value	Ponds Conservation Trust and Environment Agency (2001) and Ponds Conservation Trust (2003)	Two occasions in Aug and Oct 2000	Plant and invertebrate surveys in Ponds 1–8 using the National Pond Survey methodology	Plant and macroinvertebrate species lists and estimates of abundance. Assessment of conservation value and degree of impairment of ponds using PSYM analysis
Hydraulic and water treatment performance	Woods-Ballard *et al.* (2005)	May 2002–Jun 2004	Monitoring of site rainfall and flows in train 2. Water sampled on 13 occasions in train 2 to complement EA programme	Water samples analyzed for nutrients, TSS, Cu, Ni, Pb, Zn, total petroleum hydrocarbons (TPH)
Sediment depth and composition in Ponds 1–7	Willingale and Environment Agency. Willingale (2004)	Sep–Dec 2003	Sediment depth measured prior to removal. Sampling and analysis of sediment in situ and on 5 occasions after removal	Sediment analyzed for potentially toxic metals, PAHs, phenols, pH, sulphate, leachable NH_4-N, DOC, COD
Interceptor at inlet to Pond 3	Faram *et al.* (2007)	Sep 2005 and May 2006	Sediment sampled and depth measured in interceptor chamber	Sediment analyzed for particle size, potentially toxic metals, PAHs, TPH
Sediment quality in HGV park management train	Jefferies *et al.* (2008)	Jan, May 2007	Sampling and analysis of soil in filter strip and sediment from Ponds 1 and 2	Soil/sediment analyzed for potentially toxic metals, PAHs, TPH, pH, nutrients, organic C
Management and maintenance survey	Robert Bray Associates	Jul 2007 and Mar 2008	Structured interviews with MSA Manager and Operations staff	Benefits and disadvantages of SUDS, management and customer operspectives, maintenance costs

RESULTS AND DISCUSSION

Flow attenuation

Flow attenuation has been monitored only in management train 2 (runoff from the coach park, fuelling area and main access road) for the period May 2002-June 2004 by Woods-Ballard *et al.* (2005). On-site rainfall and flow (calculated from flow depth and velocity measurements) were monitored continuously at three points (outlet of the silt and oil interceptor and inlet and outlet of the shallow ditch/swale between Ponds 4 and 6), with some data gaps due to unreliable data and/or technical issues. Analysis of the data showed significant overall reductions and progressive attenuation of peak flows. The 2-year greenfield flow was exceeded by 70% of peak flows at the outfall of the conventional drainage network (outlet from interceptor), 30% of peak flows downstream of Ponds 3 and 4 and by only 5% of peak flows at the inlet to Pond 6 (equivalent to two to three exceedances per year). Since further flow attenuation would be provided downstream in Pond 6 and prior to discharge to the Hopwood Stream the management train is expected to meet its design objective of achieving greenfield runoff conditions.

Water treatment

Results are summarized in Table 2 of the water quality survey conducted along three of the management trains during or shortly after rainfall events, mainly between October and March.

The most contaminated runoff was from the HGV park, although runoff from the coach park and car park management trains was not sampled until after pre-treatment. Runoff from the car park was relatively uncontaminated after passage through gravel-filled collector trenches. The high NH_4-N concentrations measured in the HGV park management train have been attributed to lorry drivers urinating near their vehicles (Ponds Conservation Trust 2003). They may also result from the diesel spillage in November 2000 which was hosed into Pond 1 since the highest concentrations of NH_4-N and BOD were measured in Pond 1 inlet and outlet in January 2001, the nearest sample date after the spillage occurred. Standard deviations are of similar magnitude to mean values, indicating considerable variability in contaminant concentrations which is probably related to the sporadic and variable washoff of contaminants during rainfall events. Notwithstanding the diesel spillage, the mean concentrations of all contaminants measured, apart from NH_4-N, chloride and DOC (data not shown), were lower at the outlet of Pond 1 than at the interceptor outlet. Whilst the composition of runoff entering the interceptor is unknown, it is unlikely to be more contaminated than runoff from the HGV park. Although the interceptor was not maintained for the first 18 months, these results suggest that treatment of runoff in the grass filter strip (which has required no maintenance apart from grass cutting) is highly effective. In general, water quality improved during passage through the more extended HGV park and coach park management trains, emphasizing the importance of implementing SUDS units in management trains rather than in isolation. Removal percentages calculated from concentration data were consistently high (70–90%) for potentially toxic metals. Removal of NH_4-N, BOD and DOC in the HGV park management train was variable with medians of 80–90%, although sometimes negative values occurred. There was no apparent seasonal pattern in contaminant concentrations and removal in the management trains, apart from the occurrence of high chloride concentrations (>300–400 mg l^{-1}) in some samples in December and January which were attributed to washoff of de-icing salts. Removal percentages by concentration can give a misleading picture of SUDS water treatment performance where data are limited and/or the system influents are relatively clean (as in the car park runoff at Hopwood).

A better approach for characterizing water treatment performance from the data available is comparison of effluent quality with appropriate environmental standards to evaluate the impact of the SUDS discharge on receiving waters and also the ecological potential of SUDS ponds/wetlands (Ponds Conservation Trust 2003; Woods-Ballard *et al.* 2005). Based on the methodology of (Woods-Ballard *et al.* 2005), the water chemistry results from all samples collected by the Environment Agency were compared with the mean contaminant concentrations measured in minimally impaired ponds in England and Wales. The percentage of water samples at each stage in the management

Table 2 | Mean (±1 standard deviation) of selected chemical parameters measured in water samples collected along management trains by the Environment Agency, 2000–2005. The number of samples at each point was 12–25. NH_4-N represents $NH_3 + NH_4^+$ in samples expressed as N

Sample point	NH_4-N ($mg\,l^{-1}$)	BOD ($mg\,l^{-1}$)	TSS ($mg\,l^{-1}$)	Total Cu ($\mu g\,l^{-1}$)	Total Zn ($\mu g\,l^{-1}$)
HGV park management train					
HGV park runoff	30.8 (38.6)	81.4 (95.7)	429 (477)	343 (367)	2,438 (3,486)
Pond 1 inlet	7.38 (5.86)	7.46 (7.48)	22.5 (21.0)	22 (10)	358 (855)
Pond 1 outlet	4.94 (3.29)	4.78 (4.28)	13.1 (17.3)	15 (7)	78 (43)
Coach park, fuelling area, main access road management train					
Interceptor outlet	0.37 (0.49)	11.4 (9.94)	78.5 (91.0)	45 (43)	230 (200)
Pond 3 outlet	0.76 (0.89)	12.2 (10.3)	30.1 (29.8)	27 (25)	167 (99)
Pond 4 outlet	0.55 (0.44)	7.39 (5.17)	22.2 (14.6)	15 (11)	100 (55)
Pond 6 outlet	0.20 (0.21)	3.50 (5.50)	8.04 (4.94)	5 (3)	27 (19)
Car park management train					
Car park runoff	0.15 (0.22)	2.19 (1.77)	11.1 (10.5)	11 (8)	18 (31)
Pond 7 outlet	0.08 (0.11)	1.91 (0.91)	16.8 (19.3)	11 (8)	32 (37)

trains that did not exceed these concentrations was calculated and the results for selected parameters are shown in Figure 2.

The majority of water samples in the car park management train did not exceed the concentrations since drainage is relatively clean after passage through gravel-filled collector trenches. In the coach park management train NH_4-N, TSS and total Zn concentrations had decreased by the outlet from Pond 6 to close to the mean concentrations in minimally impaired ponds, but 32% of water samples still exceeded 2.5 mg BOD l^{-1} at the end of this management train. In the HGV park management train, although the percentage of water samples that did not exceed mean concentrations in minimally impaired ponds increased through the management train, the elevated NH_4-N and BOD concentrations at the end of the management train might still impair the wildlife value of these SUDS.

Sediment accumulation

No substantial sediment accumulation has been observed in the management trains at Hopwood, apart from the gravel filter trench designed for construction runoff, the interceptor, and Pond 3 (data presented below). The grass filter strip in the HGV park management train has not received any maintenance, apart from grass cutting, but there is evidence of only limited sediment accumulation. In their 2007 survey of sediment composition in the HGV park management train, Jefferies *et al.* (2008) were able to sample up to 20 cm depth of material from an area of apparent preferential flow in the first 1–3 m of the filter strip, but across the rest of the strip the maximum depth from which samples could be obtained was 10 cm, suggesting efficient trapping of sediment. They also found no sediment in the collector trench downstream of the filter strip, although the possibility cannot be ruled out that flow may bypass the trench. In the coach park management train sediment is being captured by the interceptor. Inspections estimated that the volume of material in the unit increased from 3 m^3 in September 2005 to 4 m^3 in May 2006. An increase in sediment D_{50} values (median diameter) from 30 μm in 2005 to 112 μm in 2006 was attributed to the presence of sand used on MSA surfaces for absorbing fuel spillages and/or de-icing (Faram *et al.* 2007).

Sediment depth and composition in Ponds 1–7 were assessed in September-December 2003 by Willingale (2004) in conjunction with the first routine sediment removal from the ponds. The maximum sediment depth (30 cm) was measured near the outlet from Pond 3. Depths decreased along the management trains. Sediment depths were ≈12 cm in Ponds 4 and 5 but only 0–3 cm in Ponds 6 and 7. Pond 1 contained depths <10 cm, whilst the sediment depth in Pond 2 was too small to measure.

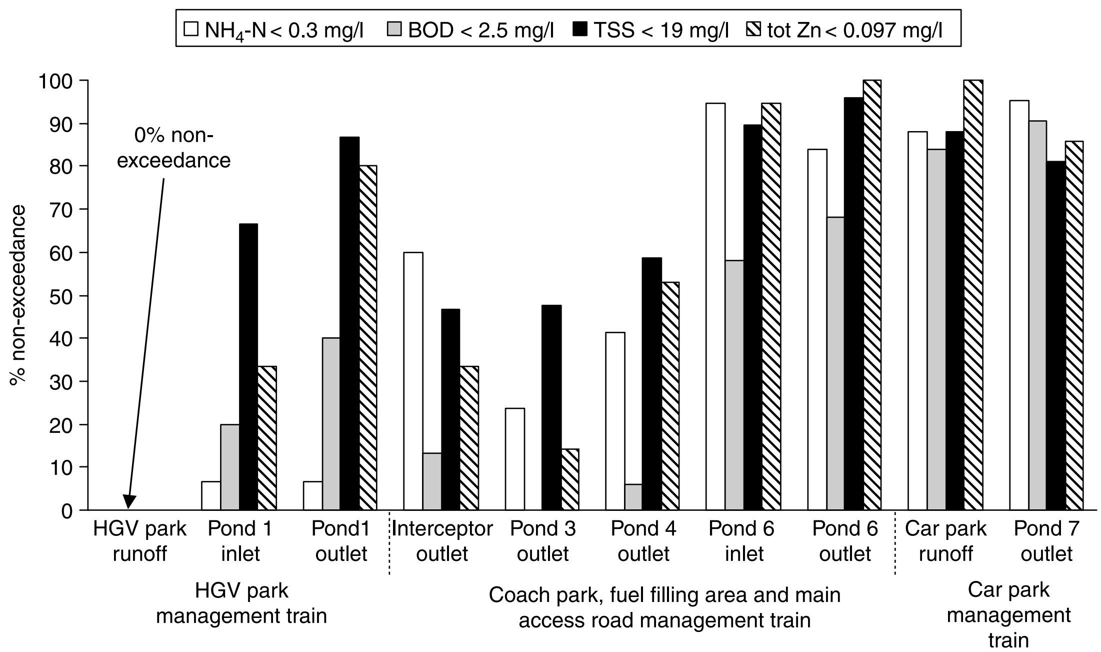

Figure 2 | Percentage of water samples collected by Environment Agency 2000–05 that did not exceed mean contaminant concentrations (values shown in legend) of selected parameters measured in minimally impaired ponds in England and Wales.

Only limited organic sediment was observed in the ponds, probably due to oxidation in well-oxygenated waters in the shallow basins. The mean sedimentation rate across all ponds was 1.7 cm $year^{-1}$, within the range of values reported from other urban ponds (0.2–3.2 cm $year^{-1}$, Heal *et al.* 2006). Prior to the sediment depth survey it had been anticipated that an excavator would be required for a whole day to remove sediment from the ponds but, because little sediment was found, the machine was only required for half a day. To minimize the impact on ecology, sediment was removed in October 2003 by pulling out ≈25% of pond vegetation and attached sediment. The material was spread at the edge of the basins to dewater for two months and then the vegetation matter was taken away for composting on site. It had been intended to incorporate any sediment residue into the raised banks surrounding the ponds but, because the amount of material remaining was negligible, this action was not required.

Sediment composition

In the HGV park management train, contaminant concentrations in the grass filter strip generally decreased with distance from the pavement edge and with depth, although the highest TPH concentration occurred at 3 m distance in a preferential flow area (Jefferies *et al.* 2008; Table 3). The highest contaminant concentrations occurred in Pond 1, presumably due to the diesel spillage in 2000, despite the removal of 25% sediment in 2003. Although the spillage affected sediment quality in Pond 1, this is preferable to direct discharge into the Hopwood Stream. In the coach park management train the highest sediment contaminant concentrations were in the interceptor and in Pond 3 immediately downstream and concentrations decreased progressively along the train (Table 3). Contaminant concentrations in Pond 3 sediment were similar to those in the interceptor and higher than all measurements in the HGV management train. This implies that grass filter strips are highly effective in runoff pre-treatment compared to conventional drainage measures, probably because conditions in the filter strip are more favourable for microbial degradation of organic contaminants. Since metal contaminants cannot be broken down it is possible that metal accumulation within the management train will eventually impact on biological functioning. In such instances the inexpensive and simple replacement of the top 10 cm of soil

Table 3 | Contaminant concentrations in sediment (mg kg^{-1} dry weight) in the HGV park and coach park management trains compared with Ontario Ministry of Environment (1993) standards (since no equivalent UK standards exist). Concentrations in excess of the standards are shown in bold

	Cd	Cu	Pb	Zn	TPH	Total PAHs
HGV park management train						
Filter PF 1 m 0–10 cm*	0.4	71	66	351	398	5.16
Filter PF 1 m 10–20 cm*	0.3	51	69	146	153	1.72
Filter PF 3 m 0–10 cm*	0.3	50	52	199	1,199	16.2
Filter PF 3 m 10–20 cm*	0.2	30	39	106	86	1.56
Filter 3 m 0–10 cm*	0.3	28	40	145	277	10.0
Filter 6 m 0–10 cm*	0.3	24	36	118	151	2.61
Filter 9 m 0–10 cm*	0.3	26	40	123	166	3.55
Pond 1*	0.7	192	92	733	3,152	19.2
Pond 2*	0.6	89	67	393	629	4.27
Coach park, fuelling area, main access road management train						
Interceptor†	2.16	350	193	2,500	10,660	112
Interceptor†	1.15	224	101	1,790	26,030	64.7
Pond 3‡	1.78	352	183	2,580	–	108
Pond 4‡	0.586	215	136	1,290	–	–
Pond 5‡	1.03	161	120	1,680	–	30.1
Pond 6‡	0.115	23.9	32.1	75.5	–	4.29
Standards	10	110	250	820	1,500	–

*Sampled in 2007 by Jefferies *et al.* (2008). Grass filter strip soil sampled at 1, 3, 6 and 9 m from the pavement edge and at a depth of 0–10 cm. In an area of apparent preferential flow (PF) samples were taken at 0–10 cm and 10–20 cm depths.
†Sampled in 2005 and 2006 (Faram *et al.* 2007).
‡Sampled in 2003 by Willingale (2004). TPH not measured. Insufficient Pond 4 sample for PAH analysis.

is suggested, with redistribution of the soil removed on site if sufficient space has been included within the design (Jefferies *et al.* 2008).

Ecology and wildlife value

Conclusions about the medium-term ecological quality and functioning of the Hopwood SUDS ponds cannot be drawn because surveys by the Environment Agency and Ponds Conservation Trust were conducted only one to two years after construction when colonisation of the ponds was still occurring. The main results from these surveys, fully documented in Ponds Conservation Trust and Environment Agency (2001) and Ponds Conservation Trust (2003), are reported here. The total number of naturally colonizing wetland plant species recorded across all ponds in autumn 2000 was 21. This figure includes at least two other wetland species, albeit indigenous non-invasive species, which are likely to have been brought in by accident, probably as seeds in grass mix and/or the soil of purchased plants. Numbers of species ranged between four in Pond 5, impacted by service yard runoff, to 12 in Pond 6, at the lower end of the coach park management train (Ponds Conservation Trust and Environment Agency 2001). The number of macroinvertebrate species recorded in the surveys conducted in 2000 varied between 22 and 58 in individual ponds, with a mean for all eight ponds of 36.9, slightly higher than the mean value for minimally impaired ponds in England and Wales (Ponds Conservation Trust 2003). A PSYM (Predictive System for Multimetrics) analysis (methodology described in Environment Agency and Ponds Conservation Trust 2002) was conducted on the summer 2000 plant and macroinvertebrate data to assess the extent to which the ponds are fulfilling their ecological potential. The ponds had PSYM scores between 33 and 61%, with the highest scores of 50–61% occurring in Ponds 4, 6 and 8 at the latter stages of management trains. Scores below 50% indicate ponds that are likely to be significantly below their full ecological potential. These scores are unsurprising as the analysis was conducted only one year after pond construction when colonization was still likely to be ongoing. Ponds Conservation Trust (2003) recommended that clean water will be required if minimally impaired ponds are desired within SUDS schemes. At Hopwood the ponds with the highest number of plant and invertebrate species occurred towards the end of the management trains where water and sediment contamination is lowest. Repeat ecological surveys are required in order to determine the longer-term wildlife value of the SUDS ponds at Hopwood and also to assess whether initially rapid colonization has been sustained or has levelled off as observed in other newly-created ponds in England and Wales (Williams *et al.* 2008).

Perception, management and maintenance

Structured interviews with the Site and Services Operational Managers at Hopwood MSA were conducted in 2007 and 2008 to obtain information on the perception, management and maintenance of the SUDS. Information and awareness about the SUDS appeared not to be widely and systematically disseminated amongst those concerned: "*Most information regarding the system was…picked up along the way*". The SUDS were well-regarded by users of the MSA: "*People often say… it's hard to believe…that we're actually on the side of a motorway because you sit out here… surrounded by countryside and…a nice pond*". Furthermore there were no perceived disadvantages of the SUDS, apart from people throwing chairs into ponds. No flooding had occurred, even after the exceptionally heavy rainfall in central England in the summer of 2007, and the health and safety officer does not have any concerns about the SUDS. The maintenance of above-ground SUDS was regarded as unproblematic, routine and cost-effective compared to conventional drainage systems: "*it's such a small amount of money…it's just like weeding an extra bed …it's as easy and simple as that…if that wasn't there, something else would be which would need to be maintained anyway*". The routine maintenance of above-ground SUDS is conducted as part of the landscape management of the whole MSA at a total annual cost of £15,000 (2007 prices). Of this, SUDS only account for £2,500, compared to £4,000 for maintaining conventional drainage structures (interceptor, gullies and pipes). No long-term maintenance or performance problems are envisaged with the SUDS: "*as long as it's well maintained I don't foresee any long-term problems*". The only additional SUDS maintenance that has been conducted since construction in 1999 was sediment removal from Ponds 1–7 in October 2003 at a total cost of £554 (2007 prices) for inspection, vegetation and sediment removal, and transfer of dewatered vegetation matter for composting on site. Since only limited amounts of sediment were found in the ponds because most is retained in the management train, particularly in the filter strip below the HGV park, it is anticipated that sediment removal will not need to be conducted so frequently in the future (perhaps every 10 years) if the SUDS design is not compromised. However, the functioning, maintenance and cost-effectiveness of the HGV park management train are likely to be severely compromised in the future since the drainage system in the HGV park was altered in 2007, when the park was extended, so that most runoff now enters Pond 1 directly by a new gully system, bypassing the filter strip and trench.

CONCLUSIONS

The Hopwood Park MSA case-study demonstrates the benefits of the management train in attenuating and treating flow, sediment and associated contaminants at a number of stages. This also means that the maintenance of SUDS is less costly and time-consuming and more straightforward than conventional drainage measures. The key findings from the case-study for practitioners are:

- Where possible, SUDS should be designed to trap sediment in areas from which it can be easily removed, e.g. filter strips. This avoids expensive and habitat-disruptive maintenance to ponds and wetlands and also reliance on below-ground conventional drainage that can be costly to maintain. In situ remediation of organic contaminants and nutrients also occurs more rapidly in filter strips than in submerged sediments.
- To maximise the ecological value of SUDS, high pollutant and sediment loads should not be discharged directly to ponds/wetlands without pre-treatment.

- There is a need to educate designers, contractors, managers and maintenance staff about SUDS as ill-informed actions can adversely impact on the performance and maintenance costs of SUDS.

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