Performance comparison between infiltration and non-infiltration type of structural stormwater treatment systems
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ABSTRACT
The study was constructed to monitor representative inflow and outflow from infiltration and non-infiltration type best management practice (BMP) sites developed at a university campus, allowing the determination of overall performance efficiency in terms of runoff reduction and pollutant removal. Based on the monitored storm events, the runoff and discharged volume and flow rates exhibited high positive correlations with total rainfall depth ($p < 0.001$). Findings revealed that as the total rainfall increases, the amount of volume reduction and pollutant removal decreases for both types of BMP. Infiltration BMP showed a higher ability in treatment performance especially during small storm events than non-infiltration type; however, the differences were not significant. Pollutant removal rates of infiltration type were in the range of 70–90% while between 35 and 80% for the non-infiltration type for storm events with less than 10 mm rainfall depth. Average volume reductions were $71 \pm 33\%$ and $32 \pm 32\%$ for the infiltration and non-infiltration type, respectively. The ratio of the discharge volume was significantly greater than the ratio of discharge pollutant load indicating a high potential for water quality improvement. Design recommendations were provided considering sizing and cost for on-site application of similar BMP designs in the future.

Key words | best management practice, infiltration, low impact development, non-infiltration, pollutant removal, runoff reduction

INTRODUCTION
Low impact development (LID) site design that incorporate stormwater features into the landscape by using techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source are being adopted in urban development to address issues of physical and biochemical impacts of watershed urbanization on the aquatic ecosystem (Davis 2005; Shuster et al. 2005; Park et al. 2008). Recently, an emerging LID technology that has been currently employed for the conveyance of stormwater runoff in road and parking lot designs in Korea is structural infiltration/infiltration best management practice (BMP). Infiltration BMPs are identified as practices that provide temporary storage of runoff using void spaces within the soil/sand/gravel or other media mixture with under-drains and impermeable liners for subsequent infiltration into the surrounding subsoil and provide groundwater recharge. Non-infiltration BMPs are designed with similar features of infiltration BMP but only use a filter media with no drain pipes installed thereby not inducing infiltration into the ground (U.S. EPA 2000b; Weiss et al. 2007).

While little consistent information on the effectiveness of LID technology is available in Korea, recent studies in the United States have revealed satisfactory performance data on structural BMPs. Based on the National Pollutant Removal Performance Database for Stormwater Treatment Practices, the median pollutant removal of infiltration practices are little higher compared with filtering practices with approximately 10% difference. Total suspended solids (TSS) and zinc (Zn) removals (86–95%) are greater than total nitrogen (TN) and phosphorus (TP) removals (38–70%) (Winer 2000). The BMP studies in Europe revealed similar ranges of pollutant removal between BMP types. The TSS and metal removals are in the range...
of 60–90% and 70–90%, respectively for filter and infiltration treatment facilities. TN removal is lower in filter type that is only between 20 and 30%, while 20–50% for infiltration type (Revitt et al. 2003).

In most studies, the BMP performance has been evaluated based solely on the pollutant removal efficiency of a practice (Winer 2000; Horst et al. 2008; Semadeni-Davies 2008). Nevertheless, removal efficiencies do not always address runoff volume reductions in BMPs resulting in the assumption that the total load reduction was due to the reduction in pollutant load. This assumption might lead to an overestimation of the pollutant removal capabilities, while ignoring the additional benefits of volume reduction (Battiata et al. 2010). To assess the overall performance of stormwater BMPs, both the pollutant removal and runoff volume reduction capabilities should be considered. Therefore, in this study, the performance of four structural BMP pilot technologies categorized to infiltration and non-infiltration type were quantified based on runoff reduction and pollutant removal during the early years of operation. Statistical analyses were conducted to determine significant differences in treatment performance between BMP types. Moreover, some guidelines and recommendations were provided in designing similar BMPs in the future.

**MATERIALS AND METHODS**

**Site description and BMP design characteristics**

The four BMP facilities namely the eco-biofilter (EBF), green eco-tree filter (GEF), and two types of gravel wetland system (GWS) were constructed at the Kongju University campus grounds in Cheonan City, South Korea (36°51’11”N, 127°9’0.23”E). Each of the facilities was designed in a typical manner following the design schematic in Figure 1. The physical design characteristics are provided in Table 1. Both the EBF and GEF facilities have infiltration function while the two types of GWS have no infiltration or drain pipes installed, rather an outflow channel were included in the system for bypassing the excess runoff during heavy storm events. Gravel filter was installed in the overflow channel for further filtration of pollutants. Except GEF, the other three facilities have pre-treatment tank with sand or gravel media to enhance sedimentation of particulates. In the case of GEF, the vegetation was employed to act as the filtration media.

**Monitoring and data analyses**

Water quantity and quality data were gathered from a total of 37 storm events monitored between May 2009 and May...
Manual grab sampling was conducted for the collection of water samples at the inflow and outflow units of each BMP facility. The sampling scheme follows the typical sample collection method practiced similarly in most non-point source pollution studies in Korea (Kim et al. 2007; Maniquiz et al. 2010). In cases where rainfall was small and runoff was short, the number of samples was adjusted. In addition to stormwater runoff sample collected to be used for chemical analysis, selected event description data were also obtained from each site. Continuous flow measurements were performed and recorded using 5 or 10 min interval and other event description data (e.g. total event rainfall, rainfall duration, antecedent dry day (ADD), etc.) were gathered for each storm event. Stormwater runoff samples obtained from entire rain events were brought in to the laboratory for analytical tests to obtain event mean concentration (EMC) for stormwater runoff.

A one-way ANOVA was performed to investigate any significant differences of the means between BMP types in terms of hydraulic and hydrologic variables, volume reduction, and pollutant removal. A non-parametric paired sample Wilcoxon signed rank test was conducted to determine if the ratio of discharge volume was greater or less than the ratio of discharge pollutant load for the BMP type. All statistical hypotheses were tested at 95% confidence level, unless otherwise specified statistically different means that p value was less than 0.05. Using the monitored storm event data and physical design characteristics (e.g. construction cost, catchment area, surface area and storage volume), regression plots were generated that could serve as a reference for future selection and application of BMP for LID site design based on stormwater needs and regulatory requirements.

### RESULTS AND DISCUSSION

#### Hydrologic and hydraulic characteristics

The summary of the 37 sampled storm events for each BMP is presented in Table 2. Based on the findings, the total event rainfall depth, rainfall and runoff duration, hydraulic retention time (HRT) and runoff coefficient were not significantly different among the sites. However, the average inflows were significantly different with the average outflows for all of the sites which signify that the flow rates were reduced significantly regardless of BMP type. In addition, the peak inflows and outflows were also significantly different suggesting that the BMPs were also capable of reducing the peak flows. Hydraulic parameters
(e.g. volume and flow rates) exhibited high positive correlations with event rainfall emphasizing that rainfall was one of the important factors in designing the BMPs (U.S. EPA 2000a).

Figure 2 shows that in Korea, a significant number of storms (70%) were expected during the summer months that resulted in an average (mean ± standard deviation) of 12 ± 17, 23 ± 25 and 16 ± 16 mm for each event rainfall for July, August and September, respectively. The rest of the months corresponded only to 30% of the total annual rainfall; however, frequent storms were associated with small rainfall as shown in Figure 3. On average, almost 80% of the total number of storms that occurred within the year was below 12.5 mm (0.5 inch). It was reflected by the storm events captured in this study.

Runoff volume and storm event concentration

The efficiency performance based on the average difference between the inflow and outflow storm event concentrations might be misrepresentative especially when inflow concentrations are low (Lenhart 2007). Therefore, for proper comparison of percentage removal of BMP facilities, the sites should be both subjected to similar pollutant input concentrations and hydraulic loading. The rainfall–runoff plot in Figure 4 shows that the runoff coefficient resulted from the monitored storm events was close for the BMP sites wherein the runoff could be estimated between 0.67 and 0.77 of the total event rainfall. In the case of inflow/outflow concentration, the EMC was used to quantify the average pollutant load washed off during a storm event with respect to the event runoff volume. Figure 5 shows the comparison of the inflow pollutant EMC for the two BMP types. The values of pollutant EMCs were similar for both sites; however, the coefficient of variation was larger in non-infiltration BMP sites in the range of 0.5–1.48, while only between 0.58 and 0.88 for infiltration BMP sites.

Volume reduction

Figure 6 shows that as total rainfall increases, the amount of volume reduction decreases for both types of BMP. The rate of decrease in volume reduction was almost 8% for every 5 mm increase in rainfall for the infiltration type while only 3% for every 5 mm for the non-infiltration type. When comparing the total runoff volume reductions for the two types, the infiltration type appears to be more effective but not significantly higher than the non-infiltration type, with average
volume reductions of 71 ± 33% and 32 ± 32%, respectively. The infiltration type exhibited a higher ability in reducing the total volume during small events than non-infiltration type; the difference however, was not statistically significant. The infiltration type attained a 50–80% volume reduction, greater than the maximum volume reduction that the non-infiltration type could achieve within 20 mm rainfall but beyond this range the discharged volume increases as rainfall increases. The difference between the peak flows at the inflow and outflow were significant for both types in the first 6 h of rainfall. Infiltration type was able to reduced the peak flows by 50–60% in the first 2 h of rainfall, and between 35 and 45% in the succeeding 4 h. On the other hand, the peak flow reduction of non-infiltration type was in the range of 33–37% in the first 2 h and increased to almost 40% in the next 4 h of rainfall.

**Pollutant removal**

The total pollutant mass removal was calculated for each event and regressed with rainfall depth for both types of BMP as shown in Figure 7. Based on the statistical analyses, the pollutant removal was not significantly different between the infiltration and non-infiltration type for TSS ($p = 0.236$), chemical oxygen demand (CODcr) ($p = 0.648$), TN ($p = 0.473$), TP ($p = 0.163$) and total Zn ($p = 0.828$) but significantly different for biochemical oxygen demand (BOD). Infiltration type performed better for the removal of pollutants, in the range of 70–90% for small storm events particularly below 10 mm rainfall while between 35 and 80% pollutant removal rate for the non-infiltration type.

**Overall efficiency**

Figure 8 shows the normalized proportion of discharge volume (m³/m³) versus normalized proportion of pollutant load (kg/kg). Based on the nonparametric paired sample Wilcoxon signed rank test, it was found out that the ratio of the discharge volume ($\text{Vol}_{\text{OUT}}/\text{Vol}_{\text{IN}}$) was significantly greater than the ratio of the discharge pollutant load ($\text{Load}_{\text{OUT}}/\text{Load}_{\text{IN}}$) for TSS, total Zn, TP and CODcr but not significantly greater for BOD and TN for the infiltration type; while only BOD was not significant in the case of non-infiltration type. The rank of pollutant removal efficiency with...
respect to discharge volume from greatest to least was particulates > metal > nutrients > organics. The results implied that suspended solid removal was controlled by mechanisms like sedimentation and filtration in the pre-treatment/gravel media area and was not dependent on HRT or infiltration effect as it was achieved by both systems. The system could not be expected to highly reduce the nutrients and organic matters as the mechanisms of treatment for these pollutants were complex and the mass flux could be greatly variable.

**Design recommendations for on-site application**

Gilroy & McCuen (2009) suggested that it is beneficial to understand the effects that the location and quantity of BMPs can have for storm runoff characteristics. Moreover, to achieve optimal effectiveness, the BMPs must be properly sized and located. Using the performance data and physical characteristics of the BMP sites in this study, satisfactory fittings were obtained when the average volume reduction was regressed with catchment area to BMP facility surface area ratio (CA:SA) as shown in Figure 9. For CA:SA below 100, the rate of decrease of mean volume reduction was 0.6% per unit increase of CA:SA. Higher reduction rates (e.g. more than 60%) could be achieved for CA:SA between 100 and 200 which correspond to facility surface area of 1–2% of catchment area. Cost could be reduced by US$5,500 per 100 unit increase in CA:SA ratio (Figure 10). The optimal facility surface area to storage volume (SA:SV) ratio was achieved at 1.6 that correspond to the intersection of total capital cost (US$11,350) and CA:SA (122.5) in Figure 10.

**CONCLUSIONS**

The purpose of this study was to compare the performance efficiency of two BMP types, similarly designed except that one has an additional advantage of infiltration capability; both subjected to similar ranges of pollutant and hydraulic loadings. Based on the analyses performed using the monitored storm event data, it appeared that both types of BMPs have functioned well and significantly reduced the flow rates, peak flows and pollutants although the efficiency levels were slightly different. The edge however of the infiltration type was its higher ability in reducing the total volume of runoff and removal of pollutants for small storm events ranging between 10 and 20 mm. As the most frequent rainfall in Korea is typically below 12.5 mm
(0.5 inch), the infiltration type could be a better choice. However, as infiltration of runoff to the subsoil might have certain limitations (e.g. soil infiltration capability, saturation, etc.) the non-infiltration type can be an option. In terms of application, it is important to consider the ratio of facility surface area to catchment area. Likewise, the facility surface area to storage volume ratio is also essential in designing the BMPs. Higher ratios could possibly decrease the total capital cost; however, the total runoff volume and pollutant loadings could not be satisfactory reduced.

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