A field study of sediments captured by flow-through stormwater interceptors

Une étude de terrain des sédiments piégés par des séparateurs hydrodynamiques

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RESUME
On sait que les sédiments présents dans les ruissellements urbains sont d’importants vecteurs de polluants. Cet article décrit les caractéristiques physiques et chimiques des sédiments piégés par 6 installations d’un dispositif séparateur. Des sites en Grande-Bretagne et en Irlande, ont été choisis pour représenter une fourchette de contextes urbains. Les valeurs particulières $D_{50}$ se situaient dans la fourchette 7-112\textmu m, en accord avec les plages indiquées pour les bassins d’orage. Les teneurs en métaux lourds et en hydrocarbures variaient également, les plus fortes correspondant aux sites les plus établis et à plus fort trafic. En plus de confirmer la capacité du séparateur à piéger les sédiments pollués, cette étude fournit des informations utiles sur l’interrelation entre les caractéristiques des sédiments et les conditions in situ.

ABSTRACT
Sediment entrained in urban run-off is acknowledged as being an important carrier of pollutants. The paper reports on the physical and chemical characteristics of sediments captured by six installations of a proprietary interceptor device. The sites, located in the United Kingdom and the Republic of Ireland, were selected to represent a range of urban contexts. Particle $D_{50}$ values were found to range from 7 to 112 microns, corresponding with ranges reported for stormwater ponds. Heavy metal and hydrocarbon concentrations were also found to vary, with the highest corresponding to the most established and heavily trafficked sites. Further to confirming the ability of the interceptor to remove contaminated sediments, useful insights are provided into the interrelation between sediment characteristics and site conditions.

KEYWORDS
Heavy metals, Hydrodynamic separators, Polycyclic aromatic hydrocarbons (PAHs), Stormwater sediment, Urban run-off.
INTRODUCTION

The polluting potential of stormwater run-off from man-made surfaces has become increasingly recognised. Run-off can carry a variety of contaminants, including amongst others heavy metals and hydrocarbons (Campbell et al., 2005).

A number of techniques have emerged for the quantity and quality control of urban run-off. These have involved the use of ‘soft’ engineered structures such as swales, wetlands and ponds (Wilson et al., 2004), and ‘hard’ engineered structures, such as underground storage, treatment and flow control facilities (Faram et al., 2005). Both have been widely and successfully applied.

In practice, the applicability of particular techniques has been found to depend on the context of the situation, for example, overall management objectives, and site factors including space availability. While there is currently a focus on ‘new’ (including ‘green field’) development activity, it is likely that this will need to be broadened in the future, to look at older/existing development infrastructure, as water-quality requirements tighten (e.g. under the Water Framework Directive (EC, 2000)). This will demand the adoption of increasingly innovative design approaches, in which clusters of techniques are integrated together and implemented around/embedded into existing infrastructure in an overall complementary fashion.

Research has highlighted the role of sediment in pollutant transport and dispersion (Pitt et al., 1995; Sansalone and Buchberger, 1997). Sediment particles can adsorb some chemical pollutants such as phosphates and pesticides, and also tend to be associated with other pollutants including heavy metals and hydrocarbons. As such, sediment entrained in urban run-off should ideally be prevented from entering watercourses.

The optimal design of systems to remove pollutants from stormwater relies somewhat on an understanding of pollutant characteristics. In particular, for sediment removal, it is useful to have an understanding of the physical and chemical characteristics of the sediments, such that those presenting most potential to pollute can be specifically targeted. This paper presents the findings of a field study of the characteristics of sediments captured by flow-through stormwater interceptors. In particular, the study considers the characteristics of sediments captured by a proprietary sediment interceptor, known commercially as the Downstream Defender® (DSD) (Figure 1).

Figure 1. Cut-away view through the Downstream Defender® (DSD) system of the study
The DSD is a chamber based device that utilises hydrodynamic vortex separation principles to capture and concentrate sediments and floatables for later periodic removal. Such systems have been extensively applied, most prominently in the USA, and have been the subject of a number of verification studies (Faram et al., 2000, 2005a, 2005b; Pratt, 2000; Phipps et al., 2005). A particular characteristic is that sediments are stored in a sheltered region, preventing their washout at high flows, a phenomenon that has been observed in other chamber types (Phipps et al., 2005).

This paper provides useful practical insights into the operation of the DSD, in terms of the nature and characteristics of the sediments that it is able to capture, while also contributing to the ‘database’ of stormwater sediment characteristics associated with different types of urban environment.

METHODS

Seven DSD installations were considered in the study, located in England, Scotland and the Republic of Ireland. This paper reports on field work conducted at six of these, selected to cover a range of scenarios, including a ‘park-and-ride’ car park, a motorway service area, an urban road, a residential development and a construction site. Details are presented in Table 1.

<table>
<thead>
<tr>
<th>DSD Size (m)</th>
<th>Site Description</th>
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<tbody>
<tr>
<td>2.4</td>
<td>Motorway service area (MSA), Birmingham, England. Surface water from a fuelling station forecourt perimeter feeds to a DSD, then to a series of reed beds and ponds, before discharging into an adjacent stream. Heavily trafficked bitumen surfaced site. DSD installed in 1999.</td>
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<tr>
<td>1.8</td>
<td>Urban road, Renfrewshire, Scotland. Surface water feeds to a DSD from a moderately heavily trafficked bitumen surfaced road, before discharging to a soakaway adjacent to a medium size stream. DSD installed in 2000.</td>
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<tr>
<td>2.0</td>
<td>Park-and-ride (P&amp;R) car park, Wiltshire, England. Surface water feeds to a flow control chamber, then to a DSD and to a petrol-oil interceptor, before discharging into an adjacent small stream. Moderately trafficked bitumen surfaced site, separated with planted areas. DSD installed in 2001.</td>
</tr>
<tr>
<td>2.0</td>
<td>Construction site (Cons. Site) for residential development, South County Dublin, Ireland. Surface water feeds to a DSD from various points, before discharging into a stream/small river. Industrial traffic and groundworks. DSD installed in 2005.</td>
</tr>
<tr>
<td>2.0</td>
<td>New residential development (Res. Dev. B), South County Dublin, Ireland. Surface water feeds to a DSD from lightly trafficked bitumen surfaced roads and driveways, before discharging into an adjacent stream. DSD installed in 2004. Adjacent to Res. Dev. B (part of the same development).</td>
</tr>
<tr>
<td>2.0</td>
<td>New residential development (Res. Dev. A), South County Dublin, Ireland. Surface water feeds to a DSD from lightly trafficked bitumen surfaced roads and driveways, before discharging into an adjacent stream. DSD installed in 2004.</td>
</tr>
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Table 1. Characteristics of the study separators and description of sites

For each site, the sediment depth in the DSD was measured and a sample of sediment removed for analysis. In order to perform this operation, it was necessary to use specially designed and developed sampling equipment. Figure 2(a) illustrates the use of a sediment surface measurement probe. Figure 2(b) shows a sediment ‘twist-scoop’ sampler. Fitted with sterile sample bags, and attached to a pole assembly, this was lowered to the base of the chamber, and then rotated, in order to collect sediment material. This was found to be very effective, though it was necessary to repeat the process several times to collect enough material for the purposes of analysis. For every site, the body of the sediment was found to be of sludge-like consistency. This enabled collection and composting of material from different bed-depths. For each site, apart from the urban road site, sampling visits were conducted...
twice within a 10 month period, between August 2005 and May 2006. The urban road site was only visited once (in May 2006).

Samples were photographed, divided and submitted to UK Accreditation Service approved laboratories for analysis. This paper focuses on sediment sizing, heavy metal, polycyclic aromatic hydrocarbon (PAH) and total petroleum hydrocarbon (TPH) analysis. Sediment sizing was conducted using a combination of laser diffraction and sieve analysis techniques. Metals analysis was conducted using inductively coupled mass spectrometry (ICMS). Hydrocarbons analysis was conducted using gas chromatography/mass spectrophotometry (GC-MS).

RESULTS AND DISCUSSION

The DSD units were found to have captured quantities of up to 4m$^3$ of sediment. Where assessed, the increase between first and second visit volumes was found to be between 0.5 and 1m$^3$ (captured over a 9 month period). The samples were found to vary in consistency, with regard to their appearance, particle sizing and chemical content. Photographs of the second batch of samples are shown in Figure 3. Particle sizing data is presented in Figure 4 (also including ranges for benchmark comparison data) and heavy metal and hydrocarbon concentrations in Figures 5 and 6.

(a) Sediment surface measurement probe (b) Sediment ‘twist-scoop’ sampler

Figure 2. Sediment depth measurement and sampling instruments developed for the study

(a) MSA (b) Urban Road (c) P&R (d) Cons. Site (e) Res. Dev. B (f) Res Dev. A

Figure 3. Photographs of the samples collected in 2006, illustrating differences in appearance
Particle size analysis for sediment samples collected in 2005 (1) and 2006 (2) alongside benchmark ranges for stormwater pond sediment and street/road dust

Particle D$_{50}$ values were found to range between around 7 and 112 microns (Figure 4). For the park and ride, construction and residential development (A and B) sites, first and second visit gradings were found to be similar for each site, and overall rank orders were the same, verifying them as being 'site' rather than 'sampling regime' characteristics. For the motorway service area, a D$_{50}$ shift from 30 to 112 microns was found between the samples. Ash tests performed on all of the samples identified between 72 and 99% as being non-volatile (average 90%).

The construction site sediment was the finest overall ($D_{50}$s from 7 to 8 microns), followed by the park and ride and urban road sediments ($D_{50}$s from 11 to 15 microns). The coarsest was that from residential development site A ($D_{50}$s from 60 to 120 microns) and the second sample from the motorway service area ($D_{50}$ of 112 microns) followed by that from residential development site B ($D_{50}$s from 30 to 39 microns) and the first motorway service area sample ($D_{50}$ of 30 microns).

The findings can be correlated to site conditions. The fine nature of sediments at the construction site correlates to a high degree of ground disturbance at this site, and the resulting passage of material into the drainage system. It is known that this DSD has required above average levels of clean-out maintenance. The coarse component of the residential development samples can be attributed to the presence of residual material from the construction process on driveways and roads. For the motorway service area site, this is attributed to the presence of grit used to absorb split fuel/oil or prevent icing, evidenced by the visible presence of orange sand particles in the samples. The respective intermittent/seasonal nature of these activities could explain the variances in gradings for the two samples taken. The urban road and park and ride sites, producing intermediate-grade sediments, were relatively established, with no recent groundwork or industrial activity in the locality.

Benchmarking with published data for stormwater pond sediments and road/street dust (shown as a range in Figure 4) generally indicates the DSD sediments as being most similar to that found in ponds. A more comprehensive discussion and comparison with the benchmarks is presented elsewhere (Faram et al., 2006).
On average, the motorway service area site was found to produce the highest metal concentrations, followed by the urban road, park and ride, construction and residential development (A and B) sites. Notably, rankings for concentrations of PAHs and TPHs were found to be the same (Figure 6).
The motorway service area was both the most established and also most ‘active’ of all of the sites, receiving high volumes of traffic, and being the most ‘industrial’ in the sense of incorporating vehicle refuelling and basic maintenance (e.g. oil and other level top-up) facilities. For this site, concentrations of Zn, Cu, Cr, Pb and Cd were higher than for most of the other sites, with Zn levels being at least four times that of any other site. PAH and TPH levels were also very high. However, Ni levels were comparatively low. The urban road, again being a relatively ‘active’ site, also produced high metal and hydrocarbon concentrations. Cr and Ni levels were higher than for all other sites. Zn, Cu, Pb, Cd, PAH and TPH levels ranked second only to those of the motorway service area.

The residential development sites generally produced lower levels of metals and hydrocarbons than the other sites, correlating with their status as being non-industrial and low-level traffic areas. In comparison to these, the construction site produced marginally higher concentrations of Cu, Cr, Pb, Cd, PAH and TPH and significantly higher concentrations of Ni (possibly due to being a diesel additive), this ranking the second highest overall. The park and ride site produced higher concentrations of Zn, Cr, Pb, PAH and TPH compared to these three sites, but below average concentrations of Ni and Cd.

Comparisons with sediment metal concentration data for stormwater ponds and street/road dust along with reference figures for sewage sludge disposal are presented in Faram et al. (2006). These generally find the study sample metal concentrations to be below or within ranges published for ponds, to span ranges published for street/road dust, and to fall below ranges for sewage sludge disposal on land. Further interpretation, also considering PAH and TPH content identifies occasional entry into ranges for ‘ecotoxic’ waste in the UK (as defined in Environment Agency, 2003).

CONCLUSIONS

1. Proprietary interceptor devices are able to remove fine sediments from urban run-off, preventing it from entering downstream watercourses or further treatment facilities. These systems therefore present practical value, whether applied in isolation or in conjunction with other stormwater quality controls.
2. The optimal design or selection of stormwater sediment management systems can be aided through an understanding of individual site conditions and requirements and related sediment physical and chemical characteristics.

3. The physical characteristics of stormwater sediments are largely site specific (D50 ranges of 7 to 112 microns found in the current study), though some basic correlations with site conditions can be made. For example, sites where there is ground disturbance are most likely to produce fine sediments.

4. Sediment metal and hydrocarbon concentrations can be correlated with site conditions. In the current study, the most contaminated sediments were those from a motorway service area and an urban road, both the most established and heavily trafficked sites. Those from a residential development were the least contaminated.

5. The study contributes to the ‘database’ of concentrations of pollutants in stormwater sediments. Such data sets will be valuable in enabling the effective ongoing development and implementation of the associated regulatory programmes in the USA and Europe, with further potential for adaptation and adoption in other developed and developing regions of the world.

REFERENCES


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