

AN EVALUATION OF FILTER MEDIA FOR TREATING STORMWATER RUNOFF

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ABSTRACT

In dry retention ponds, urban runoff contaminants are removed by numerous physical, biological and chemical processes as water percolates through the bottom and side wall soils. Many of these same mechanisms are harnessed in engineered devices, such as sand filters, that intercept runoff either before entering or after leaving a detention facility. We conducted two experiments to examine the ability of filter devices to remove total suspended solids (TSS), total phosphorus (TP), and selected dissolved metals from urban runoff. In the first study, triplicate mesocosm sand filters situated next to a wet detention pond were loaded once weekly with urban runoff that had been augmented (spiked) with P and metals. Performance of the filters initially was good, but for several constituents removal effectiveness declined with time. During a 16 month period the filter was moderately effective at removing TSS, copper and phosphorus, and less effective for removing cadmium and nickel. In a second experiment, we used laboratory columns to test the effectiveness of quartz sand, peat, limerock and wollastonite (a mine tailing) as filter media for removing these same contaminants. Peat was the most effective filter matrix for metal removal and wollastonite was the most effective for TP removal. Filter matrices other than sand therefore may prove useful for selected urban runoff treatment applications.

INTRODUCTION

In the past decade, there has been an increased focus on mitigating the detrimental effects of stormwater pollutants on receiving waters. Fortunately, the physical structures used to moderate peak runoff flows from developed areas, such as wet detention ponds, dry retention areas and swales, have been found to be fairly successful at removing stormwater contaminants. However, in regions where high levels of runoff pollutant removal are required due to sensitivity of receiving waters, or in selected urban locations where space constraints limit the construction of detention or retention facilities, more effective contaminant removal techniques are required.

Because many urban runoff pollutants are associated with particles, devices that use physical filtration (e.g., sand filters) have been implemented as a means of improving runoff

quality. Sand filters, however, have not received widespread use, largely because of two constraints: first, they require careful design and periodic maintenance to ensure consistent hydraulic performance, and secondly, they are not thought to be effective at removing soluble runoff pollutants. Phosphorus is a runoff constituent that commonly occurs in both soluble and particulate fractions, and heavy metals such as zinc, cadmium and copper are washed from roadways principally in dissolved forms (Sansalone and Buchberger 1997).

In the present study, we tested a mesocosm sand filter for its ability to remove phosphorus and selected heavy metals from an urban runoff stream containing low concentrations of particles. In a second experiment, we conducted a microcosm laboratory study to test the contaminant removal effectiveness of peat, wollastonite tailings

and limerock as alternative filter media. Limerock has been used in some subsurface flow treatment wetlands to facilitate removal of wastewater phosphorus (Axler *et al.* 1996). Organic compounds such as peats and composts have been used to enhance fecal coliform and metals removal from wastewaters and runoff streams (Richman 1997; White 1995), and laboratory studies have demonstrated that wollastonite mine tailings have a high P adsorption capacity (Geohring *et al.* 1995).

METHODS AND MATERIALS

The first experiment was conducted at a 0.5 ha wet detention pond located in southwest Orange County, Florida. The pond receives runoff from a 29.5 ha drainage basin, more than 80 percent of which is covered with impervious structures. A small deck was constructed over the pond to hold the experimental apparatus. Three mesocosm sand filters were fabricated from high density polyethylene barrels with tops removed. The filters were 84 cm deep, with a crosssectional area of 0.25 m. The bottom of each filter was equipped with a fiberglass-screened drain. A small amount of inert gravel matrix was placed over the drain, and the barrel was filled with a clean, quartz builder's sand to a depth of 25 cm. Each sand filter was equipped with a cover to exclude rainwater.

Once each week the three sand filters were dosed with 55 cm of detention pond water amended with metals and phosphorus (P). The pond water was pumped to a pair of head tanks where native pollutant concentrations were augmented with a spiking solution. The spiking solution was formulated to increase the native runoff pollutant concentrations by specified levels: 0.4 mg total P/L, 15 ug cadmium/L, 30 jig nickel/L and 30 ug copper/L. The spiking solution was mixed in the head tanks by circulating the water between tanks rapidly for 0.5 hr. After mixing, the spiked water was gravity fed to the mesocosm sand filters. The sand filters were loaded once weekly for 67 weeks (April 1995 - August 1996).

Influent water samples were collected as the spiked water was fed to the surface of the sand filter. After passing through the filter, water drained into an underlying catch basin for 18 hours. During most of the study, water samples from the triplicate filters were composited prior to analysis. We also conducted three "intensive" sampling periods during July 1995, December 1995-January 1996, and June - July 1996, during which we analyzed samples from each catch basin separately. Water samples were analyzed for total phosphorus (TP) and total suspended solids (TSS) by EPA methods 365.1 and 160.2, respectively (EPA 1983). The metals copper (Cu), cadmium (Cd) and nickel (Ni) were analyzed by ICP-mass spectrometry after acid digestion.

In a second study, laboratory columns were used to evaluate the effectiveness of different filter media for runoff pollutant removal. We evaluated four media: quartz builder's sand; fresh organic (peat) soil; crushed limerock (2.5 cm nominal size); and wollastonite (a mine tailing containing calcium metasilicate + ferrous metasilicate). Each substrate was placed in triplicate filter columns (7.6 cm dia. X 100 cm long) to a depth of 50 cm. The top of each substrate was covered with polyester filter Ross to prevent media scouring during water addition. Layers of filter floss, nylon mesh and fiberglass window screen were placed below each substrate to facilitate column draining.

The column media were first conditioned with three rinses of deionized water. Effluent samples from the three rinses were combined for each column and saved for analysis. Following media rinsing, the columns were loaded with spiked urban runoff. On nine occasions, 50 cm. of spiked urban runoff (described above) was added to each column which were then allowed to slowly drain. Water retention time in the columns was kept at 4 - 6 hr by means of a pinch clamp placed on each column's drain tube. The columns were rested for 1 - 2 days between loadings. Influent and effluent samples were collected and analyzed for pH, TP, Cu, Cd and Ni.

RESULTS AND DISCUSSION

During the mesocosm. study, the sand filter was loaded with approximately 37 m of spiked runoff (55 cm/week for 67 weeks). Suspended solids removal performance of the filter was consistently high during the experiment (Table 1). It is likely that the percentage solids removal would have been even higher had the filter received runoff containing higher solids concentrations. The filters also drained well during the study, which is to be expected due to the low solids loading. Some decline in filter draining rate did occur, but this appeared to be more related to clogging of the effluent drains with sand particles than to an overall reduction in hydraulic conductivity of the sand media.

Total P removal by the sand filter initially was moderate (38% removal), and declined slightly during the study (Table 1). Previous studies have shown that those Florida sands with little mineral coating have poor binding capacity for P (Harris et al. 1996). The quartz builder's sand used in our filter appeared "clean", and likely had poor affinity for the orthophosphate anion.

Metal removal performance of the mesocosm sand filter varied among the three elements tested. Copper removal initially was high, but the percentage removal rate gradually declined (from 76 - 26%) (Table 1). Nickel removal was moderate initially, and then dropped sharply during the two 1996 intensive sampling periods. In the first months of the study, only native pondwater Cd concentrations were in the runoff water fed to the filter, and no net removal of this element was observed (Table 1). Cadmium spiking was initiated during fall 1995, and Cd removal by the filter was moderate to low for the remainder of the study.

Table 1. Mean mesocosm sand filter contaminant removal performance (influent & effluent concentrations and percent removal) during three "intensive" sampling periods at the beginning (summer 95), midpoint (winter 96) and end (summer 96) of the study period.

	<i>summer '95</i>	<i>winter '96</i>	<i>summer '96</i>
TSS in (mg/L)	3.7	2.8	2.7
out (mg/L)	1.3	0.7	0.7
% removal	65	75	74
TP in (mg/L)	0.579	0.464	0.398
out (mg/L/L)	0.360	0.341	0.285
% removal	38	27	28
in (mg/L/L)	42.2	39.6	39.0
out (ug/,-)	10.0	22.5	28.8
% removal	76	43	26
in (ug/L)	1.6	13.0	14.7
out (mg/L)	2.1	8.9	11.8
% removal	0	32	20
Ni in (mg/L)	28.4	30.3	31.1
out W/P	17.1	29.7	27.2
% removal	40	2	13

The laboratory column study was designed to assess whether different filter media could provide better performance than the quartz sand. With respect to physical characteristics, the fine wollastonite provided the lowest hydraulic conductivity of the media, and the coarse limerock, the highest. Bulk densities of the sand, peat, limerock and wollastonite media were 1.36, 0.102, 1.32 and 1.58 g/cc, respectively.

The diverse chemistries of the media caused widely different effluent pHs among treatments. The influent runoff water was circumneutral. After passage through quartz sand matrix, the pH was increased slightly, by about 0.5 units. The effluent from the limerock columns exhibited a consistent pH near 7.8. Effluent from the peat columns initially was acidic (6.0), and gradually approached neutrality (6.7). The effluent from the wollastonite columns was alkaline (pH above 9), and declined to pH 8.5 by the completion of the study.

The filter media differed widely in their contaminant removal performance (Table 2).

Mean TP removal during the experiment was comparable (41 % removal) among the sand, peat and limerock treatments. The wollastonite, in contrast, was markedly more effective at removing P (88% removal), providing extremely low effluent P concentrations. The peat was the most

85

effective matrix for Cu removal (86% removal), and limerock, the least effective (32% removal). All matrices removed the bulk of the loaded Cd, with the peat and wollastonite the most effective (98% removal) for removing this element. The peat matrix was by far the most effective matrix for Ni removal and the limerock, the least effective.

Table 2. Mean influent and effluent contaminant concentrations for laboratory columns that received spiked urban runoff. Total P values are in mg/L, metal values are in ug/L/L. Effluent values represent mean (std. dev.) for triplicate columns.

	Influent	Effluent			
		<i>Sand</i>	<i>Peat</i>	<i>Limerock</i>	<i>Wollastonite</i>
TP	0.41(0.02)	0.24(0.11)	0.23(0.04)	0.24(0.04)	0.05(0.04)
Cu	29.5(3.2)	6.8(3.6)	4.0(1.3)	20.0(7.5)	5.5(2.6)
Cd	13.4(0.6)	0.8(1.0)	0.3(0.4)	2.5(1.4)	0.3(0.5)
Ni	30.0(0.6)	6.7(4.3)	2.3(1.0)	20.6(6.7)	5.9(3.6)

All filter columns exhibited a general trend of declining contaminant removal performance over time (see Cu example, Figure 1). However, in this short duration experiment, we never reached "breakthrough" for any of the contaminants, where effluent concentrations equaled (or exceeded) influent concentrations. Previous laboratory adsorption studies using mechanically agitated test tubes indicated that wollastonite potentially can bind 5 mgP per g substrate (Geohring *et al.* 1995). In our short term study, the wollastonite columns removed only 0.04 mgP/g substrate, so we likely did not come close to exhausting the P retention capacity of the matrix. The ultimate capacity of a wollastonite filter matrix would depend on the operational P concentration range and other chemical characteristics of the runoff stream.

Adsorption, in which ions transfer from solution phase to solid phase, is an important mechanism whereby filter media remove soluble constituents from runoff. There are a host of media-specific, as well as, constituent-specific factors that influence the magnitude and reversibility of solid phase ion binding. In mineral soils, P anions selectively bond to variable-charged mineral surfaces and to layer silicate particulate edges (McBride 1994). Our data demonstrate that the calcium and iron silicates that comprise wollastonite provide a matrix for P adsorption that is superior to the quartz sand minerals.

Neither limerock nor peat enhanced P removal over that of the quartz sand. Limerock is thought to remove solution P by adsorption and co-precipitation reactions with CaCO₃. The low pH of the influent runoff water may have limited P removal within the limerock column. The moderate P removal performance of the peat correlates with previous findings which have shown that organic soils are not overly effective at retaining anions.

Positively-charged metals can be removed from solution by cation exchange and by bonding on variable-charge minerals, and, in organic soils, by complexation with organic functional groups (McBride 1994). The slightly acidic peat utilized in this study was the most effective matrix, while the Fe- and Ca-dominated wollastonite was the second most effective matrix for metals removal.

The differential removal rates observed among the metals during both the mesocosm and microcosm studies likely was due to between-element differences in physical and/or charge characteristics. For example, factors such as electronegativity and charge-to-radius ratio have been suggested as key parameters in defining adsorption (McBride 1994).

Filters provide only finite removal capacities for soluble runoff-borne P and metals. Our data demonstrate, however, that moderate to low contaminant removal rates can be obtained over a long duration with sand filters, and that alternative media types can enhance contaminant removal performance. Prior to full-scale field application, alternative media need to be assessed for their ability (and long-term capacity) to remove target pollutants, as well as, for their potential release of pollutants native to the matrix. Following matrix selection, appropriate filter design and operational procedures must be followed to ensure hydraulic conductivity and to facilitate periodic media replacement.

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