NWRI Cont 99-090

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MANAGEMENT PERSPECTIVE

High way runoff is a major cause of toxic effects in urban receiving water. While discharges of untreated highway runoff may cause acute toxic effects, chronic effects may result from accumulation of contaminated runoff sediments in the receiving waters. Major toxicants in highway runoff include heavy metals (particularly Cd, Cu, Pb and Zn) and some polynuclear aromatic hydrocarbons (PAHs). Management mearsures which have been proposed for mitigating these toxic impacts include runoff management ponds, vegetated biofilters, infiltration areas, wetlands and oil/grit separators. While many of these measures are effective in immobilizing particulate bound toxicants, there is a growing interest in measures which effectively remove dissolved contaminants and prevent the contaminant uptake by wildlife attracted to ponds or vegetated facilities. This report examines the feasibility of using biofilters for the removal of dissolved metals from highway runoff. Biofilm growing naturally on coarse substrates was used to fileter synthetic stormwater and the sorption of dissolved heavy metals (zinc, lead, cadmium and copper) was determined for a variety of operational conditions. Preliminary results indicate that the removals of dissolved heavy metal in the range from 40 to 90% can be achieved with this method. Further testing using real highway runoff is planned.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Le ruissellement routier contribue de façon importante à la toxicité des eaux réceptrices urbaines. Tandis que les rejets d'eau de ruissellement routier non traitée peuvent avoir des effets toxiques aigus, l'accumulation de sédiments contaminés de ces eaux dans les eaux réceptrices peut avoir des effets chroniques. Au nombre des principales substances toxiques présentes dans le ruissellement routier, on compte des métaux lourds (Cd, Cu, Pb et Zn particulièrement) et certains hydrocarbures aromatiques polycycliques (HAP). On a notamment proposé à titre de mesures de gestion visant à atténuer ces effets toxiques la création d'étangs pour le traitement des eaux de ruissellement, l'utilisation de filtres biologiques végétaux, l'aménagement de zones d'infiltration, l'utilisation de milieux humides et l'installation de séparateurs permettant de retenir les hydrocarbures et les particules grossières. Bien que bon nombre de ces mesures permettent d'immobiliser les toxiques liés aux particules, on s'intéresse de plus en plus aux mesures qui permettent de retirer les contaminants dissous et préviennent l'absorption de ces derniers par les organismes attirés par les étangs ou les installations végétalisées. Dans le présent rapport, on examine la possibilité d'utiliser des filtres biologiques pour éliminer les métaux dissous dans les eaux du ruissellement routier. On a utilisé des films biologiques croissant naturellement sur des substrats grossiers pour filtrer des eaux pluviales synthétiques, et on a déterminé la sorption de métaux lourds dissous (zinc, plomb, cadmium et cuivre) sous diverses conditions opérationnelles. Les résultats préliminaires indiquent qu'il est possible d'éliminer 40 à 90% des métaux lourds dissous avec cette méthode. On prévoit réaliser de nouveaux essais avec de vraies eaux de ruissellement routier.

ABSTRACT

Experiments were conducted to test the feasibility of using biofilters for removing dissolved heavy metals from highway runoff. Biofilm was allowed to develop on fine gravel in cylindrical filters as well as on the bottom of an annular flume. Synthetic stormwater containing dissolved copper, lead and zinc was used in the tests which showed that the biofilm was effective in removing all three metals.

Keywords
stormwater, biofilter, heavy metals, runoff

RÉSUMÉ

On a effectué des expériences visant à déterminer s'il est possible d'utiliser des filtres biologiques pour éliminer les métaux lourds dissous présents dans les eaux du ruissellement routier. On a fait croître un film biologique sur du gravier fin dans des filtres cylindriques ainsi qu'au fond d'une canalisation annulaire. Les essais effectués avec des eaux pluviales synthétiques contenant du cuivre, du plomb et du zinc dissous ont montré que le film biologique parvenait à éliminer ces trois métaux.

Mots clés

eaux pluviales, filtre biologique, ruissellement, métaux lourds

INTRODUCTION

Highway runoff conveys such pollutants as solids, hydrocarbons, heavy metals, nutrients, deicing agents, phenols, and herbicides (Marsalek *et al.*, 1997; Barrett *et al.*, 1998; Wu *et al.*, 1998). In general, studies indicate that highway runoff pollution is particularly of concern in the case of urban highways with traffic density of more than 30,000 vehicles·day^{-1} (Ellis *et al.*, 1997) and direct discharge of runoff into receiving waters without any runoff control by infiltration or treatment (Barrett *et al.*, 1998).

Discharges of untreated highway runoff may adversely impact on receiving waters through degradation of water quality and exertion of toxic effects. The causes of toxic effects were investigated by means of Toxicity Identification Evaluation (TIE) procedures, which tentatively identified the chemicals causing toxic effects, including copper, zinc, cadmium, lead, several PAHs, and chlorides (Maltby *et al.*, 1995; Mulliss *et al.*, 1996; Boxall and Maltby, 1997; Rokosh *et al.*, 1997). Among these toxicants, heavy metals were particularly important, because they were found in high concentrations and with high proportions (35-60%) of the total metal burden in the bioavailable dissolved form (Marsalek et al., 1997; Sansalone and Buchberger, 1997).

While many best management practices (BMPs) can effectively control suspended solids and the adsorbed chemicals in stormwater, control of dissolved chemicals is much more difficult to accomplish by a limited number of options. The measures most frequently recommended for control of dissolved metals include constructed wetlands, or other vegetative measures, and filters (Anderson et al., 1997). Two types of filters were recommended for stormwater treatment, enhanced sand filters and biofilters. Sand filters are relatively cheap, but ineffective in adsorption of dissolved heavy metals and must be therefore enhanced either chemically (i.e. using chemicaly coated sand) or by addition of organic matter (e.g. peat moss layers) to improve their performance.

Biofilters, with biofilm growing on granular filter media, were also recommended for treatment of urban stormwater and removal of dissolved constituents. In typical experiments, the biofilter would be loaded with stormwater conveying the metal burden in two components, particulate and dissolved. When analyzing results of such experiments, it was impossible to distinguish between metal removals by mechanical filtration of solids (and/or metal adsorption on solids) and metal sorption by biofilm (Anderson et al., 1997). Therefore, the main objective of this exploratory study was to examine the feasibility of removing dissolved heavy metals from stormwater by biofilm only. To avoid uncertainties re dissolved and particulate removals, at this stage of investigation, synthetic stormwater with dissolved metals but no suspended solids was fed into the biofilter. This arrangement is realistic and should be viewed as representing the final stage of a customary stormwater treatment train comprising a pretreatment unit (e.g. an oil/grit separator), a settling unit (e.g. a stormwater pond), and a unit for removing dissolved pollutants.

EXPERIMENTAL METHOD

Two sets of experiments were carried out, one to investigate the adsorption of dissolved heavy metals by biofilms in a flow-through type biofilter and another to investigate the adsorption by a bottom-attached biofilm.

The test for adsorption by a bottom-attached biofilm was carried out in an annular flume which consists of a stainless steel annular trough, having an outside diameter of 2 metres, width of 20 cm and walls 12 cm high. A top cover which just fits inside the trough is mounted on a threaded center shaft, allowing the cover to be raised or lowered. The top cover can be rotated by locking it to the shaft and then running the motor which drives the shaft. By lowering the cover so that it just touches the water in the trough, flow is generated by the shear exerted by the rotation of the cover. The flume bed was covered with a layer of fine gravel having a mean diameter of 2.5 mm. To develop the biofilm, the flume was filled with water from Hamilton Harbour to a depth of approximately 8 cm and the cover was rotated to produce an average flow velocity of about 3 cm/s. Two ppm of sodium acetate was added to the water daily as nutrient. After the biofilm was allowed to develop for three weeks, the water was spiked with synthetic stormwater containing three heavy metals, namely copper, lead and zinc. The resulting concentrations in the flume were 0.3, 0.2 and 0.8 mg/L, respectively, and corresponded to an upper range of values observed at a highway site (Marsalek et al., 1997). The flume was kept running and water samples were withdrawn periodically for analysis.

The flow-through biofilters consisted of 10 cm diameter Plexiglas cylinders which were each filled with a 30 cm long column of gravel. The gravel was the same as that used in the flume experiment and was held in place by stainless steel screens. To develop a biofilm on the gravel substrate, water from Hamilton Harbour was circulated through the filter. About 20 ppm of sodium acetate per day was added to the water as nutrient. The adsorption test was carried out after the biofilm was allowed to develop for three weeks.

To begin the test, water was drained out of the cylinder through a conical funnel attachment with a stainless steel needle valve at the bottom for flow control. The valve was closed as the water level dropped to the top of the gravel. Synthetic stormwater containing dissolved metals was then added to the cylinder on top of the gravel and the valve was opened to allow the stormwater to flow downward through the filter at a prescribed rate. The flow rate through the cylinder was adjusted to a discharge of approximately 1 L/h. A separate container fed stormwater at the same rate into the cylinder from the top in order to maintain a constant head over the filter.

Six flow-through filters were tested, three with stormwater spiked with all three heavy metals simultaneously but at different concentrations and three with stormwater spiked with one single metal. These conditions are summarized in Table 1.

Table 1 Summary of test conditions.

	Synthetic stormwater initial concentration (ppm)		
	Copper	Lead	Zinc
Annular flume	0.3	0.2	0.8
Filter No. 1	0.3	0.2	0.8
Filter No. 2	0.10	0.1	0.3
Filter No. 3	0.02	0.01	0.06
Filter No. 4	--	--	0.8
Filter No. 5	--	0.2	--
Filter No. 6	0.3	--	--

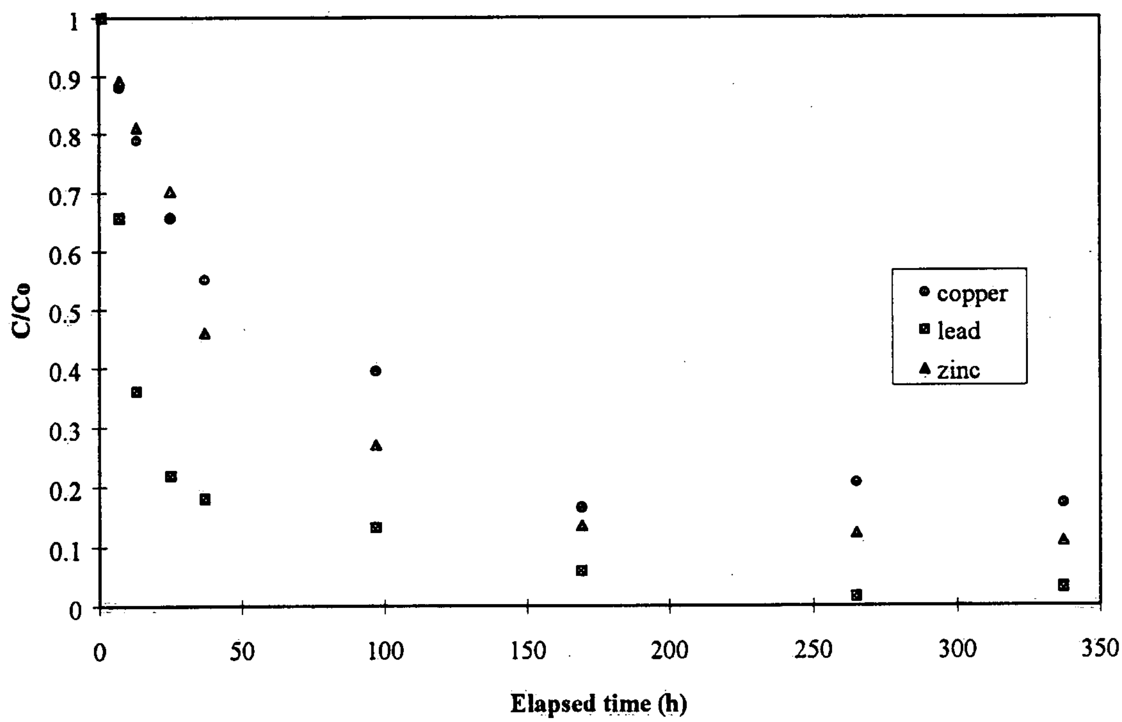

Figure1 Changes in metal concentration in flume water with time.

RESULTS

Figure 1 gives the results from the flume test in terms of the change in dimensionless concentration C/C_o with time. C is the concentration of the sample and C_o is the initial concentration. The concentration for all three metals decreased significantly during the two-week period of sampling. In the case of lead, eighty percent had been removed in two days. For copper, eighty percent removal took two weeks. A sample of the biofilm and gravel was taken for analysis at the end of the experiment. From these concentration data, the content of metals in all the biofilm was computed, assuming that the adsorption was uniform over the whole flume. The results indicate that, of the metals lost from the flume water, the recovery in the biofilm was 76% for copper, 34% for lead and 81% for zinc. Although these figures are not exact because there was only one sample, they do indicate that the loss of metals from the water was a result of adsorption by the biofilm.

The results from filter no. 1 are presented in Figure 2. Three consecutive 1 L samples were collected and analysed. From the concentrations of the spike water and the discharge, the amount of metals removed could be calculated. It can be seen that the

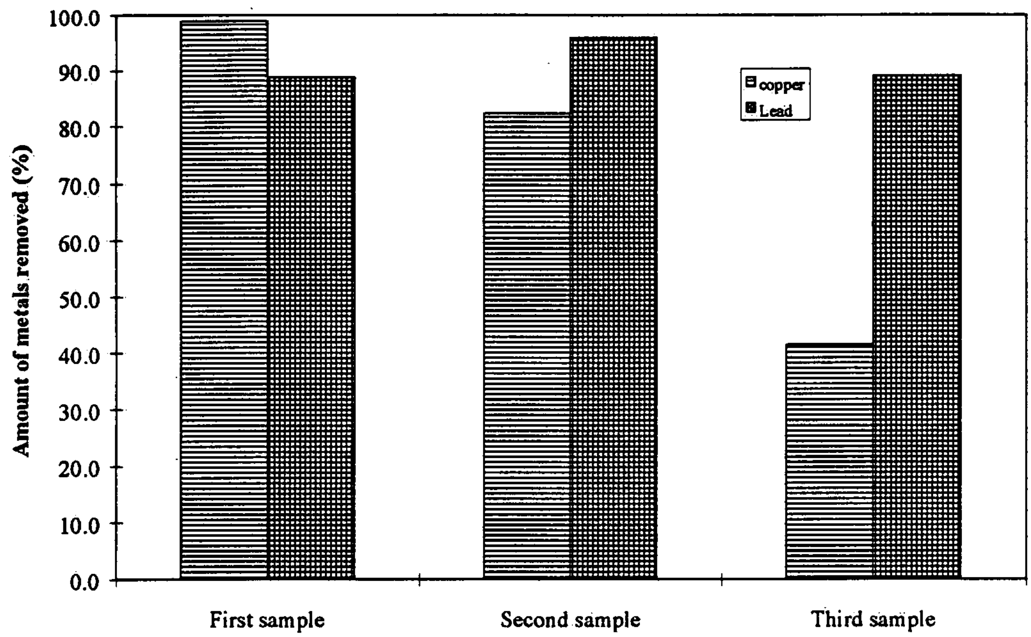

Figure 2. Removal rate of copper and lead from filter number 1.

removal rates were quite high, mostly in the eighty and ninety percent range (no zinc data were available for filter no.1 due to sample contamination).

The rate of removal did not seem to be dependent on the concentration of the spike water. As shown in Figure 3, the removal rates did not vary much between filters, even though there was an order of magnitude difference in the concentrations of the stormwater, as

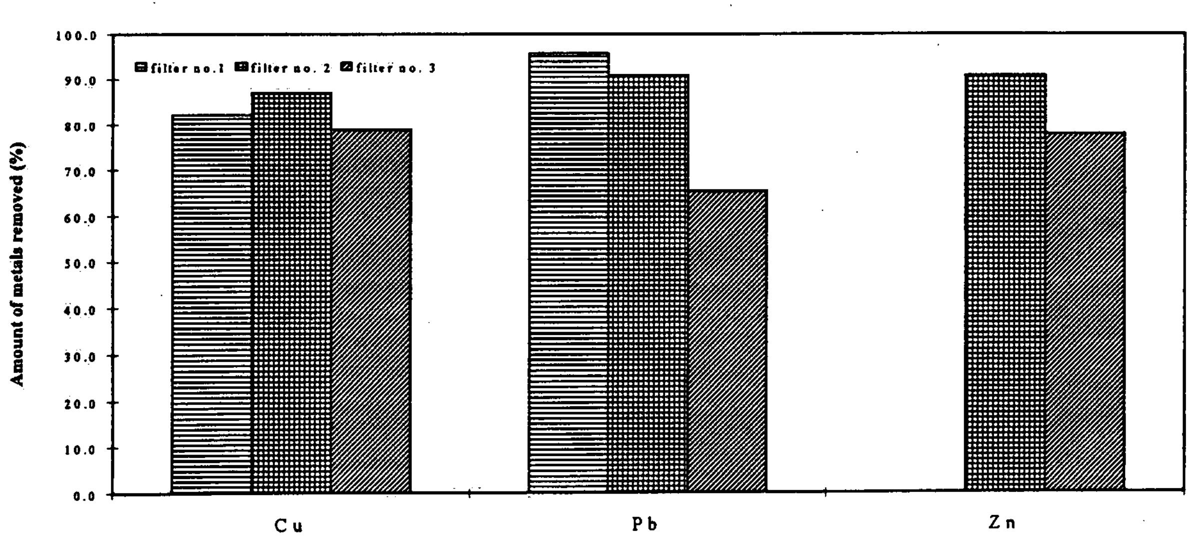

Figure 3. Removal rates from filters no. 1, 2 and 3 - three metals.

shown in Table 1.

Filters no. 4, 5 and 6 were each tested with stormwater containing one single metal only. The test on filter no. 6 lasted eight hours and multiple samples were taken. Because of the limitation on the number of samples which could be analysed, only one sample each was taken for filters no. 4 and 5. Figure 4 shows the removal rates for filter no. 6, in which copper was the metal tested. Within the limited duration tested, the removal rate did not decrease by any significant amount as time progressed.

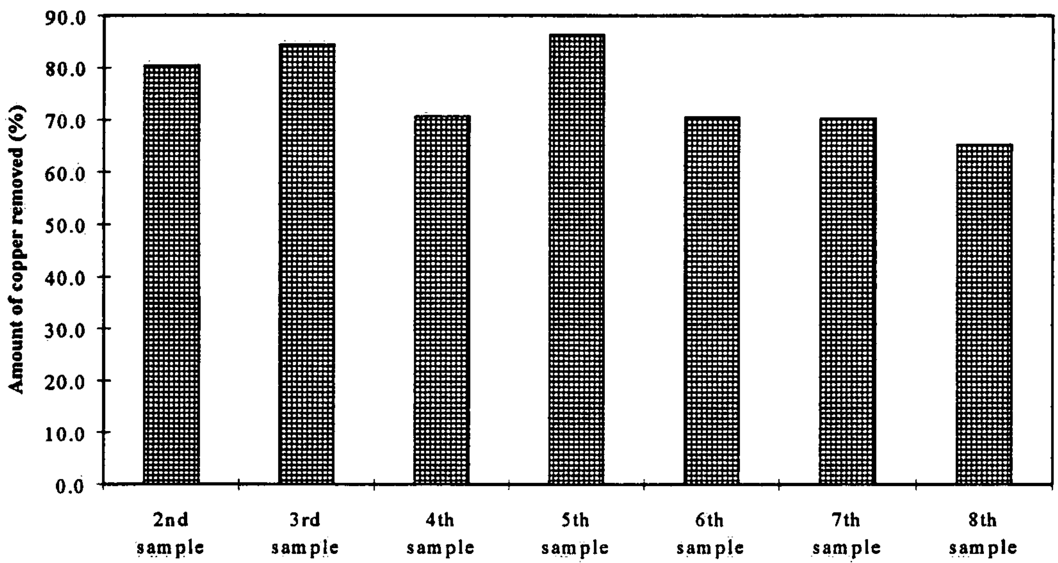

Figure 4. Removal rates for filter no. 6 - copper only.

Filters no. 4 and 5, which were tested with zinc and lead respectively, had removal rates of ninety three and ninety five percent. These rates are comparable to those from the first three filters in which all three metals were present together.

CONCLUSIONS

Preliminary experiments with biofiltration of synthetic highway runoff indicate 40 to 90% removals of dissolved trace metals (Cu, Pb and Zn). These tests should be further extended by examining the sustainability of the biofilter performance in treating runoff with low concentrations of fine particulate and the associated maintenance needs.

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