

Metals in sediments of sustainable urban drainage structures in Scotland

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Abstract Sustainable urban drainage solutions increasingly use structures, such as wetlands and ponds, to improve water quality. Previous studies have demonstrated the effectiveness of these structures in removing metals from runoff, but the fate of the captured contaminants has been neglected. Whilst organic contaminants and nutrients may biodegrade and be taken up by plants, metals are expected to accumulate in sediments. EDTA-extractable cadmium, chromium, copper, lead, nickel and zinc were measured in sediment sampled from three urban drainage structures (a wetland and two ponds receiving industrial and residential storm drainage) in Scotland, UK. Metal concentrations showed considerable variability within each structure, probably reflecting short-circuiting of flow. Zinc, chromium and cadmium concentrations were at very low levels at all sites, but copper, nickel and lead exceeded background concentrations for aquatic sediments. An index of metal contamination showed that the metal content of sediments increased with the age of the structure.

INTRODUCTION

Sustainable solutions to urban drainage, or Best Management Practices (BMPs), include a wide range of structures which have been shown to improve water quality, e.g. wetlands, swales, detention and retention basins, and ponds (Lawrence *et al.*, 1996). The contaminant removal capabilities of these structures are widely reported but the fate of the captured contaminants has been neglected. Organics and nutrients should be recycled to an extent within the structure, through chemical and microbial degradation and plant uptake, respectively. However, elevated concentrations of heavy metals have been measured in soil below highway runoff infiltration systems in Switzerland (Mikkelsen *et al.*, 1996) and Sweden (Lind & Karro, 1995). The risk of groundwater contamination from heavy metals in wet detention ponds was assessed to be negligible if sediments were removed every 25 years (Yousef & Yu, 1992).

The accumulation of metals in sediment may also have important implications for the management of sustainable drainage structures. If metals reach critical levels which are toxic to plants and animals, then excavation of the substrate may be required. Furthermore, the disposal costs of any excavated sediment will depend on its composition. If the material is classified as a hazardous waste on account of metal content then additional costs will be incurred in disposing of it, e.g. to landfill. The aims of this study were to quantify the metal content of sediments from three sustainable urban drainage structures in Scotland, UK, and assess the implications for management.

STUDY SITES

The characteristics of the three study sites are summarised in Table 1. The wetland system was retrofitted to treat dry weather flow plus the first flush of storm water draining from a large industrial estate. The industrial pond is one of a series of ponds designed to control runoff volume and quality and increase amenity at the site. The residential pond was originally designed as a flood abatement facility, but has been found to also have a beneficial effect on water quality (Dowswell, 1997).

Table 1 Characteristics of the study sites and structures.

	Wetland	Pond (industrial)	Pond (residential)
Location (Lat, Long)	55° 51.42' N 3° 30.00' W	55° 51.42' N 3° 34.44' W	56° 10.04' N 3° 09.04' W
Type of drainage	Runoff from industrial estate.	Runoff from loading area and part of roof area.	Runoff from residential development (1.27 km ² area), though evidence of cross-connections with sewers*.
System design	Flow piped into settlement pond before overflowing into planted overland flow zone.	Drainage piped to oil interceptor then flows into swale, leading to pond. Pond margins planted. Overflow outlet for high water levels.	Pond consists of two basins, each with an inlet and oil interceptor. One outlet from pond. Pond capacity 900 m ³ .
Year operational	1997	1995	1987

* Dowswell (1997).

DATA COLLECTION

Sediments were sampled in July 1998 at five points in the wetland, four in the industrial pond and six in the residential pond. Five sediment samples were collected at 0–5 and 5–10 cm depths at each point with a gouge auger. The samples for each depth interval were bulked and transferred to plastic bags which were sealed and stored at 4°C.

In the laboratory, samples were oven-dried at 35°C, ground and sieved to obtain the 2 mm fraction. EDTA-extractable cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn) were determined by shaking 10 g of prepared sediment with 0.05M EDTA for 1 h, filtering the suspension and measuring the metal concentrations by atomic absorption spectrophotometry. Total metal concentrations may not reflect the potential sediment toxicity because most of the metal may be held in stable forms which are not bio-available (Himer, 1992). Hence EDTA-extractable metals were analysed in the sediment as a measure of their bioavailability.

RESULTS

The median and range of concentrations (dry weight) of EDTA-extractable Cd, Cr, Cu, Ni, Pb and Zn in the three structures are shown in Fig. 1. The results show that there is no difference in metal concentrations between the 0–5 and 5–10 cm depths. Spatial variability in metal concentrations occurs within each structure, particularly in the

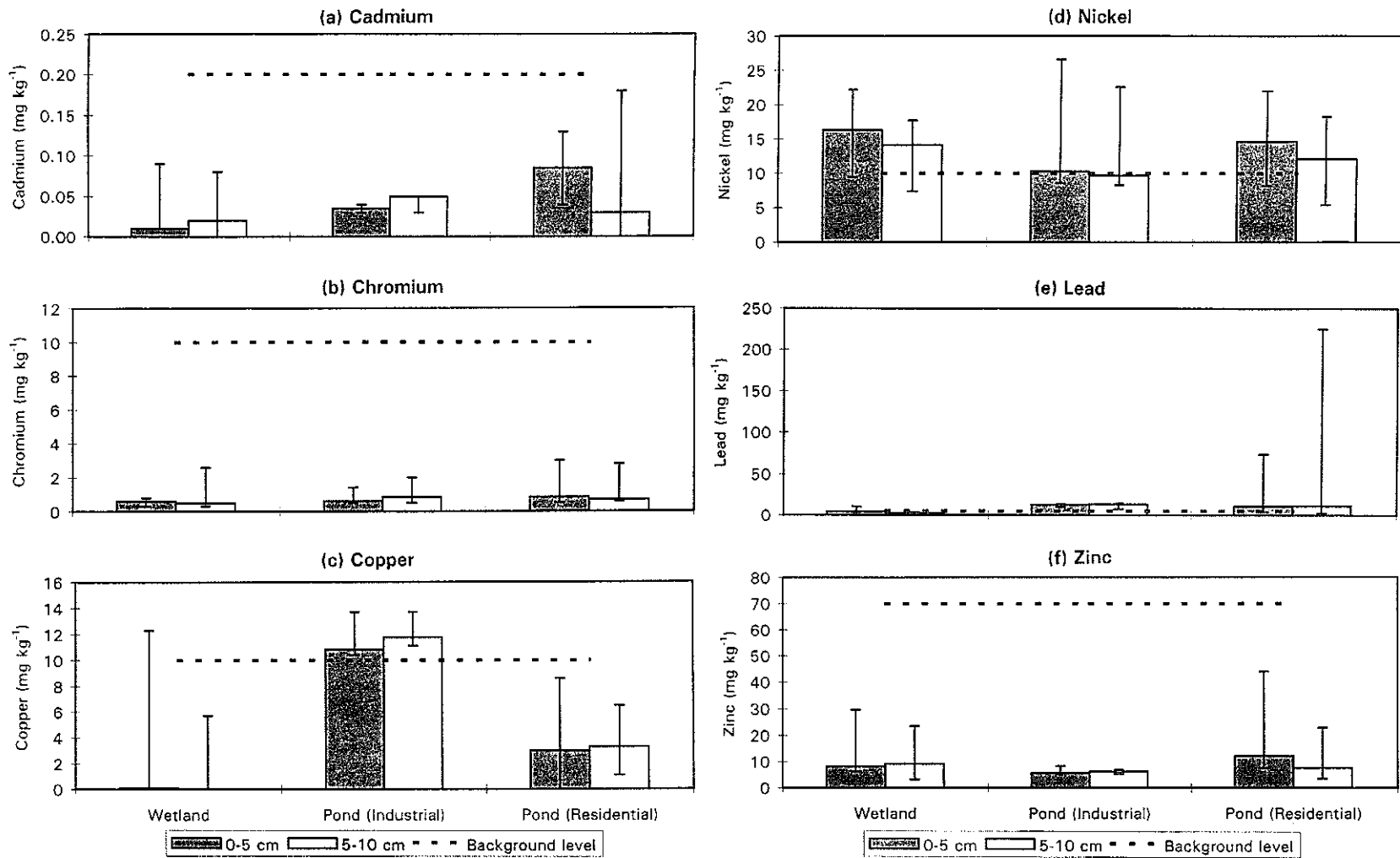


Fig. 1 Concentrations (dry weight) of EDTA-extractable metals in sediments from three structures.

wetland and residential pond, probably due to short-circuiting of flow between the inlets and outlets. Figure 1 also includes for comparison the natural background concentration for total metals found in the Swedish Environmental Protection Agency (Swedish EPA) survey of aquatic sediments in Sweden (Swedish EPA, 1991). Water chemistry data for the inlets and outlets of the structures are shown in Table 2, with the exception of the industrial pond which has an overflow outlet. Comparison of inlet and outlet concentrations shows that Cu, Pb and Zn are accumulating in the wetland, Cr, Cu, Ni and Zn in the industrial pond, and Cd, Ni and Zn in the residential pond. The other metals present in the sediments may therefore be contributed either by larger storm events than the grab samples, or from atmospheric deposition or other sources which are no longer active.

Table 2 Metal concentrations (mg l^{-1}) in water samples at site inlets and outlets.

Site	Cd	Cr	Cu	Ni	Pb	Zn
Wetland*						
Inlet	0.001–0.004	0–0.003	0.003–0.009	0	0–0.008	0.038–0.110
Outlet	0.001–0.004	0–0.003	0.001–0.007	0.005	0–0.006	0.017–0.157
Pond (industrial)*						
Inlet	0	0.001–0.004	0.001–0.003	0.001–0.079	0	0.004–0.038
Pond (residential)†						
Inlet	0–0.003	0.002–0.006	0.011–0.026	0.014–0.032	0.002–0.005	0.083–0.361
Outlet	0–0.001	0.014–0.120	0.011–0.026	0.013–0.028	0.004–0.011	0.003–0.008

* Bowden (1998), three measurements June–July 1998.

† Dowswell (1997), three measurements September 1996–July 1997.

DISCUSSION

Measured metal concentrations

Median Cr, Ni and Zn concentrations are similar in sediments from all the sites studied, indicating, given the difference in site age, that there is no accumulation of extractable Cr, Ni and Zn in sediment over time.

Median Cu concentrations in sediment from the industrial pond are considerably higher than the residential pond and the wetland (Fig. 1(c)), but Cu concentrations measured in runoff entering the industrial pond are lower than at the other sites (Table 2). This suggests that there is an additional source of copper in storm runoff from the industrial site.

Median Pb concentrations are higher in the ponds than the wetland (Fig. 1(e)), and the maximum concentration in the residential pond is an order of magnitude higher than elsewhere. Pb concentrations entering the structures in runoff do not explain this observation, as levels are similar at all sites (Table 2). Elevated Pb concentrations in the residential pond may be caused by historically higher atmospheric emissions from leaded petrol (Jones *et al.*, 1991), though this would be expected to affect the whole pond uniformly, unless sediment redistribution has occurred. Alternatively, Pb accumulates in sediments over time, and is therefore present at elevated concentrations in the oldest structure.

Median Cd concentrations are also higher in sediment from the industrial pond and residential ponds, compared to the wetland. Cd concentrations measured in runoff are similar at all site inlets, suggesting that Cd may also accumulate in sediment.

Comparison with background sediment concentrations

Cd, Cr, and Zn concentrations measured in sediments for all three sites lie within background levels for total metals. Even though the measurements of EDTA-extractable metals in the present study underestimate total metal concentrations, the results indicate that sediments are not contaminated by Cd, Cr and Zn in the structures studied.

Median Cu concentrations in the sediment from the industrial pond exceed background values and are designated as "low" compared to Swedish levels. Median sediment concentrations at all sites exceed background levels for total Ni and Pb. Ni levels in the sediments from the three sites are classified as "low". Pb levels are designated as "low" in the wetland and industrial pond, but "high" in the residential pond. Although Cu, Ni and Pb concentrations exceed background levels, the sediments analysed do not appear to be contaminated with these metals, apart from with Pb in the residential pond.

Overall sediment contamination

To provide an overall assessment of the metal contamination of sediment at each site, a scoring system was devised which compares measured metal concentrations with the Swedish EPA classification and the UK Interdepartmental Committee on the Redevelopment of Contaminated Land (ICRCL) trigger values for contaminated land (ICRCL, 1987). The scoring system used the mean sediment composition of the depth measurements. Each metal was compared with the Swedish EPA classification, scoring 1 for the "background" category, 2 for "low", 3 for "moderate-high", 4 for "high" and 5 for "very high". Metal concentrations were also compared with the ICRCL threshold trigger values for domestic gardens and allotments, and scored as the percentage of the appropriate concentration. The total scores for each site, compared with the Swedish EPA and the ICRCL trigger values are shown in Table 3.

Table 3 Scoring system for metal contamination in sediments.

Site	Cd	Cr	Cu	Ni	Pb	Zn	Total score
Wetland							
Max concentration (mg kg ⁻¹)	0.085	1.6	7.05	20.0	5.8	26.6	–
Swedish EPA score	1	1	1	2	2	1	8
ICRCL score	2.8	0.27	5.42	27.9	1.16	8.85	46.5
Pond (industrial)							
Max concentration (mg kg ⁻¹)	0.045	1.7	13.7	24.6	13.7	7.1	–
Swedish EPA score	1	1	2	2	2	1	9
ICRCL score	1.50	0.28	10.5	35.1	2.74	2.37	52.6
Pond (residential)							
Max concentration (mg kg ⁻¹)	0.155	2.9	7.55	20.8	133	33.4	–
Swedish EPA score	1	1	1	2	4	1	10
ICRCL score	5.17	0.48	5.81	29.7	26.6	11.2	78.9

Comparison with the Swedish EPA classification indicates the degree of sediment contamination *in situ*, whilst the ICRCL trigger values indicate potential disposal routes for sediment excavated from the structure (e.g. spreading on land, landfill). The total scores for both scoring systems follow the pattern: residential pond > industrial pond > wetland, indicating that the sediments in the residential pond are overall more contaminated and more hazardous to dispose of than sediments in the industrial pond and wetland systems. Nevertheless, the total scores are considerably less than the maximum potential scores of 30 and 600 for the Swedish EPA and ICRCL scoring systems, respectively. This suggests that the overall quality of the sediment is not of immediate concern, in terms of metal concentrations, at the sites studied.

CONCLUSIONS

The fate of contaminants removed in sustainable urban drainage systems has been neglected in most studies of these systems, resulting in the identification of "sustainability deficits" (Boller, 1997). The concentrations of extractable metals measured in this study do not exceed background levels of total metals in aquatic sediments, with the exception of Cu, Ni and Pb. Although the degree of contamination has probably been underestimated, the results suggest that excavation of sediment on the grounds of metal toxicity is not required for approximately 10 years from the oldest structure and 20 years from the newer structures. Further investigation of the fate of metals in sustainable urban drainage structures is needed to inform management practice, e.g. in the setting of critical levels of contaminants for excavation. In defining such limits, account should be taken of concentrations in urban soils and also of the health and ecological effects of dispersing pollutants in urban watercourses or concentrating them within drainage structures.

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