Bagging Industrial Drains:
A Solid Media Survey of Stormwater Contamination

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Abstract

Conventional approaches to stormwater quality evaluation combine continuous flow rate monitoring and automated sample collection for chemical analysis to derive an event mean concentration for each pollutant of concern. This approach requires expensive flow monitoring and automated sample collection equipment and the costly analysis of high numbers of water samples. Consequently, such monitoring is prohibitively expensive and is rarely conducted. We trialled an alternative monitoring approach using adsorptive solid media, developed to evaluate a stormwater education and enforcement (E&E) program targeted at industrial precincts in the City of Kingston. Adsorptive solid media are secured in stormwater drains for subsequent analysis of accumulated pollutant concentrations, thus providing an integrated measure of pollutant concentrations after a standard period of exposure. This approach is more cost-effective than continuous monitoring as the lower variability of pollutant concentrations in solid media compared to water obviates the need for analysis of high numbers of samples.

Introduction

Urban streams often have waters and sediments that are toxic to aquatic ecosystems (Pettigrove and Hoffmann 2005). Pollutants frequently present in urban runoff include heavy metals (Pettigrove and Hoffmann 2003a), petroleum hydrocarbons (Pettigrove and Hoffmann 2003b) and pesticides (Schiff and Sutula 2004). Runoff from industrial catchments usually contains disproportionately high levels of these pollutants (Pettigrove and Hoffmann 2003a). The City of Kingston received funding through the Coastal Catchment Initiative (DEWR 2004) to conduct an Education and Enforcement (E&E) program aimed at reducing diffuse pollution of stormwater by runoff from industrial sub catchments. The E&E Program is a pilot project that will undertake an audit of stormwater management practices in industrial catchments, with follow up enforcement where necessary. Quantifying an E&E program's impact on stormwater quality would be valuable for the development of future programs, yet evaluating the effectiveness of such a program can be problematic (Taylor and Wong 2002). An indirect evaluation by follow-up survey questionnaire is affordable and quick but may be of questionable value, as this approach relies heavily on businesses self-reporting behavioural changes. Observational techniques to evaluate behaviour change are complex, difficult to apply and costly. Practical evaluation of an E&E program requires estimation of the prevailing runoff water quality pre- and post-program; however, it is particularly difficult to estimate the quality of runoff water from small (<100 ha) urban sub-catchments.

Currently there are three options for assessing the quality of runoff from urban sub-catchments: A water quality survey may be conducted where water samples are collected on a sufficient number of occasions so the prevailing water quality may be determined (Pettigrove and Hoffmann 2003a). This approach can be prohibitively expensive, as high variability in concentrations of pollutants necessitates the collection and analysis of many water samples. Continuous water quality samplers may provide an assessment of contaminant concentrations given sufficient time and adequate flow. However; installation and maintenance of the automatic sampling equipment is prohibitively expensive where numerous sub-catchments must be surveyed. A third approach is to measure the concentrations of pollutants in sediments. This approach is more cost effective for two reasons: Concentrations of contaminants such as heavy metals in fine-grained river sediments can be more than 100,000 times higher than in the overlying water (Horowitz 1991) and contaminant concentrations in sediments tend to fluctuate over longer time scales than concentrations in surface waters. Therefore, considerably fewer sediment samples are required to adequately assess sediment quality, and by implication, the quality of the overlying water. The utility of sediment quality assessment as a cost-effective approach for identifying major pollution sources has been demonstrated in the Merri and Darebin Creeks in Melbourne, Australia (Pettigrove and Hoffmann 2003a), but it is obviously restricted to drainage systems which accumulate sufficient sediment for analysis.

We developed a simple solid-media method for estimating the quality of runoff from concrete-lined channels and subterranean drains where sediment accumulation is minimal. This method utilizes solid absorptive medium contained in polythene mesh bags to collect contaminants present in industrial runoff. The method is significantly more cost-effective than water quality surveys or continuous monitoring, as the lower variability of pollutant concentrations accumulated in solid media compared to water reduces the number of samples required. We trialled the solid-media method to survey relative contaminant levels in runoff from industrial sub catchments in the City of Kingston, prior to delivery of an E&E program. This monitoring survey establishes a baseline for future work to evaluate the impact of changes in stormwater management practices as a consequence of the E&E program.

Methods

Study area and selection of sub catchments

This study was conducted at industrial precincts within the City of Kingston, about 25 km south-east of Melbourne. This area forms part of the catchment of the Mordialloc Creek estuary, which is contaminated with high concentrations of heavy metals and petroleum hydrocarbons (Melbourne Water, unpublished data). A diverse range of industries is represented in the study areas, including textile clothing, footwear and leather manufacture, wood and paper product manufacture, non-metallic mineral product manufacturing, general construction, construction trade services, basic material wholesaling, machinery and motor vehicle wholesaling, motor vehicle retailing and services and transport and storage (City of Kingston, 2002).

Sites were initially selected by reference to a GIS drainage plan maintained by Kingston Council. The Braeside and Mordialloc areas were selected for this study because the drainage network is primarily open concrete-lined channels, facilitating access to sub catchment drain outfalls. Once sub catchments containing land zoned residential, traversed by major roads, or with significant areas currently under construction were excluded, 22 suitable sub catchments served by a single drain outfall were identified. Visual inspection excluded a further two drains which were either submerged or could not be accessed safely. Drains not marked on the drainage plan were identified at sub catchments D2 and H3. An extra monitoring bag was mounted at these two sub catchments for preliminary monitoring of both drains; we subsequently selected the drain with the most consistent dry-weather flow and contaminant concentrations to exclude auxiliary storm drains potentially dominated by road runoff. The characteristics of the remaining 20 sub catchments served by the Dunlops, Settlement and Heatherton open channel drains are summarised in table 1.

Table 1. Braeside and Mordialloc sub catchment characteristics and receiving open channel drains

Receiving Drain	Sub catchment	Sub catchment Age (years)	Approximate Size of Premises	Number of Premises
Dunlops	D1	25	M	11
Dunlops	D11	10	M	69
Dunlops	D2A	25	L	11
Dunlops	D3	25	S	16
Dunlops	D4	25	S	9
Dunlops	D5	25	M	8
Dunlops	D6	25	S	20
Dunlops	D7	5	M	15
Dunlops	D8	10	M	50
Dunlops	D9	10	L	21
Dunlops	DE1	20	M	9
Heatherton	H1	50	S	22
Heatherton	H2	50	S	22
Heatherton	H3A	50	S	21
Heatherton	H4	50	S	22
Settlement	S1	30	M	10
Settlement	S2	30	M	6
Settlement	S3	30	M	8
Settlement	S5	30	S	20
Settlement	S6	30	S	16

Media deployment, collection and analysis

Polyethylene mesh bags measuring 400mm x 300mm edged with 40mm strips of Velcro were filled with 500mL of granular activated carbon (GAC). Polyvinyl chloride (PVC) mounting plates fitted with 40mm Velcro strips were fastened to drain surfaces with construction adhesive. Bags of media were then secured to the PVC mounting plates with Velcro strips either in (figure 1) or immediately below (figure 2) each drain. After approximately one weeks exposure (including five business days) media were collected, replaced with fresh media, and the bags re-deployed. Media concentrations of hydrocarbons (TPH) and heavy metals (As, Cd, Cr, Cu, Fe, Ni, Pb, Zn) were determined by Ecowise Environmental (Mt Waverley, Victoria, 3149) according to methods WSL030 and WSL-032 respectively.

Figure 1. Monitoring bag fitted inside drain

Figure 2. Monitoring bag fitted below drain

Data analysis and parameter selection

For a preliminary monitoring period of three weeks, accumulated concentrations of heavy metals and TPH in media were determined at weekly intervals. Exploratory analyses indicated that pollutant concentrations were not normally distributed, therefore all data were $\log_{10}(x+1)$ transformed prior to parametric statistical tests. Where remaining parameter concentrations were below detection limits (DL), ½ DL was substituted. From week four onwards, parameters which were highly correlated with Cu (Fe, Ni, Cr) or which were consistently below detection limits (As, Cd, Pb) were not determined. Differences in mean pollutant concentrations between sub catchments and collection weeks were evaluated by 1-way ANOVA. Corrections for multiple post-hoc comparisons used Tukeys B method where variances were homogeneous as indicated by Levene's test, otherwise Dunnets C method was used.

Results

Preliminary results

Of 69 media samples analysed after 3 weeks monitoring, 100% of As, 66% of Cd and 88% of Pb concentrations were below analytical detection limits, therefore these metals were excluded from subsequent data analysis. Principal component analysis extracted three factors accounting collectively for 88% of the variation in the remaining six parameters: The first factor correlated with Fe, Ni, Cr, and Cu, the second factor correlated with Zn, and the third factor correlated strongly with TPH concentrations. Pair wise comparisons indicated Cu and Zn were significantly correlated (Pearsons coefficient = 0.57, $p < 0.01$), as were Fe, Ni, Cr, and Cu ($p < 0.01$).

Observations

149 GAC samples were collected from the 20 sub catchments over approximately 8 weeks. Storm flows caused by heavy rainfall prevented collection of bags from 4 sub catchments on Nov 8th and 7 sub catchments on Nov 15th. All outfalls to the Heatherton drain showed evidence of immersion prior to the collection week of Nov 8th, although this did not appear to reduce accumulated pollutant concentrations at this catchment compared with previous weeks. When the Heatherton catchment was considered separately, mean Cu, Zn and TPH concentrations in the last 2 collection weeks were not significantly lower than previous weeks (Dunnett C, $p>0.05$). Oily hydrocarbon residues were noted on six collections, including three times at sub catchment D9. A medical odour was consistently noted at DE1, while a strong odour of organic waste was noted at S1, D4 and D8.

Pollutant concentrations accumulated by GAC

Mean Cu, Zn and TPH concentrations accumulated by GAC media were 10.2 (±4.4), 112 (±89) and 1134 (±5419) mg/kg, with Cu and TPH concentrations below detection limits in 5 and 14 samples respectively. Cu concentrations ranged from <DL to 32 mg/kg, Zn concentrations ranged from 13 to 660 mg/kg, and TPH concentrations ranged from <DL to 60,135 mg/kg. The mean TPH concentration (1134mg/kg) was approximately four times that of the median (257mg/kg), illustrating the extent to which the distribution of TPH concentrations was skewed by a few extremely high values.

Pollutant differences between sub catchments

Cu concentrations varied significantly between sub catchments (ANOVA, $F_{(19,129)} = 2.24$, $P=0.004$). Sub catchment D5 had significantly elevated Cu concentrations compared with H3A, H4, S2 and D4 (Tukey B, $p < 0.05$).

Week of collection **Sub catchment**

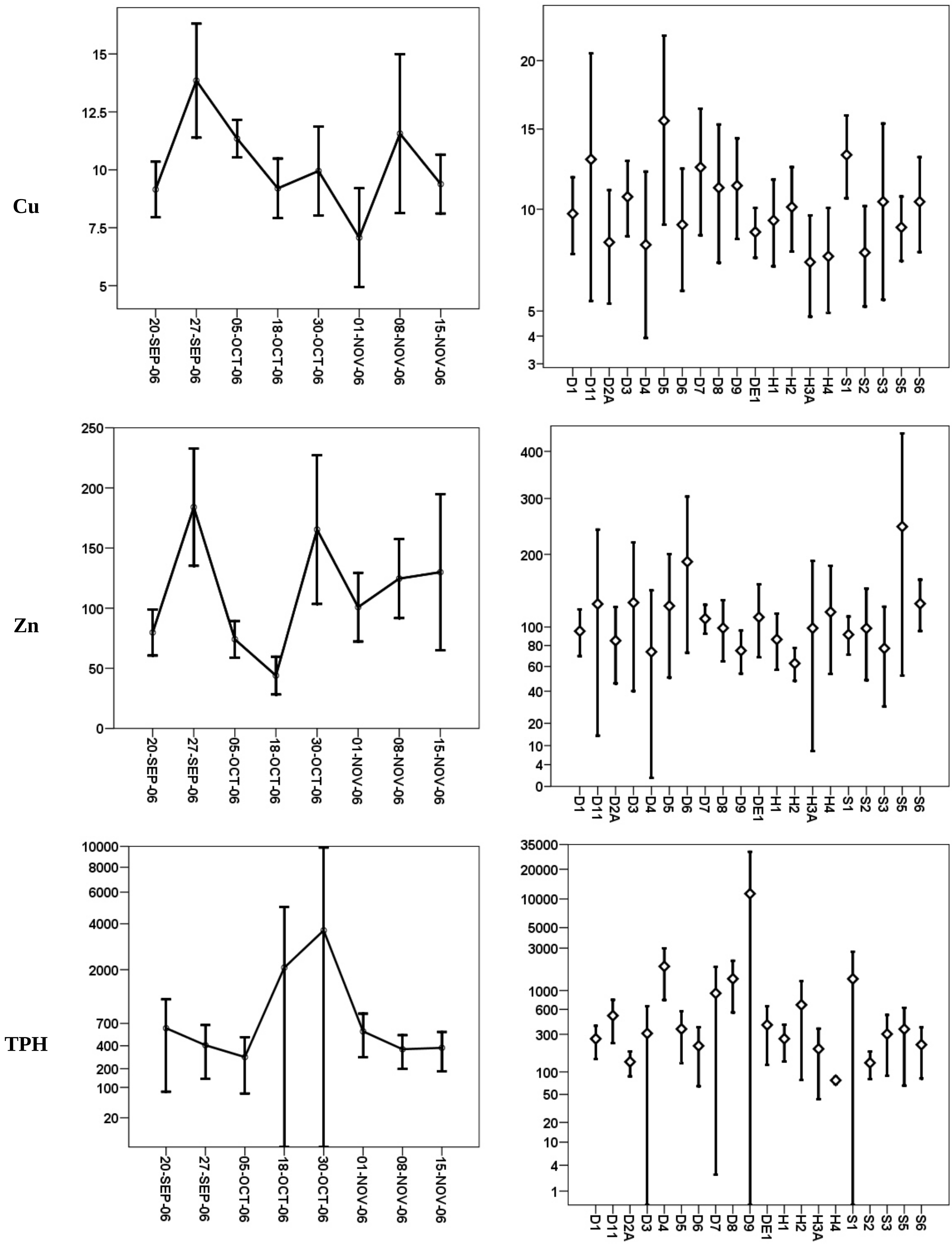

Figure 3. GAC media pollutant concentrations (mg/kg dry weight) grouped by collection week and sub catchment. Mean pollutant concentrations ±95% confidence intervals.

Zn concentrations did not vary significantly between sub catchments (ANOVA, $F_{(19,129)} = 1.04$, $p = 0.42$), whereas mean TPH concentrations varied significantly between sub catchments (ANOVA, $F_{(19,129)} = 5.31$, $p < 0.01$). For example, sub catchments S1 and D8 had significantly elevated TPH concentrations compared with D2A, H4 and S2 (Dunnet C, $p < 0.05$). TPH and Cu concentrations were significantly correlated with catchment age, although the correlation was weak in both cases (Kendals tau = -0.22 and -0.14 respectively, $p<0.05$), and average size of premises was negatively correlated with catchment age (Kendals tau = -0.53, $p<0.001$)

Pollutant trends over time

Cu concentrations accumulated by GAC media varied significantly among collection weeks (ANOVA, $F_{(7,141)} = 8.13$, $p < 0.001$) as did Zn concentrations (ANOVA, $F_{(7,141)} = 15.48$, $p < 0.001$). Mean Cu and Zn concentrations were significantly elevated on Sep 27th compared with Nov 1st (Dunnet C, $p < 0.05$). In contrast, mean TPH concentrations on Sep 27th were no different to any other week, but rose significantly from Oct 5th to Oct 30th (Dunnet C, $p < 0.05$). Significantly lower concentrations of Cu and Zn and TPH were accumulated on Nov 1st, Oct 18th and Oct 5th respectively (Tukey B and Dunnet C, $p < 0.05$). On Oct 18th and Oct 30th, media at sub catchment D9 contained 28,320 and 60,135 mg/kg TPH. This spike in TPH concentrations contributed to an increase in the mean TPH concentration for 2 weeks, and to D9 yielding the highest mean TPH of all sub catchments.

Discussion

The potential impact of urban stormwater on receiving water quality is well known (House, Ellis et al. 1993). Wider appreciation of the relationships between catchment land use and runoff quality have lead to targeted approaches to improving the quality of urban runoff (Pitt 2002), but evaluation of the effectiveness of these methods remains problematic. As a simple indicator of urban runoff quality, the solid-phase media method currently under development has the potential to contribute to evaluation of a wide range of these approaches, although this evaluation should be considered qualitative rather than quantitative at this stage.

The PVC mounting plate / Velcro system of securing media bags was convenient and generally successful, although six bags were lost during storm flow events. At the Heatherton catchment, immersion by storm flows prior to sample collection on the week of Nov 1st and Nov 15th did not appear to cause dramatic reduction in the amounts of pollutants accumulated. Although further testing is required to validate this performance, this observation suggests monitoring during periodic rainfall may be feasible.

The even distribution of Zn concentrations between sub catchments may indicate relatively diffuse input sources. For example, galvanised iron roofing, atmospheric deposition and road surface materials have all been implicated as possible sources of Zn to urban runoff (Pitt and Lalor 2000; Brown and Peake 2006). Consequently, reduction in Zn inputs may not be readily achievable through behavioural changes, which could have important implications for stormwater management in these catchments. TPH pollution appeared episodic, with low base loads punctuated by occasional pollution events. This could indicate regular accidental hydrocarbon spills, or even dubious practices such as dumping of waste oil. The connection between Cu, TPH and catchment age may indicate that newer catchments are more likely to contain a particular type of industry associated with high hydrocarbon use, or may simply reflect the greater car parking area available on the larger blocks prevalent in new sub catchments. Substantially more data on sub catchment properties will be available on completion of the E&E program, enabling more definitive characterisation of the factors influencing these two pollutants during follow-up monitoring.

Limiting the range of pollutants analysed to Zn, Cu and TPH reduced chemical analysis costs considerably, while maintaining the ability to discriminate between relatively clean and heavily polluted sub catchments. Further testing with alternative media is recommended, as more sensitive detection may be achieved with multiple media targeted to individual pollutants (Madrid and Camara 1997).

In summary, GAC media exposed to runoff from sub catchments in the Kingston study area consistently exhibited elevated pollutant concentrations, particularly Zn and petroleum hydrocarbons. These correspond with the major pollutants present in sediments of the Mordialloc Creek estuary (Melbourne Water, unpublished data), suggesting that GAC is a useful media for the major pollutants of ecological concern in this catchment. Our preliminary results demonstrate that solid-phase media can be a useful approach to identify sub catchments of concern for further investigation and potential remediation.

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