

REDUCING ROAD RUNOFF CONTAMINANTS THROUGH LOW-COST TREATMENT WALL (FILTER) SYSTEMS

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ABSTRACT

Under laboratory conditions, *sphagnum moss*, crushed limestone, waste wood pulp, bottom ash, and waste wool felt were tested for their potential use as substrates in treatment filters/walls, by determining their ability to remove Copper (Cu), Zinc (Zn), lead (Pb), pyrene and fluoranthene from artificial road runoff. In laboratory leaching experiments, the lime and bottom ash columns proved very effective, removing >95% of applied heavy metals and polyaromatic hydrocarbons (PAHs). The other media, particularly *sphagnum*, were effective in removing heavy metals, but not PAHs, although wool felt was not tested for PAHs removal. Two mixed media, *sphagnum*/lime and *sphagnum*/bottom ash, containing 10% by weight of *sphagnum*, were also tested. The *sphagnum*/bottom ash column performed well, removing >86% of PAHs and >94% of the heavy metals. There was an initial release of both Cu and Zn from the *sphagnum*/lime mixture, although it removed >93% of the PAHs.

To confirm these results for the field situation, treatment walls/filters have been installed at 3 different sites: (1) roundabout at the corner of River Road and Wairere Drive in Hamilton; (2) at the Shakespeare Road/SH1 intersection in Cambridge near Hamilton; and (3) at Henderson recreation centre and swimming pool car park in Waitakere City. A *sphagnum*/wood ash mixture was tested as the filter substrate at both the Hamilton and Cambridge sites. At the Henderson site, we are testing wood ash and sand on their own, as well as locally available green-waste Compost mixed with sand (20% sand), as filter media. Measurements have been made for input and output concentration of heavy metals and PAHs, as well as build-up in the interior substrate of the filters/walls.

KEYWORDS

Contaminant removal, filters, heavy metals, PAH, road runoff

1 INTRODUCTION

Roading infrastructure contaminants are deposited on road surfaces and median areas from atmospheric fallout, fuel combustion processes, lubrication system losses, tyre and brake wear, transportation load losses, de-icing agents, and paint. During storm events, rainwater first washes out atmospheric pollutants then, on surface impact, picks up roadway deposits and runs off into receiving water bodies. Pollutants found in runoff are generally classified under six broad categories: heavy metals, suspended solids or particulates, trace organics, oxygen consuming constituents (e.g., Biochemical Oxygen Demand), nutrients, and microorganisms.

These pollutants can harm the environment in various ways. Heavy metals are usually bound to particulates (Robien *et al.*, 1997) which can settle as sludge, and 80 percent of this remains potentially bioavailable and a source for further pollution (Colandini *et al.* 1995, Mikkelsen *et al.* 1996). Boxall and Maltby (1997) consider PAHs the major toxicant in road runoff. Toxic substances can affect human health or various plant or animal species. Oxygen consumption (from high BOD) harms aquatic life, while nutrients cause eutrophication, where excess aquatic plant growth can block sunlight, also harming aquatic life. There is thus a need for an effective, low-cost remediation system to reduce the impact of road runoff.

Treatment of road runoff could potentially be achieved by relatively low-cost treatment wall systems. Treatment walls are permeable barriers that allow the passage of water while prohibiting the movement of pollutants by

employing agents such as reactants for degrading volatile organics, chelators for immobilizing metals, nutrients, and oxygen for microorganisms to enhance bioremediation, or other agents (United States Environmental Protection Agency, 1999). With water as the major vector for waste constituent movement, we hypothesise that the contaminant load in a runoff stream will be decreased if we intercept the flow by constructing across the flow path a filter treatment wall containing a substrate that will remove targeted contaminants.

The specific substrate chosen for a permeable wall is based on the nature and characteristics of the pollutant stream. Depending on the specific substrate, the mechanism of removal of pollutants will follow different chemical processes (United States Environmental Protection Agency, 1996): sorption, precipitation, and/or degradation.

Under laboratory conditions, we have examined five media (Table 1) that may be suitable as a substrate in treatment walls because of their ability to remove the heavy metals copper (Cu), lead (Pb), zinc (Zn) and selected polyaromatic hydrocarbons (PAH) (fluoranthene and pyrene) from artificial road runoff. The media tested were commercially available *sphagnum moss*, crushed limestone, waste wood pulp, bottom ash, and waste wool felt. These materials have previously been shown to be capable of removing pollutants such as heavy metals (Ho et al., 1996), nutrients (Kadlec, 1987), and trace organics (Toller & Flaim, 1988).

Table 1: Substrates Tested under Laboratory Conditions for Pollutant Removal Capacity

Media	Origin
<i>Sphagnum moss</i> (floor sweepings)	West Coast Region of New Zealand
Limestone (“blue-chip” <25 mm)	McDonald’s Lime, Otorohanga
Waste Wood Fibre	Carter Holt Tissue, Kawerau
Bottom Ash (from burning wood)	Carter Holt Harvey Pulp and Paper, Kinleith
Felted Waste Wool	Wool Research Organisation of New Zealand, Christchurch

Based on these results, three field studies have been established using the most promising substrate, or a combination of them, as the treatment wall media, intercepting runoff directly from the road surface. Input and output concentrations of heavy metals and key organics (which will be a constituent of the road runoff) and their build-up in the treatment wall have been measured over time to help establish design specifications for a treatment wall to remove heavy metals, incorporating size and operational conditions for different flow rates.

2 LABORATORY EXPERIMENT

2.1 METHODOLOGY

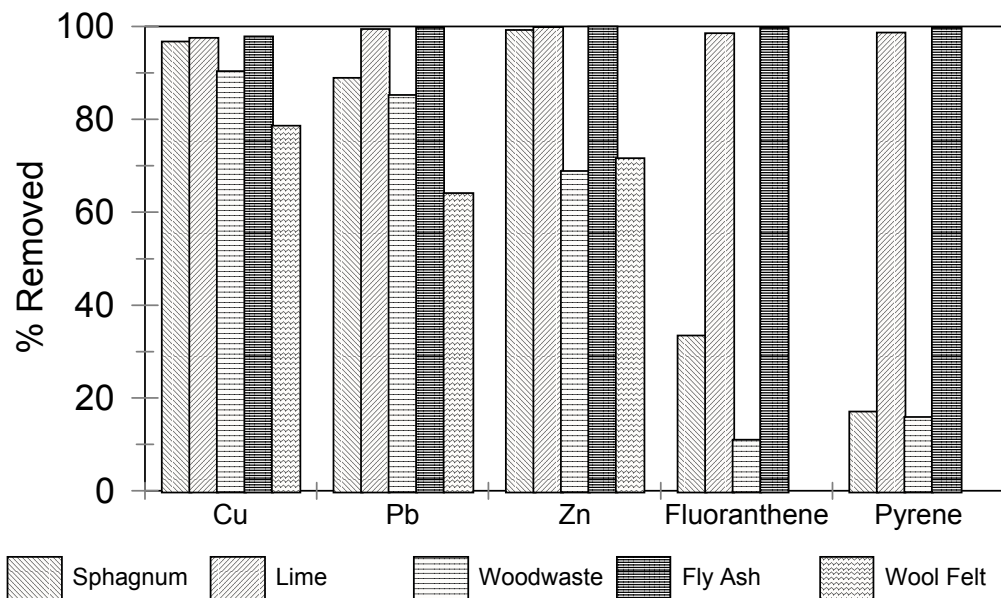
Plastic drainpipes (600 by 60 mm) were filled with each substrate (3 replicates), and plastic mesh was glued over the ends of the pipes to hold the media in place. The *sphagnum* was packed at a bulk density of approximately 0.04 t m^{-3} , the mixed media at 0.17 t m^{-3} , and the remaining single medium at 1.18 t m^{-3} . Artificial road runoff was applied by a peristaltic pump to the top of the substrate contained in the drainpipe, at a constant rate, and allowed to drain by gravity, with the leachate analysed for heavy metals and PAH. Further details and analytical methods are given in Lee et al (2000) and Pandey et al. (2002).

2.2 RESULTS

SINGLE SUBSTRATES

Initial leaching showed that lime and bottom ash were more effective (greater than 3 times) in removing PAHs than *sphagnum* and waste wood fibre, therefore only the first two continued to be irrigated with artificial road runoff containing PAHs. Wool felt was not examined for its ability to remove PAHs. The lime and bottom ash columns removed more than 96% of the applied PAHs during the experiment (Figure 1). Removal could be due to adsorption of PAHs to the substrates or microbial decomposition of PAHs. Thiel and Brummer (1998) showed that microbial decomposition of PAHs in contaminated soils increased with the addition of lime, probably due to increased pH.

Figure 1: Removal of pollutants from artificial road runoff by single substrates

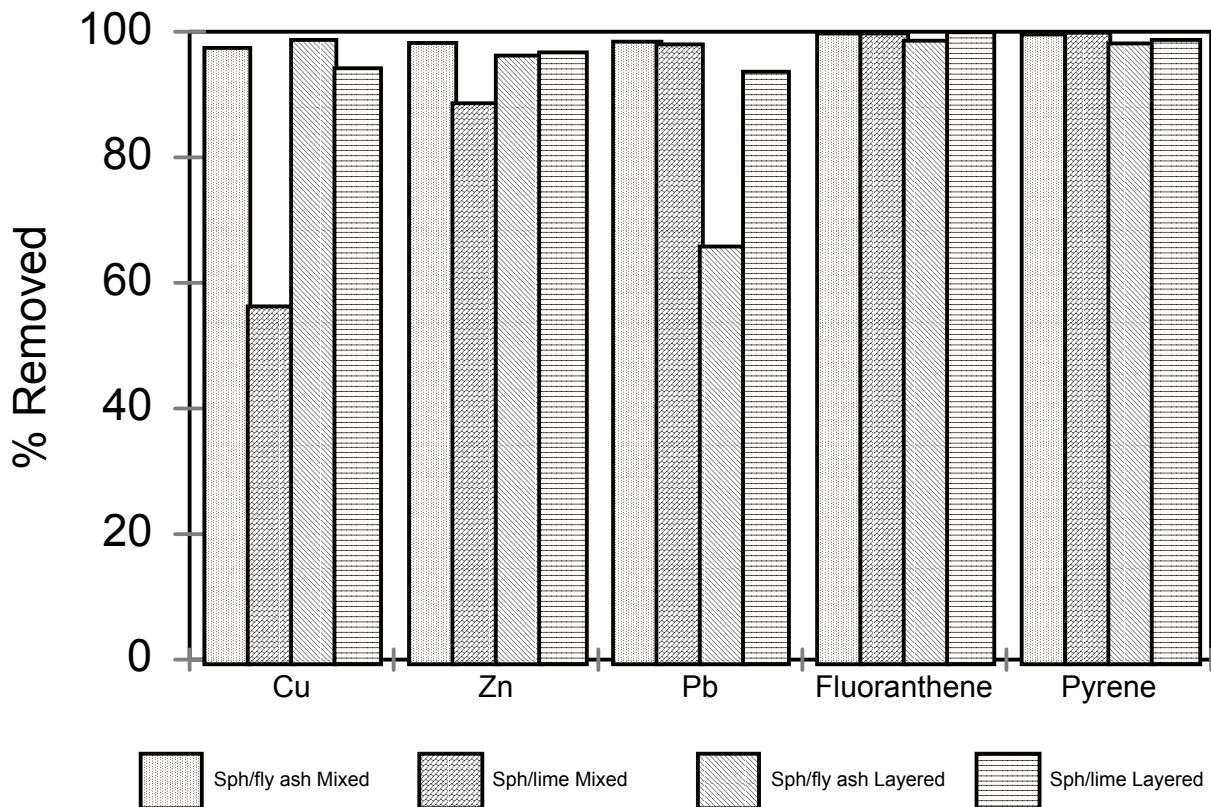


Lime and bottom ash removed >98% of Cu and Zn (Figure 1), presumably because these metals become less soluble as pH increases. *Sphagnum* was almost as efficient, removing >97% of Cu and Zn, while waste wood fibre removed 85% and 60% of Cu and Zn, respectively. *Sphagnum* has been shown to have a large number of adsorption sites capable of rapidly binding metals (Gardeatorresdey et al., 1996), and this is most likely the reason for its better performance. The waste wood fibre was largely made of lignin and would have less adsorption sites available. Behaviour of Pb was slightly different. Lime and bottom ash removed >99%, as Pb becomes less soluble with increasing pH, while *sphagnum* removed >87%, and waste wood fibre >82%. The lesser removal of Pb by *sphagnum* and waste wood fibre could be due to mobilisation of Pb by dissolved organic matter (Jordan et al., 1997). Wool felt was the least efficient of the substrates at removing heavy metals.

MIXED SUBSTRATES

The *sphagnum*/bottom ash mixture performed well, removing over 99% of the PAHs added, 94% of the copper, and 99% of the Zn (Figure 2). The *sphagnum*/lime mixture proved marginally better in removing PAHs, but did not perform so well with Cu and Zn. In both instances there was an initial release of these two metals from the mixture. As a result, the cumulative total of Cu removed was still negative after 3 applications, i.e. more was released than was added with the artificial road runoff. The effect on the Zn was not so marked, the initial release resulting in a cumulative total removal of 86%. The initial leachate from the *sphagnum*/lime mixture was coloured and this was suspected to be dissolved organic carbon (DOC). The elevated levels of DOC could be from readily available carbon released with the initial wetting of dry substrates. Carbon-entrained Cu and Zn would then be released with the leachate generated from the initial wetting-up. The colouration had gone by the time of the third application or 'rainfall' event, which coincided with much lower levels of Cu and Zn in the leachate.

Figure 2: Removal of pollutants from artificial road runoff by mixed substrates



2.3 ADDITIONAL ISSUES

To treat road runoff usefully, a treatment system must not only remove contaminants cheaply and efficiently, but must also not pollute the environment itself. Two potential environmental issues were identified with the substrates tested. First, as well as the initial release of carbon and associated Cu and Zn from the *sphagnum*/lime mixed media, there was an initial release of dissolved carbon from each single medium (up to $250 \mu\text{g mL}^{-1}$), which would have resulted in increased Chemical Oxygen Demand. Levels reduced rapidly to background levels after 3 'rainfall' events. After the initial wetting, drying and re-wetting had no further effect on release of carbon. Second, *sphagnum*-treated leachates had pH levels below 6.0 and would not meet suitability thresholds for aquatic systems (Ministry for the Environment, 1997). Mixing the *sphagnum* with lime and bottom ash substrates brought the pH up sufficiently for safe environmental use, but in the case of the lime mixture this led to the initial release of carbon and associated metals. Treated leachates from the remaining single substrates were within suitability thresholds, with the mixed substrates giving leachates with pH levels around 7.5.

Among the individual substrates, infiltration and water movement, as measured by saturated hydraulic conductivity, was greatest for *sphagnum*, followed by bottom ash and lime. Waste wood fibre had a much slower conductivity and was not suitable for treating large volumes of road runoff. Mixed *sphagnum* and bottom ash provided the greatest saturated hydraulic conductivity of the combination.

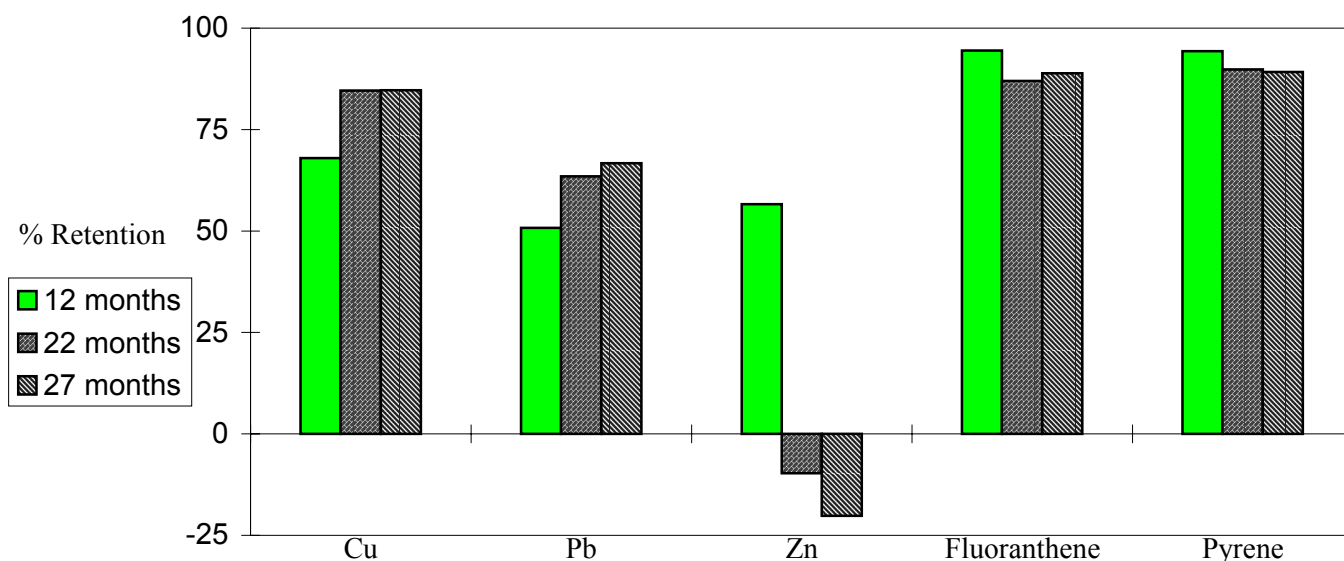
3 TREATMENT WALL PILOT STUDIES

3.1 SITE LOCATION AND ESTABLISHMENT

Based on the laboratory results, a treatment wall/filter was constructed at the corner of River Road and Wairere Drive in Hamilton in December 2000, to intercept the runoff from a portion of a roundabout. The treatment wall consists of *sphagnum*/wood ash substrates (1:1 by volume, 1:10 by weight) housed in two stormwater pipes (1.5 m deep by 1.05 m in diameter), placed side by side. Each pipe receives road runoff entering at the top and percolating through the substrate by gravity. The treated runoff exiting the treatment wall re-joins the normal flow path for the stormwater system and finally enters the Waikato River. Measurements are made for input and output concentration of heavy metals and PAHs, as well as for build-up in the filters/walls.

More recently two additional walls have been established in Cambridge and Waitakere City. In contrast to the Hamilton trial, in the second treatment wall on the side of State Highway 1 in Cambridge (near Hamilton), we are testing an increased ratio of *sphagnum* (20% by weight). The Cambridge treatment wall is configured in a similar fashion to the Hamilton site. The third treatment wall at the Henderson recreation centre and swimming pool complex in Waitakere City, intercepts runoff from a car park. Here we are testing wood ash, as in the previous studies, as well as sand and Green-waste Compost, as filter media. The substrates are "housed" in standard sand-filter units supplied to Waitakere City Council by Hynds, arranged in parallel and receiving similar amounts of runoff through the pre-treatment chamber. The outflows join the Henderson creek.

Figure 3: Removal of pollutants from road runoff by mixed substrates at the Hamilton site, after 27 months



3.2 RESULTS

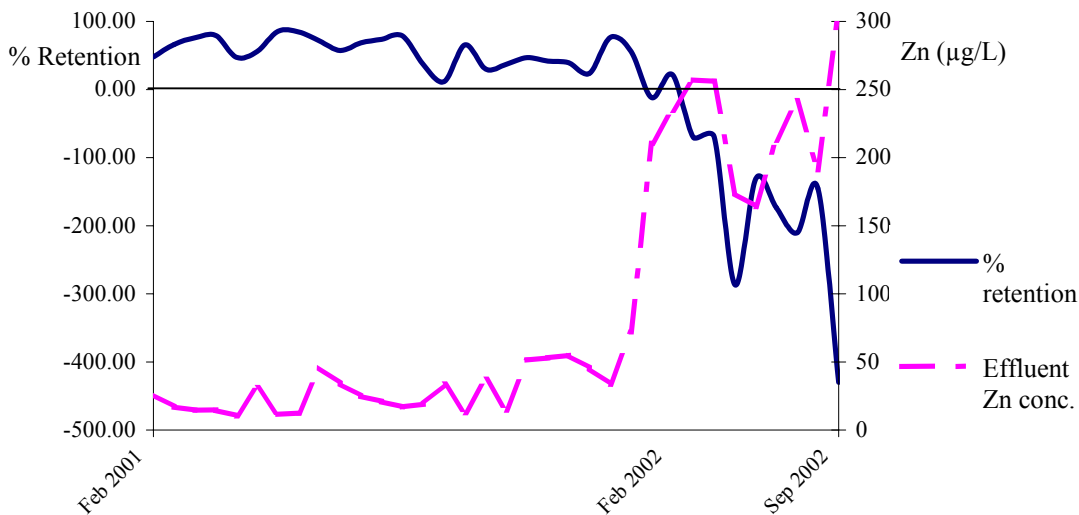
Over the first 13 months, the results from the Hamilton site (Figure 3) were similar to those found in the laboratory studies. After 13 months of operation, the percent retention for Zn dropped and has continued to do so (Figure 4), probably representing the longevity of the substrate to treat Zn effectively within the design parameters of the trial. It is also likely that sediments trapped on top of the substrate are acting as a source of Zn. Under normal operating conditions, this sediment layer would be removed in the same way the sediment layer from stormwater sand filters is removed. However, as we wish to observe the timing of the breakthrough of other contaminants, we have left the sediment layer intact. Analysis of the sediment revealed very high concentrations of zinc (Table 2). The used, underlying, substrate also showed greatly enhanced concentrations of Cu, Pb, and Zn compared with new substrate, indicating it has removed contaminants from the runoff (Table 2).

Table 2: Copper, lead and zinc concentrations in road runoff sediment, used and new substrate

Sample	Cu mg/kg	Pb mg/kg	Zn mg/kg
Sediment	41	28	658
Used substrate	59	52	816
New substrate	5	1	56

This changed behaviour may signify that all the sites available for Zn retention have been filled and/or that other pollutants (not present in the artificial runoff used in the laboratory study) are competing for limited retention sites on the substrate.

Figure 4: Changes in Zn retention and effluent concentration at the Hamilton site



The increased ratio of sphagnum in the Cambridge wall has been used to test whether this has any influence on Zn retention. Monitoring of this wall over its initial six months of operation shows (Figure 5) that the retention of pollutants is similar to those found in the laboratory study, as well as at the Hamilton site over the corresponding period. No breakthrough has yet been observed and on the basis of the results from the Hamilton site would not be expected for another eight months or so

Figure 5: Removal of pollutants from road runoff by mixed substrates at the Cambridge site, after 6 months

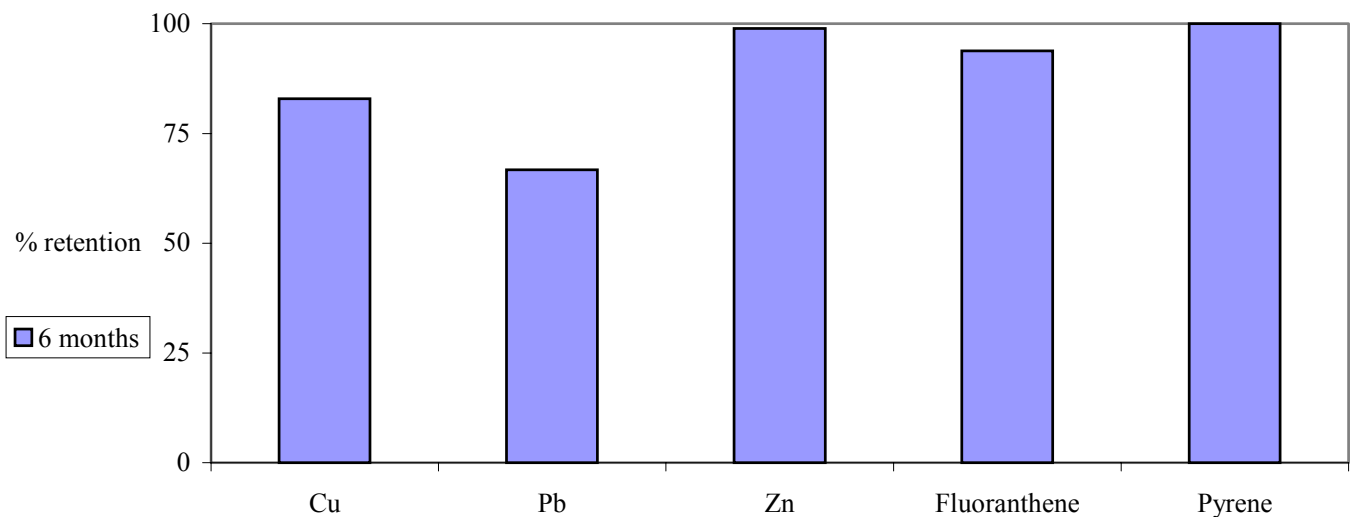
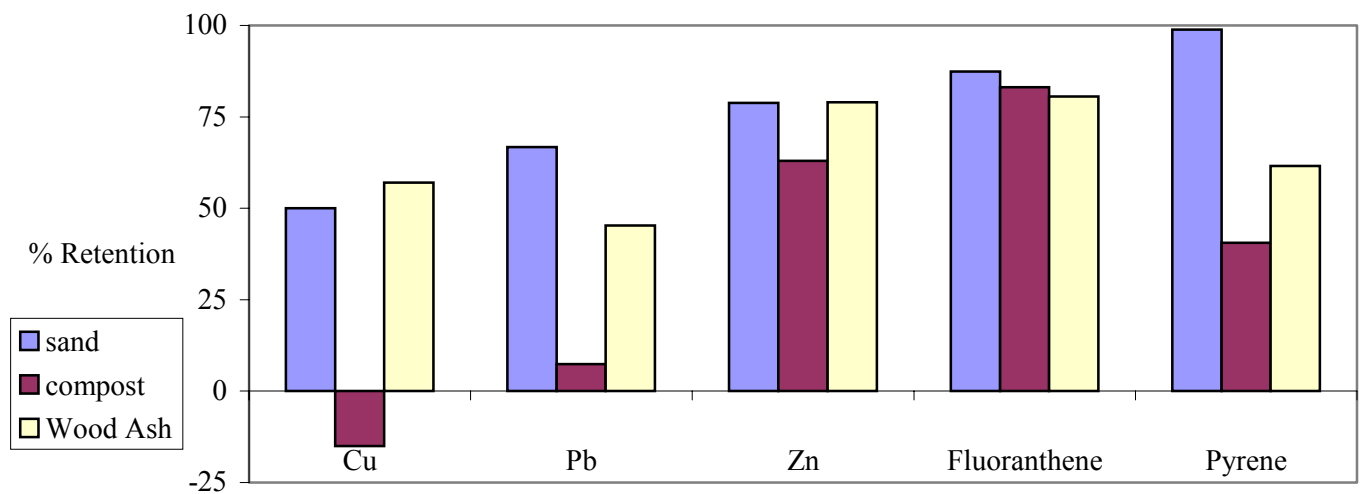


Figure 6 shows the pattern of retention of pollutants obtained over the initial months of operation of the Henderson wall. The marked difference in Cu retention compared with the other sites is likely due to the presence of Cu in the compost itself, and could have originated from the use of copper-based fungicides/bactericides used in many fruit and vegetable crops, and for needle blight control in pine trees. The compost could have originated from a source that processed a lot of "spring-pruning" and vegetable matter containing the fungicides/bactericides. As more monitoring continues, more data will become available. One problem worth pointing out is the distribution of equal amounts of runoff from the pre-chamber through the different filter units. Initially, the unit containing sand as the test media did not receive an equal amount of runoff (under low rainfall intensity periods). Therefore, at this stage it may indicate higher retention rates of pollutants compared with other media. However, this situation of un-equal flow has been rectified and further monitoring results will be better comparable.

Figure 6: Removal of pollutants from road runoff by various substrates at the Henderson site (preliminary)



3.3 EFFECT OF SITE ON RUNOFF COMPOSITION

The runoff composition from the different sites is vastly different. Table 3 shows that highest concentrations of Cu and Pb are found at the River Road site in Hamilton, while the highest Zn is found at the Shakespeare Road/SH1 intersection at Cambridge. Henderson metal concentrations are low, perhaps reflecting vehicle numbers. The difference between the Hamilton site and the Cambridge site is most likely due to the Hamilton site receiving runoff from a roundabout, while the Cambridge site treats runoff from an intersection. Roundabouts have been shown to contribute higher concentrations of contaminants than intersections (O’Riley et al., 2002).

Table 3: Concentrations of copper, lead and zinc in road runoff from 3 sites minimum-maximum (average)

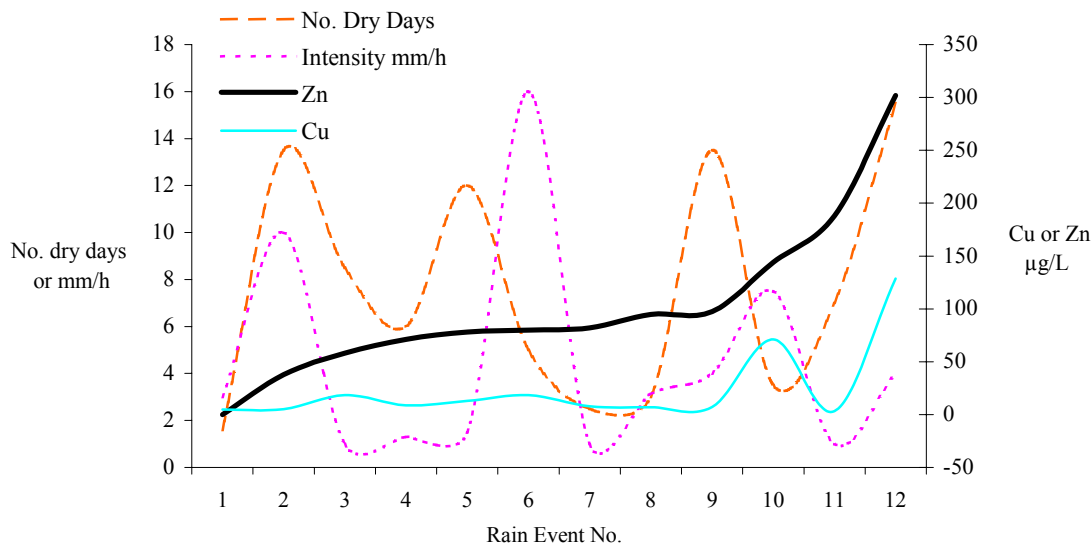
Site	Time in operation	Cu ($\mu\text{g L}^{-1}$)	Pb ($\mu\text{g L}^{-1}$)	Zn ($\mu\text{g L}^{-1}$)
Hamilton	27 months	3.24–128.6 (16.19)	0.0–37.5 (11.4)	20–459 (127)
Cambridge	6 months	3.80–20.10 (8.57)	0.0–15.4 (8.2)	3–3460 (492)
Henderson	2 months	1.20–16.70 (3.00)	0.2–7.1 (3.0)	13–113 (35)

3.4 EFFECT OF TIME BETWEEN RAIN EVENTS AND RAINFALL INTENSITY ON EFFLUENT CONTAMINATION

The Hamilton treatment wall was observed to treat all runoff from light rainfall events. These events had the highest concentration of contaminants in the runoff. Two of the factors that affect contaminant concentrations in runoff are the time between rainfall events (dry days) and the intensity of the rain event. Longer periods between rainfalls allow contaminants to build up on the road surface. A light rainfall that runs off the road slowly, allowing time for road dust to release soluble contaminants into the runoff, results in a high contaminant concentration (Figure 7).

An intense rainfall is more likely to wash particulate matter off the road but the greater volume dilutes contaminants, resulting in a lower contaminant concentration.

Figure 7: Relationship between Cu and Zn concentration in first sample and rain intensity and number of dry days before rainfall event



4 CONCLUSIONS

In laboratory studies, lime and bottom ash were very effective at removing (>90%) heavy metals and PAHs from artificial road runoff. *Sphagnum* moss was also effective at removing heavy metals, but largely ineffective at removing PAHs. Both the wood waste and wool felt removed over 60% of applied heavy metals, but were not as effective as the other substrates. The wood waste was poor in removing PAHs. While mixing *sphagnum* with lime and bottom ash substrates raised the pH sufficiently for safe environmental use, in the case of the lime mixture this led to the initial release of carbon and associated metals.

A mixture of *sphagnum* and bottom ash, used in the pilot field trial in Hamilton, showed similar results to the laboratory studies over the first 13 months of operation, but subsequently allowed breakthrough of Zn. The source of this Zn appears to be a layer of high-Zn sediment deposited on top of the substrate. We have left this sediment layer in place to observe if breakthrough of other contaminants occurs (unlike normal operational practice where the sediment layer containing this extra source of Zn would be removed).

Monitoring at the Cambridge site shows that retention of pollutants over the initial months of operation is similar to that found in the laboratory, as well as to that at the River road site in Hamilton over the corresponding period. So far no breakthrough has been observed.

Pollutant retention over the initial months of operation of the Henderson site shows a different pattern. The marked difference in Cu retention compared with the other sites is likely due to the presence of Cu in the compost used in the treatment wall, coming from the use of copper-based fungicides. These results, however, are preliminary and more results are becoming available as the monitoring progresses.

These tests show that treatment walls could be an effective tool to reduce contamination from road run-off, thereby benefiting not only the local environment, but also the wider receiving environment such as estuaries and coastal margins. Benefits therefore accrue not only to the local community but the wider community in general. Applications extend from treating run-off from roadways, to their use in such areas as petrol station forecourts, car parks and landfills around the country. Appropriate strategies may lie in initially targeting hot spots, ie those areas which either through their use (eg petrol stations) or high traffic density and tyre wear (eg roundabouts, major intersections), could be expected to have higher levels of contaminated run off.

On-going monitoring will provide useful information for deriving appropriate design parameters (e.g., frequency of sediment layer or substrate removal, if necessary) in the use of modified filter media for stormwater treatment, and is likely to influence engineering design for stormwater interceptor devices suggested by Auckland Regional Council (ARC, 2003) and Auckland City Council (ACC, 2003).

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