Effects of Antecedent Moisture on Bioretention Cell Mitigation of Storm Water Peak Flow

H. Klein[A], D. AbdelHameid[B], P. Shrestha[C], S. Hurley[C]

[A]Environmental Science Department, University of Vermont, [B]Geology Department, College of William and Mary, [C]Plant and Soil Science Department, University of Vermont

Background

In 2014 3.9 billion of the world's 8 billion inhabitants, were living in urban environments (United Nations, 2014). As cities grow and change so does human impact on landscape and the ways in which we impact the environment. A major factor of increased urbanization is a dramatic increase in non-porous surface area (buildings and roads etc.) and a concentrated drop in porous surface area (grass, exposed soil, etc.). Lack of porosity prevents the slowing and diffusion of storm water as well as the recharging of ground water. Instead, water runs off non-porous surfaces, such as concrete, at high rates and charges through sewer systems often overloading them (Li et al. 2009). Storms, like Hurricane Sandy and Irene, highlight our cities vulnerabilities to intense storm events and their inability to deal with large volumes of water. In addition to the dangers of large storm events, normal instances of precipitation carry urban pollution into rivers, estuaries and surrounding environments loading them with heavy metals, nutrients and other pollutants.

Introduction

Storm water management is a crucial step in constructing safe and sustainable cities. Bioretention basins are an increasingly common feature for addressing this problem and are becoming a staple of low impact development and green storm infrastructure. Bioretention basins reduce the adverse effects of storm water and work to improve water management and quality through evapotransportation, infiltration, adsorption, and biotransformative mechanisms (Li et al. 2008). Bioretention basins are typically composed of engineered soil and specially selected plants with deep and large root networks.

This study looked at the effects of antecedent dry periods on bioretention basin performance in order to better understand optimal conditions for efficacy. Past studies have found that antecedent dry periods enhanced bioretention basin's performance in the reduction of many target pollutants, such as TSS and TP (Manganka et al. 2014). In addition other studies have shown the benefits of antecedent dry periods on bioretention cell's hydraulic performance by expediting infiltration (Trobmble et al. 1974). This study further investigated the effects of antecedent soil conditions, specifically, whether and how they affect peak flow reduction. In addition to a field study of bioretention basins on Jeffords lot at the University of Vermont, a small column study was performed.

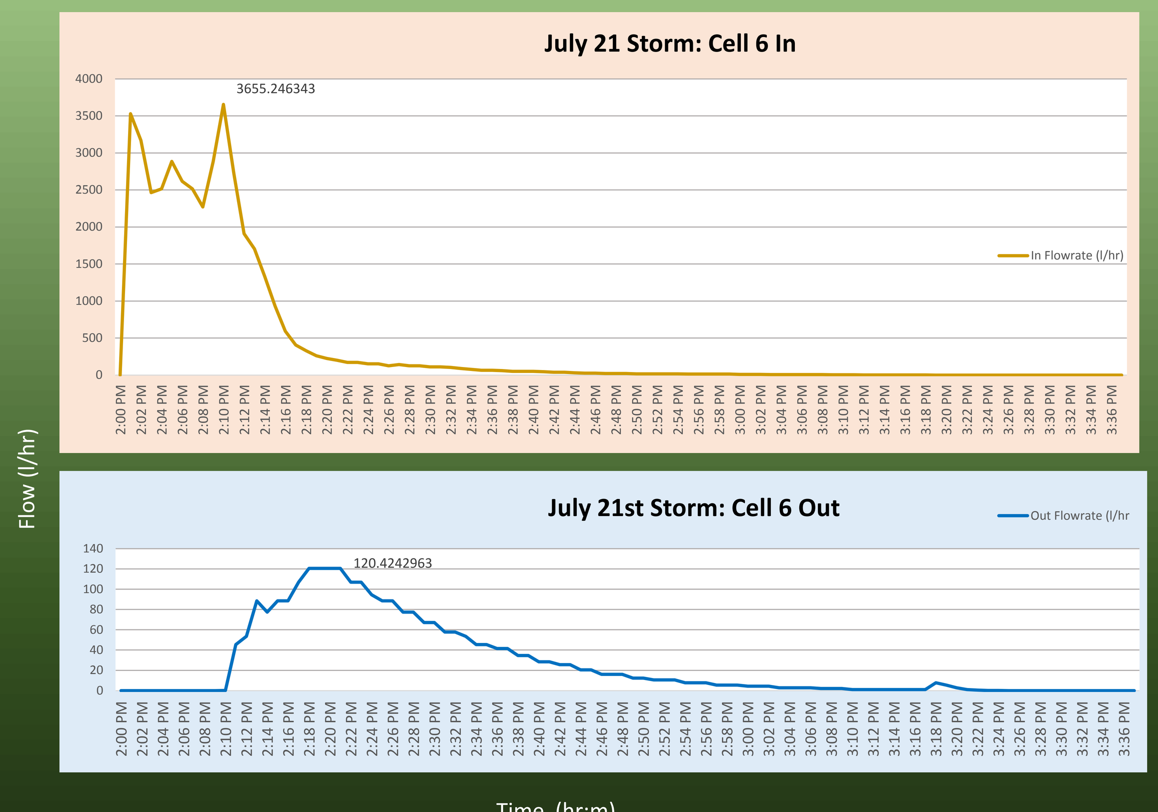

FIGURE 3: July 21 Storm Flow Charts
A comparison of storm water flow (l/hr) on July 21st. This storm had a 96% reduction between inflow and outflow, and a delay of 11 minutes. Peak volumes are noted.

Results

A step wise regression was run to assess various antecedent precipitation and moisture indicators and their relationship with percent reduction in peak flow. The step wise regression of field tests indicated that an increase in precipitation in the ten days before a storm decreased the percent reduction of peak flow by 5.79% per inch of rain ($p = 0.017$, $r^2 = .23$). While the stepwise regression was only significant for the last ten days of precipitation, Pearson's correlation indicated a strong relationship between the last ten days of precipitation and precipitation in the last five days (Pearson Correlation Coefficient = 0.4361, $p < 0.0001$), precipitation the day of the storm (PCC =0.4803, $p = 0.0151$), and the average moisture content (PCC = 0.7355, $p = 0.0003$). In addition, an analysis of variance (ANOVA), was run on to assess variance between the seven cells, of these only cell four and one had significant difference ($p = 0.0267$).

A covariant ANOVA of lab data indicated a significant difference among all four moisture treatments specifically that higher moisture contents resulted in more leachate ($p < 0.0001$, $r^2 = 0.93$). A covariant analysis was conducted to account for possible discrepancies between trails.

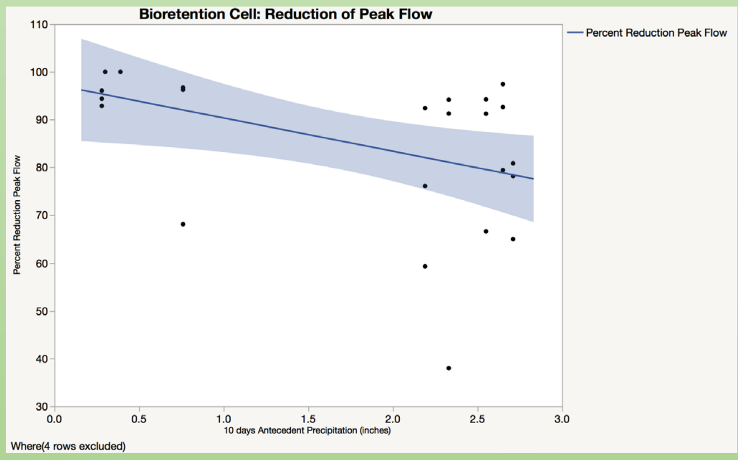

FIGURE 1: Bioretention Cell Study
Higher levels of precipitation in the 10 days prior to storm events lead to smaller reductions in peak flow.

Discussion

The field tests indicated that antecedent dry periods enhanced performance while antecedent moisture negatively impacted bioretention cells ability to to reduce peak flow (Fig 1). The lab test corroborated this evidence, indicating a negative relationship between soil moisture and storm water retention (Fig 2).

The results of this study have various implications for the construction of bioretention cells and their optimization. The use of plants and soil media with high levels of evapotranspiration that expedite the drying process between storm events, may increase cell efficacy. In addition, the study indicates that bioretention cells will be most efficient in regions with dry periods between storm events.

Further studies should analyzes volume reduction and peak flow delay as well as peak flow reduction. This study and the UVM bioretention cell study could be expanded on by creating cells in areas capturing larger amounts of run off/ larger water shed basins. This would increase the the number of usable storms, as the small water shed required heavy storms to produce data. This would also show bioretention cells' ability to perform with larger quantities of storm water. In addition, the construction of more duplicates or cells with fewer variables would increase the power of the study.

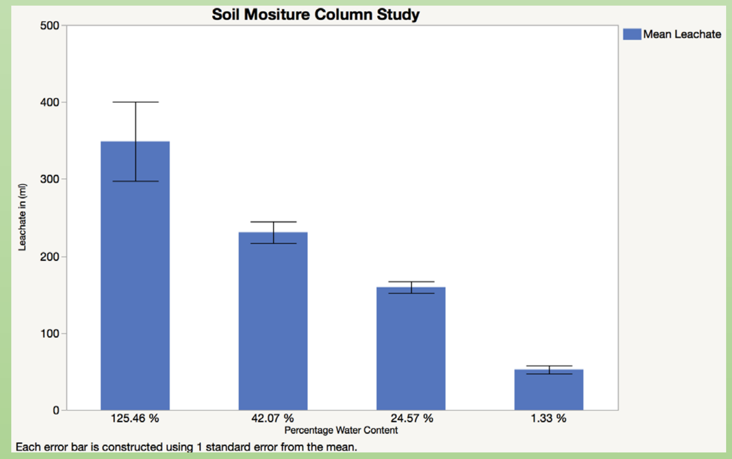

FIGURE 2: Soil Moisture Column Study
More saturated soils produced larger volumes of leachate.

Experimental Design

Outflow weir

Samples collected with an ISCO auto-sampling, each device holds 24 bottles

Eight watersheds drain into corresponding cells (4ftx 10ft) via curb cut → Water flows from the curb down a gravel path into a weir box → Inflow Sampled (weir) → Water flows over the notch and is distributed into the cell by a perforated drain → Water infiltrates the soil and is received by an underdrain → Outflow Sampled (underdrain) → Storm Sewer

- Each weir is fitted with a 90 degree v-notch and contains water sampling apparatus

- Samples every 2 minutes
- 300 ml per sample
- 3 samples per bottle

- The underdrain is fitted with a 90 degree v-notch and sampling apparatus

- Samples every 2 minutes
- 150 ml per sample
- 3 samples per bottle

Methods

Field Study: Jeffords Storm Water Bioretention Cells

- The study consisted of 8 (4x10ft) bioretention cells located along Jeffords parking lot.
- All flow and time values were taken with an ISCO auto sampler. Samples were collected by the ISCO from in and outflow weir.
- If no outflow data was recorded the data was noted as a 100% reduction in peak flow, unless a known error occurred.
- 8 distinct storms were monitored.
- Volumetric water content (VMC) was recorded as a moisture index. VMC was obtained with a Frequency-domain reflectometry (FDR) sensor and recorded in before forecasted storms.
- Rain data was obtained from The National Weather Services' Burlington International Airport location via the NOAA online weather database.
- Data from was analyzed with JUMP software.

Lab Study: Soil Moisture Column Study

- A total of two trails were conducted, each containing four duplicated water contents i.e. two trials of eight columns.
- The Gravimetric Oven Drying Method was used to discover water content.
- The soil media was 85 to 88 percent by volume sand (USDA Soil Textural Classification); 8 to 12 percent fines by volume (silt and clay); and 3 to 5 percent organic matter by weight (ASTM D 2974 Method C)
- Each soil sample had an initial weight of 5.0 mg; 420 ml, 210ml, 105 ml, and 0 ml of water were added to the soil media to produce 100% saturated, 50% saturated, 25% saturated, 0% saturated soil.
- Polycarbonate Columns of 4cm diameter and 59.5 height and glass wool were used to hold the soil.
- Solution was poured through the columns and collected to simulate storm water percolation.

Acknowledgments

I would like to thank Danya AbdelHamid, Paliza Shrethsa, Stephanie Hurley, Don Ross, Joel Tillye, and Jennifer Pontius for all their help and assistance throughout this project. Funding provided by NSF EPS Grant #1101317.

WORK CITED:

Mangangka, I., Liu, A., Egodawatta, P., & Goonetilleke, A. (2014). Performance characterisation of a stormwater treatment bioretention basin. Journal of Environmental Management, 173-178.

Franks, C., Davis, A., & Aydilek, A. (2012). Geosynthetic Filters for Water Quality Improvement of Urban Stormwater Runoff. Proceedings of the Water Environment Federation Proc Water Environ Fed, 2944-2953.

Goonetilleke, A., Thomas, E., Ginn, S., & Gilbert, D. (2004). Understanding the role of land use in urban stormwater quality management. Journal of Environmental Management, 31-42.

Li, H., Sharkey, L., Hunt, W., & Davis, A. (2009). Mitigation of Impervious Surface Hydrology Using Bioretention in North Carolina and Maryland. Journal of Hydrologic Engineering J. Hydrol. Eng., 407-415.

Tromble, J., Renard, K., & Thatcher, A. (1974). Infiltration for Three Rangeland Soil-Vegetation Complexes. Journal of Range Management, 318-318.

Li, H., & Davis, A. (2008). Urban Particle Capture in Bioretention Media. I: Laboratory and Field Studies. J. Environ. Eng. Journal of Environmental Engineering, 409-418.

Li, H., & Davis, A. (2008). Urban Particle Capture in Bioretention Media. II: Theory and Model Development. J. Environ. Eng. Journal of Environmental Engineering, 419-432.

United Nations (2014). World Urbanization Prospects: 2014 Higlights. New York. United Nations Pub. ISBN 978-92-1-151517-6