Performance of and Amendments to Urban Bioretention Systems for Removal of Stormwater Contaminants

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Introduction

As urbanization has expanded, so has the area of impervious surfaces, such as roads, rooftops and parking lots. Thus, when a storm event occurs, less of the rainfall infiltrates into soils, and more becomes urban runoff. This runoff often picks up non-point source pollution, such as pesticides, detergents, flame retardants, herbicides, insecticides, and traffic pollution (Schwarzenbach et al., 2006). While originally installed to control water quantity by smoothing out urban runoff hydrographs, Best Management Practices (BMPs) such as bioretention systems may also remove these pollutants (Grebel et al., 2013).

An example of a state-of-the-art bioretention system is the Iris Rain Garden located in Lakewood, CO. The rain garden contains a planted layer of growing media, a mixture of compost and filter material, overlying a layer of CDOT Class C Filter Material. This system was implemented in 2010; however, testing has not been done at this point to determine if the rain garden is effectively removing contaminants. One category of compounds that bioretention systems such as the Iris Rain Garden may remove are trace organic contaminants (TOrCs). These include compounds such as fipronil, diazinon, atrazine, and 2,4-dichlorophenoxyacetic acid (2,4-D) (LeFevre et al., 2014). Bioretention systems also target the removal of toxic metals, such as Cd, Cu, Pb, and Zn (LeFevre et al., 2014).

The properties of the filter material in bioretention systems have significant impacts on the systems' removal of contaminants. Different geomedia, such as sand, woodchips, and zeolites, can be used to target different contaminants. Furthermore, the hydraulic conductivity of the geomedia impacts the runoff retention time and thus the amount of time the contaminants have to react with and be sorbed by the geomedia. These geomedia could be added to a bioretention system to improve the system's performance.

Research Goals and Procedure

This project has three primary objectives. The first goal is to evaluate the performance of the Iris Rain Garden with respect to the removal of dissolved TOrCs. This was done by first collecting influent and effluent samples from the bioretention system. The samples were then filtered, using a 2.7 μm filter followed by a 0.7 μm filter to remove suspended solid particulates. A Solid Phase Extraction (SPE) was then run, followed by a nitrogen gas blow-down and reconstitution with methanol. Targeted Liquid Chromatography- Mass Spectrometry (LC-MS) analysis was then performed for a list of 33 TOrCs to determine the presence of these compounds.

The second objective of this project is to determine the hydraulic conductivity of various media through constant head testing. In these tests, columns were systematically packed with the desired media, and tap water was then run through the column via a reservoir above the water level in the column. The flow rate of the water passing through the system was measured, and the hydraulic conductivity was derived according to Darcy's law.

The final goal of this project is to determine the ideal composition of geomedia to remove targeted metal contaminants, such as Cd, Cu, Pb, and Zn. To do this, batch sorption tests were performed. A contact solution containing a suite of the desired metals was developed, and then placed in test tubes with the desired geomedia. Timed samples were taken of the contact solution to determine the amount of metals sorbed by the geomedia.

Results and Discussion

Influent and effluent samples from the Iris Rain Garden representing one storm event were analyzed using LC-MS, and the results are displayed in Figure 1. As the data show, the rain garden reduced the amounts of atrazine, caffeine, carbendazim, and triphenyl phosphate in runoff. However, the level of benzotriazole remained the same and the level of DEET increased from influent to effluent samples.

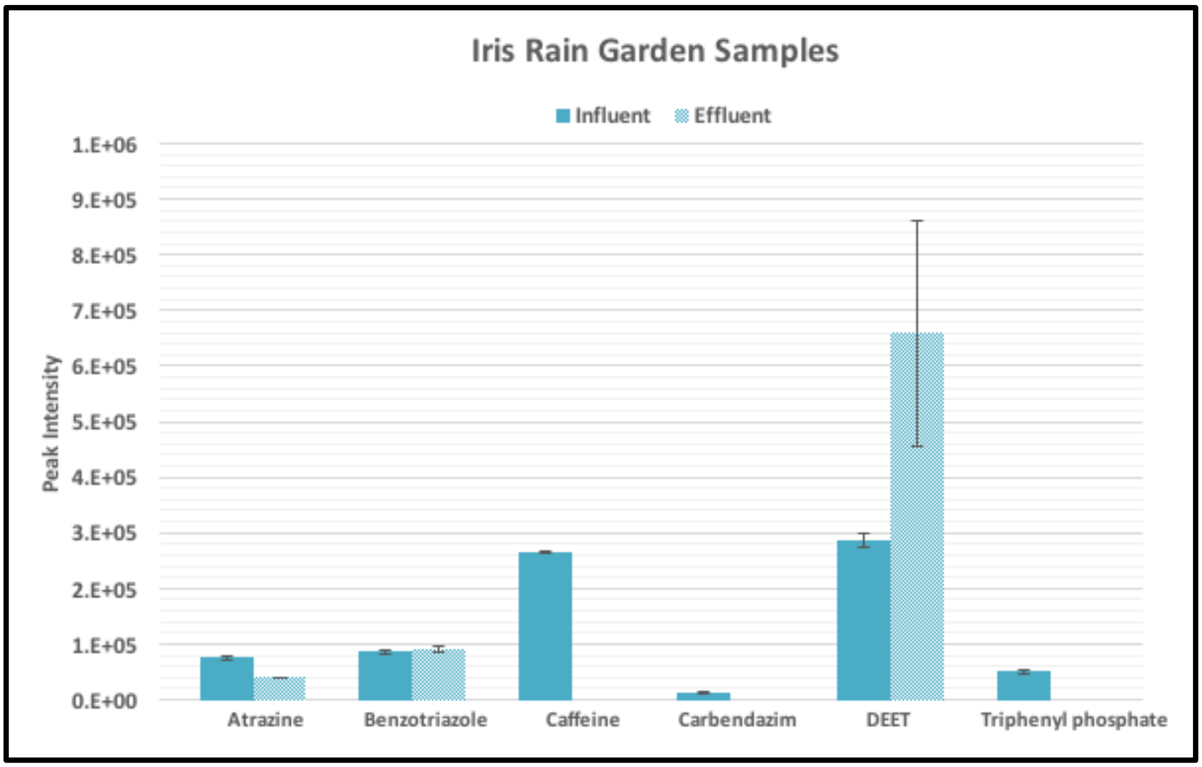

Figure 1. LC-MS results for influent and effluent samples from the Iris Rain Garden.

It should be noted that this case study is an initial screening process, to be built upon in the future. In addition to only looking at one storm event, there is further potential for improvement with this project. In particular, the auto samplers used to collect runoff samples from the rain garden often malfunctioned. For the storm event characterized above, the effluent sampler was not functioning properly, so samples were collected from the runoff present at the time of collection. This means that the effluent sample is not representative of an event mean concentration, which would be influenced by events such as a first flush.

Hydraulic conductivity values for various geomedia and media mixes are shown below in Table 1. As the data show, the addition of fine sand significantly lowers the hydraulic conductivity of the media. This is an important finding because a lower hydraulic conductivity value corresponds to a greater retention time, and thus more time for the media to interact with and potentially remove contaminants. Additionally, this data shows that it is difficult to accurately predict the hydraulic conductivity of mixtures of geomedia, and thus it is necessary to experimentally determine these values. Furthermore, knowing the hydraulic conductivity of the geomedia used in BMPs is important if targeting the removal of certain contaminants. The sorption of different contaminants will have different kinetics, and matching the retention time to the reaction rate is an important component of contaminant sorption. Finally, while lower hydraulic conductivity means greater residence times, it also means the runoff will move through the bioretention system at a slower rate. Thus, if flooding of the system is a concern, one would want to use a coarser sand as opposed to a finer sand. It should be noted that the filter media in the Iris Rain Garden is most similar to the coarse sand in Table 1. Overall, knowing the hydraulic conductivity of the geomedia used in BMPs is important when tailoring the system to meet the specific water quality and quantity needs of an environment.

Type of Geomedia	**Average Hydraulic Conductivity (cm/s)**	**SD**
Coarse Sand	0.48	0.025
2:1 Coarse Sand:Woodchips Mixture	0.44	0.0057
Fine Sand	0.17	0.021
1:1 Coarse:Fine Sand Mixture	0.16	0.023

Table 1. Hydraulic conductivity (K) values for various geomedia.

Batch sorption testing is currently being performed to characterize the removal of heavy metals by different geomedia. The metals included in the contact solution as targets for removal are Cd, Cu, Pb, and Zn. The geomedia tested are coarse sand, woodchips, and Clinoptilolite zeolites. Finally, two pH values are being examined: 5.5 and 6.5, both within the expected range for stormwater. Zeolites are expected to show the most effective sorption of the targeted heavy metals due to the ion exchange mechanism Clinoptilolite uses (Sprynskyy et al., 2006).

Going forward, it will be essential to continue to characterize the Iris Rain Garden's removal of TOrCs. Batch sorption testing will be continued and likely expanded to cover a wider range of geomedia and contact solution temperatures. Finally, this research could be applied to other filtration-based BMPs, such as Dr. Herzog's Biohydrochemical Enhancements for Streamwater Treatment (BEST), to improve customized contaminant removal for different environments (Herzog et al., 2015).

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