ICUD2021 extended abstract: Hydrologic and Water Quality Implications of Real-Time Control Schemes in Bioretention

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Highlights

- Real-time control resulted in >40% NH_4^+-N, and >73% NO_3^-N removal.
- Aerobic and anaerobic conditions were balanced in controlled bioretention relative to static designs.
- Hydrologic results suggest controls can provide volume reduction while reducing overflow events.

Introduction

Management of urban stormwater has become a growing issue as aging infrastructure proves inadequate at peak flow regulation, watershed hydrology is altered, and pollutants are routed directly to rivers and streams (Brabec et al., 2002). Bioretention practices have been shown to help mitigate these issues, but concerns such as incomplete nitrogen processing remain. Because bioretention nutrient processes are biotic, there is a heavy reliance on soil moisture conditions (Hunt et al., 2009), which are largely defined by site geology and design specifications. However, the use of real time control (RTC) systems to actively manage stormwater infrastructure is growing. Although not well studied for bioretention, RTC offers a potential avenue to optimize the bioretention environment for pollutant removal by managing conditions such as the soil moisture regime. RTC may also allow balancing of desirable hydrologic outcomes such as volume reduction and mitigation of overflow events. This research furthers bioretention design by implementing two sensor informed, real-time control schemes over the course of two column studies. Two control schemes employed are either (1) soil moisture based, or (2) a storage volume based. The operating goal of the system was to improve pollutant removal without sacrificing volume reduction capacity. Comparisons were made to free draining bioretention and internal water storage practices as "controls". Improvements in water quality and differences in hydrologic processing were observed because of the use real-time control.

Methodology

A nine-week column study yielding 18 storm events was conducted to test the use of two real-time control configurations against traditional bioretention design for water quality. A soil moisture control was used with the objective being to maintain field capacity of the soils while a volume control was used to maintain internal water storage levels. These configurations were compared to free draining and internal water storage bioretention designs (Figure 1). The first and second configurations were set up to replicate free draining and internal water storage bioretention designs. Soil moisture sensors were buried in each column at depths of 30.5 and 61 cm from the top of the media to record soil moisture and inform control in the third configuration. Pressure transducers were used in the fourth configuration to measure water storage levels. Each column was also outfitted with a small valve to mimic seepage as traditional operation in the United States do not use impermeable liners. After slight modification of the volume control algorithm, an additional 12 events were monitored for hydrologic endpoints (seepage, drainage, storage/ET, bypass, prediction). This modification was made to allow the water level to vary within a small range to avoid rapid opening and closing of the valve.
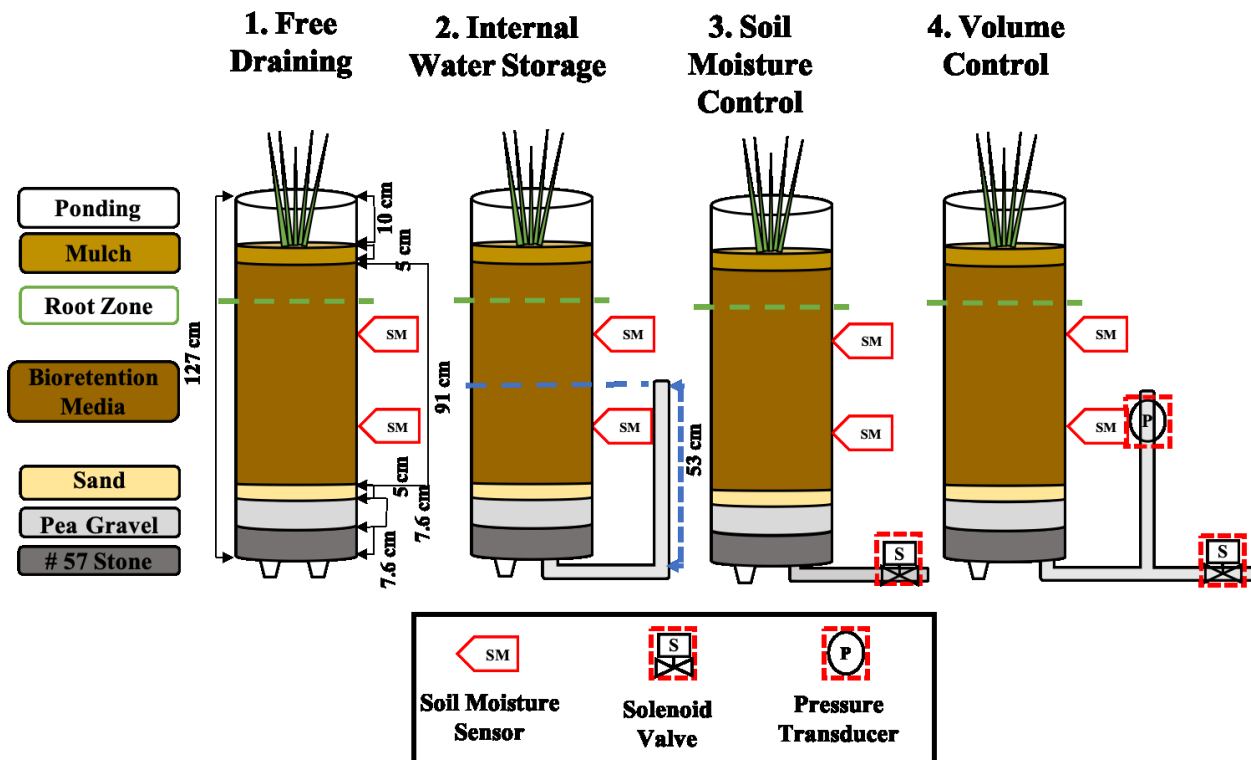
Figure 1. Bioretention Column Designs

Weather Data

Rainfall data recorded by the National Oceanic and Atmospheric Administration (NOAA) were used in this study to inform the number and size of storm applications. Additionally, the 12-hour precipitation forecast for each storm was used to inform real-time control treatments in an effort to prime each system for incoming precipitation.

Stormwater Application

A synthetic stormwater mixture was used in this study with target concentrations outlined in previous research by Bratieres et al. (2008). Storm events were applied to each column with an initial water quality sample of the inflow collected. Effluent water quality samples were then collected 24 hours later. Samples were tested for TSS, nutrients and metals. Reductions were tracked over the course of the study to determine water quality differences between treatment types.

Results and discussion

Water Quality Study

Over the 9-week study real-time control and static bioretention designs were compared by observing water quality improvements of each treatment. Of particular importance were the differences in water quality for nutrients. Specifically, soil moisture control's performance (43% ammonia removal and 74% nitrate removal) compared to that of free draining systems (71% ammonia removal and 39% nitrate removal), and internal water storage systems (26.3% ammonia removal and 95.6% nitrate removal) suggest a high potential for promoting both nitrification and denitrification beyond the capabilities of free draining and internal water storage systems.

Deeper water storage zones provided more anaerobic conditions that allowed for better denitrification which was exhibited by internal water storage columns. Conversely, the free draining columns were the most anaerobic systems and had the greatest ammonia removal which indicates better nitrification environments. While removal rates for RTC columns did not exhibit these extremes with nitrification and

denitrification, they did simultaneously provide conditions for aerobic and anaerobic processing, hence a balance between the systems can be accomplished.

Volume Reduction Study

Of the two RTC treatments, SM treatment was better performing with similar storage to IWS, 18% and 16% respectively, as compare to the storage of VC (11%). Further, there was 7% Bypass from the SM system when compared to VC (11%), indicating a greater ability of this system to take on larger stormwater volumes. Compared to traditional practices, the SM treatment could lend itself to becoming a more functional design practice than IWS and FD systems. Considering the water quality benefits of this practice noted above and seen in research by Persaud et al. (2019), the SM control scheme could be a reasonably well performing system as it manages larger stormwater volumes while also promoting nitrification and denitrification.
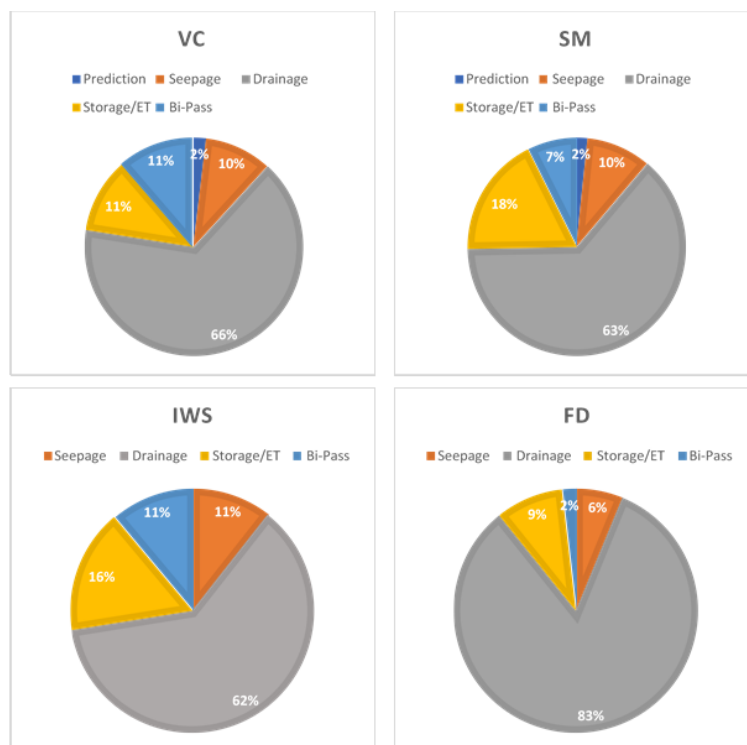

Figure 2. Bioretention Column Hydrologic Balances

Conclusions and future work

RTC has the potential to create a more cohesive environment for aerobic and anaerobic processing within bioretention (while not sacrificing desirable hydrologic outcomes). Future work aims to study microbial processing to further inform RTC optimization and understand how communities are shifting with various environmental changes. While RTC holds substantial promise for contributing to urban drainage challenges, research is still in its infancy. There are substantial research gaps related to when and how to implement RTC to achieve the greatest benefits.

References

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