Toxic compound capture and fate in bioretention

Piégeage et évolution des composés toxiques dans les systèmes de bio-rétention

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RESUME

Les études sur la qualité de l'eau à l'entrée et à la sortie des systèmes de bio-rétention en exploitation dans le Maryland aux Etats-Unis ont démontré la très bonne performance de ces systèmes pour le piégeage des métaux tels que le chrome, le cuivre, le plomb et le zinc avec des teneurs moyennes en sortie s'élevant à quelques µg/L. Pour certains métalloïdes tels que l'arsenic, le cadmium et le mercure, les teneurs moyennes présentes dans les eaux de ruissellement à l'entrée lors de chaque événement sont souvent trop faibles (<2 µg/L) pour permettre des mesures de performance de piégeage. Une détermination de la variation spatiale du zinc accumulé effectuée dans une autre cellule de bio-rétention a montré que la réduction du métal accumulé est d'autant plus importante que l'on s'éloigne de la canalisation d'admission des effluents.

ABSTRACT

Input/output field water quality studies for two bioretention facilities in Maryland, USA, demonstrate very good performance for metals (chromium, copper, lead, zinc) removal, with output event mean concentrations of a few µg/L. For several of the metal(loid)s (arsenic, cadmium, mercury), event mean concentrations in input runoff are frequently very low (<2 µg/L), preventing calculations for removal performance.Determination of spatial variation of accumulated zinc in another bioretention cell shows reduction in accumulated metal with increased distance from the flow inlet.

KEYWORDS

Bioretention, heavy metals, toxics, treatment, accumulation.

1 INTRODUCTION

Bioretention is a soils/mulch/vegetation-based stormwater runoff practice employed to manage runoff from parking areas and roadways. Structurally, bioretention facilities consist of approximately 0.76 m of a porous media mixture, typically 50% (by volume) construction sand, 30% topsoil, and 20% organic matter (such as mulch). This media layer is covered with a thin (3-9 cm) layer of hardwood mulch. Various grasses, shrubs, and small trees are established to promote evapotranspiration, maintain soil porosity, encourage biological activity, and promote uptake of some pollutants. Stormwater runoff is directed into the facility, allowed to pool, and infiltrates through the plant/mulch/soil environment, providing the treatment.

Several laboratory studies have evaluated the performance of bioretention in addressing a number of pollutants, including heavy metals (Davis et al. 2001, 2003), suspended solids (Hsieh and Davis 2005a, 2005b), and nutrients (Davis et al. 2006, Hsieh et al. in press). This work describes the water quality results of field studies for two bioretention facilities in Maryland, USA. Input/output water quality monitoring is ongoing, with an emphasis on toxic compounds. Metals monitored include zinc, copper, lead, chromium, cadmium, mercury and arsenic. Also described in this work is the spatial variability of zinc accumulation in the surface media of a bioretention facility that has been in place for nearly four years.

2 METHODS

2.1 Water Quality Monitoring

Two bioretention sites were constructed specifically with channels, flumes, and weirs for water quality monitoring. The first is on the University of Maryland campus in College Park (CP), MD (Figure 1). This facility drains a parking lot and roadway and has been in use since spring 2004. The second facility is about 8 km away in Silver Spring (SS), MD (Figure 2). This facility came online in spring 2006 and drains a parking lot.

The monitored pollutants include total suspended solids (TSS), heavy metals and a metalloid (arsenic, cadmium, chromium, copper, lead, mercury, and zinc), total organic carbon, total phosphorus, nitrogen species, oil and grease, and microbiological pollutants. The particulate/dissolved copper, lead and zinc distributions for both influent and effluent are also determined. To date, eight storm events have been monitored for water quality. All pollutant levels are event mean concentrations (EMC) based on flow-weighed composite samples. Cadmium, mercury, and O&G concentrations were below analytical detection limits for all inputs and outputs in both bioretention cells. Arsenic concentrations were also very low. The EMC removal efficiencies (R_{EMC}) were evaluated via:

$$R_{EMC} = 1 - \frac{C}{C_0} \quad (1)$$

where C_0 and C are influent and effluent pollutant concentrations, respectively. The mass removal efficiencies (R_{Mass}) were calculated according to Equation (2):

$$R_{Mass} = 1 - \frac{C V}{C_0 V_0} \quad (2)$$

where V_0 and V are influent and effluent runoff volume, respectively.

Figure 1. College Park, MD bioretention facility

Figure 2. Silver Spring, MD bioretention facility.

2.2 Zinc Accumulation

Surface concentrations of heavy metals are currently being investigated in another bioretention cell located at the University of Maryland, College Park, MD. The cell has been operational since spring 2003 and treats runoff from a heavily used commuter student parking lot.

The main flow path across the cell surface was identified by a dye tracer test. Five 0.45 m x 0.75 m zones were delineated along the flow path: at the inflow area, adjacent to the overflow riser, and at three intermediate points. Two additional zones were delineated outside of the main flow path. Figure 3 shows the location of each zone within the cell footprint.

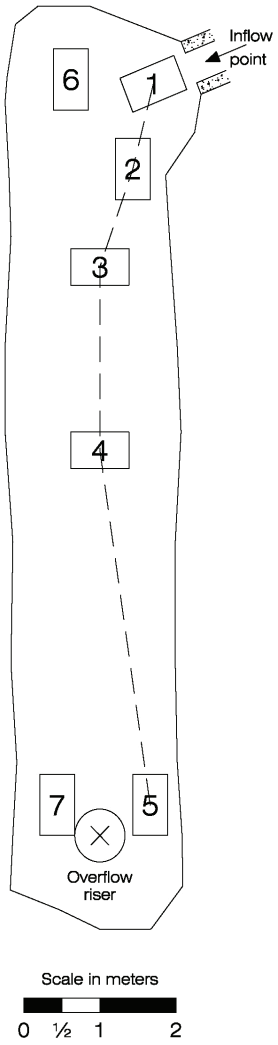

Figure 3. Bioretention cell footprint with locations of the five zones used for sampling. The dashed line is the approximate flow path.

Three media samples were taken at different points in each zone to a depth of 2.5 cm. All samples, along with a sample of the original bioretention media collected at the time of construction, were air-dried, crushed by hand, sieved through a 2 mm mesh, and oven dried at 103 – 105 °C for three days. Two 1.0 g (dry weight) replicates of each sample were digested using the U.S. EPA 3050B method. The method was slightly modified to account for the high organic content (approximately 25% volatile solids by mass) by increasing the volume of HNO_3 added and allowing a minimum of 6 hours for the reaction. The digestate was analyzed using a Perkin-Elmer Model 5100PC atomic absorption spectrophotometer.

3 RESULTS AND DISCUSSION

3.1 Water Quality Monitoring

Available results to date suggest that the two bioretention cells did fair to good in particulate pollutant removal in terms of TSS (median removal efficiency (R_{EMC}) =87% and >78%, respectively, for CP and SS sites) and total heavy metals (Cr: <4%/46%, Cu: 1/-6%, Pb: 55%/60%, and Zn: 63%/56%), which suggests that the pollutant removing mechanism is primarily adsorptive filtration; only limited removal or export occurred for the nutrients and pathogens. Significant chloride export was observed (-496%/-81%). To date, the median event mean influent/effluent pollutant levels were 4/29 mg/L (CP) and <2/3 mg/L (SS) for chloride, <3/3 µg/L and <2/<2 µg/L for chromium, 14/15 µg/L and 11/14 µg/L for copper, <3/<2 µg/L and <2/<2 µg/L for lead, 23/3 mg/L and 24/4 mg/L for TSS, and 35/11 µg/L and 18/8 µg/L for zinc. The median dissolved event mean influent and effluent copper concentrations were <3/<6 µg/L (CP) and <3/<3 µg/L (CP). Overall, the effluent pollutant levels were generally very low. Events that demonstrated total infiltration produced R_{EMC} and R_{Mass} of 100%, but were not included in water quality monitoring because the effluent water samples were not measurable. As a result, the current R_{EMC} and R_{Mass} is an underestimate for the water quality improvement.

These results are in general agreement with the laboratory studies discussed above and some limited published field studies (Dietz and Clausen 2005, 2006). In general TSS and oil/grease removals via bioretention are excellent. Similarly, heavy metal removals are very good-to-excellent with effluent concentrations in the low µg/L levels. Mechanistically, physical and chemical processes must be controlling pollutant removals because of the relatively short time (minutes) that the water flow is in contact with the bioretention media.

3.2 Zinc Accumulation

Results indicate that significant Zn accumulation has occurred on the bioretention media surface, with concentrations increasing by a factor of 9 to 23. The Zn concentration of the original media was found to be 12 mg/kg. Zone 1, closest to the inflow area, has the second-lowest average concentration, 114 mg/kg. Zone 2, approximately 1 m downstream from Zone 1, has the highest average concentration, 281 mg/kg. Starting with Zone 2, average surface Zn concentrations decrease with distance from the inflow area (Figure 4). The average concentrations in Zones 3 and 4 are 241 and 144 mg/kg, respectively. The concentration in Zone 5, at the downstream end of the cell, is 110 mg/kg, or 39% of the concentration in Zone 2.

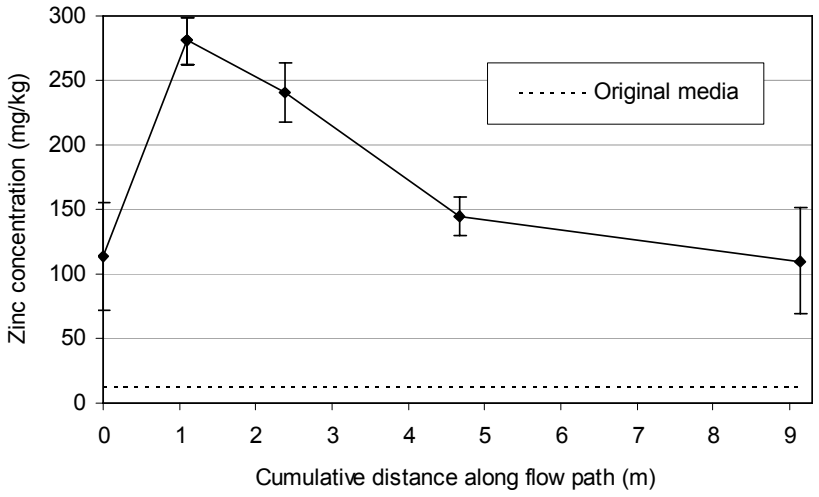

Figure 4. Zinc surface concentrations in bioretention media along the main flow path. Zinc concentration in original media is shown as dashed line. Error bars are calculated as the standard deviation divided by the square root of the sample size, 3.

Despite the numerical similarity of their average concentrations, zinc accumulation in Zones 1 and 5 is not attributable to the same physical and chemical processes. Zone 1 is the first point of contact for stormwater entering the cell. Over the 3.5-year lifespan of the cell, this area has been repeatedly scoured and subjected to deposition of particles originating from the parking lot, as the cell does not have flow dissipation devices. In addition, maintenance has not been performed to replace the bioretention media or remove sediment deposits.

The decrease in surface concentration with distance between Zones 2 and 5 should be related to the probability distribution of rainfall intensities. Relatively frequent low-intensity storms generate a low flow rate, allowing water to infiltrate within the first 1 – 2 meters of the flow path. Runoff from storms with a higher intensity but a short duration may also infiltrate at the upstream end of the cell, with little or no surface runoff reaching the back of the cell. Cells with alternate physical configurations, such

as multiple inflow points or a different length-to-width ratio, will likely behave differently. It is important to note that the location of the main flow path cannot be assumed to be constant, because the microtopography of the cell surface may change over time.

4 CONCLUSION

Overall, the two bioretention cells have indicated good performance in particulate/ adsorptive pollutant removal and effluent runoff quantity improvement.

The Zn results lead to several preliminary recommendations for operations and maintenance. Zn accumulation appears to be strongly dependent on the distance along the preferential flow path and the condition of the inflow area. The physical configuration of the cell likely plays an important role in determining the location and magnitude of surface Zn concentrations. Targeting areas for possible media replacement should be based on observations of the flow paths.

Understanding and managing these long-term issues are important from a sustainability perspective, but translate into practical recommendations for maintenance activities.

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