

Characterization of Metal Accumulation in Bioretention Media

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The propagation of non-point source pollution by stormwater runoff is a leading cause of water quality impairment in many urban watersheds. Bioretention is a soil- and plant-based technology that provides source control of urban runoff, effectively reducing runoff pollutant loads. By sequestering captured pollutants, bioretention creates a new runoff treatment paradigm. Heavy metals are a unique concern because they cannot be broken down and may pose ecological and human health risks. Long-term management issues include accumulated metals' environmental availability, oral bioavailability, relationship to regulatory cleanup thresholds, and spatial distribution within the cell.

Media samples from a bioretention cell in a heavily used commuter parking lot (Lot 11) at the University of Maryland, College Park were examined after four years of operation. Bioretention media was sampled across the cell surface and to a depth of 90 cm to assess the spatial distribution of accumulated metals in the media. Total metal, environmentally-available metal, bioavailable lead, and media pH and organic matter content were analyzed to determine cumulative metal accumulation over four years, long-term environmental fate, human health risks, and factors that influence metal concentrations in media.

Metal concentrations in the media have increased substantially over the original values, indicating that the Lot 11 cell acts as a sink for metals. Lead, copper, and zinc concentrations generally exceeded soil background estimates for eastern Maryland, but were far below EPA and

Maryland residential cleanup standards. Lead concentrations did not attain the Federally-specified threshold for toxicity.

Metal concentrations at the cell surface are highest at the front of the cell, closest to the inflow point, and generally decrease with distance from that point. A simple mechanistic model for inflow behavior over four years of Lot 11 cell operation suggests that the trend in metal concentrations with distance can be explained by cumulative exposure to inflow volume, which is highest near the inflow point and decreases with distance.

Metal accumulation is largely confined to the top 3 to 12 cm of media, coinciding with the organic layer. This layer contains the remnants of the original mulch, as well as decomposed plant matter. Little change has occurred in the underlying bioretention soil media (BSM) layer because of efficient metal capture in the organic media through sorption and particle capture. This top-heavy profile agrees with previous studies of a bioretention cell and infiltration basins.

A five-step sequential extraction procedure found all three metals to be tightly bound to the media. The mean fractions of lead, copper, and zinc in the most environmentally available fraction were 3.9, 3.9, and 13%, respectively. Although the metal fractionation is operationally defined, the results strongly suggest that captured metals should remain immobile and be sequestered indefinitely in bioretention media. This finding agrees with previous sequential extraction studies of bioretention media and roadway soils.

An *in vitro* bioavailability assay indicated that approximately 25% of lead in surface media would be absorbed into the body if ingested, comparable to generic estimates for soil. This result implies that the potential health risk from ingestion of Lot 11 cell media is similar to the risk associated with “typical” contaminated soil containing the same total lead concentration.

The Lot 11 bioretention cell has functioned as a resilient, self-contained system despite a lack of basic maintenance. Hydrologic performance remains good and vegetation has evolved into a dense mix of original plantings and volunteers. The operating life of the Lot 11 cell is unlikely to be either clogging- or breakthrough limited, given the absence of any observed clogging layer and the abundance of clean BSM below the surface. The most likely constraint on continued operation is the formation of metal hotspots that reach regulatory thresholds. Assuming constant accumulation rates, metal concentrations will begin to reach residential cleanup values after 20 additional years of operation for lead and copper and 30 years for zinc.

The greatest metal accumulation has occurred along the first 30% (3.3 m) of the flow path, in the organic media layer (0-12 cm depth). This hotspot represents a relatively small area for any future remedial action such as media replacement. The need for cleanup actions could be forestalled through simple maintenance practices such as replacing mulch every 1 to 2 years, removing any large deposits of runoff particles, and keeping flows as evenly distributed across the cell surface as possible. Mulch replacement would also ensure a continued high affinity for metals at the top of the media profile.

As systems that rely on natural processes, bioretention cells cannot be expected to be static, nor free of influence from their surrounding environments. These findings will help to refine bioretention design and maintenance considerations and will help to address the long-term sustainability of bioretention as a stormwater management practice.