

# A comparative study between high and low infiltration soils for use in water sensitive urban design

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## Highlights

- The applicability of high and low infiltration soils in LID structures was compared.
- Runoff reduction in high infiltration systems are more affected by rainfall depth and inflow rates as compared to low infiltration systems.
- Low infiltration systems are more susceptible to horizontal flow thus, the length of the structure may be more critical than depth in this condition.

## Introduction

The rapid shift from pervious to impervious surfaces due to urbanization quantifiably decreased the amount of area available for stormwater infiltration. This has become apparent through frequent flooding, declining base flows, and water quality impairment in streams, rivers, and shallow groundwater (USEPA 2001; Shuster, 2005). As a result, stormwater management solutions leaned towards low impact development (LID) strategies that mimic pre-urbanization hydrology through retention, infiltration, evapotranspiration and filtration (USEPA, 2000). Typically, the goal is to allow the infiltration of treated stormwater runoff to the surrounding soil for groundwater recharge. However, in areas that are experiencing periods of drought, like South Korea, or where the in-situ soil infiltration capacity is low, the treated stormwater may be stored for reuse instead. Therefore, the application of stormwater infiltration LID systems may be broadened instead of being limited by in-situ soil or rainfall characteristics. This has also been in an interest in Australia which has experienced droughts and where water scarcity is a major challenge (Begum et al., 2008; Akram et al., 2014).

LID structures can be designed as either infiltration systems or flow-through systems that have impervious bottoms and collects treated stormwater and conveys it to a destination point. In this study, a high infiltration system (HIS) can promote groundwater recharge while a low infiltration system (LIS) can promote collection for reuse and minimal infiltration. Using experimental methods, a system utilizing gravel and soil media was investigated in order to determine its suitability for infiltration or flow-through design. The runoff capture capacity between high infiltration and low infiltration media were compared and their corresponding effect on pollutant removal with emphasis on suspended solids were analysed. The study aims to develop basic design provisions for LID applications under different rainfall and soil characteristics.

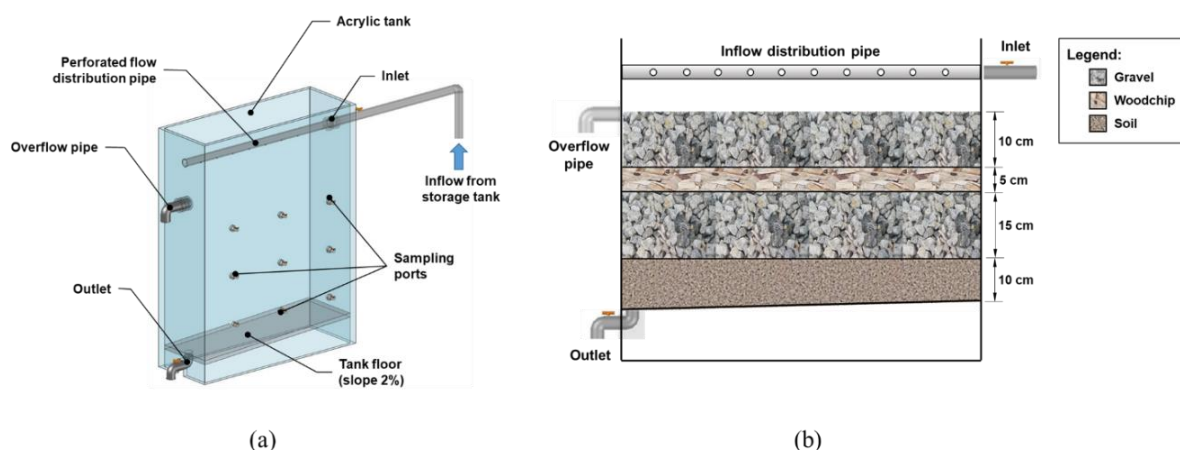
## Methodology

### Infiltration system

A lab-scale infiltration device as shown in Fig. 1(a) was constructed and assembled for the experiments. It is composed of a 0.7x0.2x0.6 m (LxWxH) acrylic tank and polyvinyl chloride (PVC) pipes for the inlet and outlet. The media were arranged inside the tank as depicted in Fig. 1 (b). The storage volume is 0.028 m<sup>3</sup> which is equivalent to a 4 mm assuming a catchment area of 7 m<sup>2</sup> which will create a facility surface area to catchment area of 0.02 according to design guidelines. Two setups were studied; one employs a uniformly-graded sandy soil representing a high infiltration system (HIS) while the other one employs a well-graded clay soil representing a low infiltration system (LIS).

A semi-synthetic stormwater was used as inflow and was prepared by mixing highway sediments with municipal tap water. Inflow turbidity was maintained at 100 NTU (equivalent to 1600 mg/L) and was fed to

the infiltration device at inflow rates of 250, 500, and 1000 mm/h, equivalent to rainfall intensities of 5, 10, and 20 mm/h over a 7 m<sup>2</sup> catchment area. The water level in the tank were observed while the outflow and overflow rates were measured volumetrically from the start of outflow and every 5 min thereafter. Inflow outflow, and overflow samples were collected by time-weighted discrete sampling from the start and every 10 min thereafter for turbidity measurement and PSD analysis. Each experiment was conducted for 1 h after which the remaining water in the tank was allowed to drain while the water level and outflow rates were continuously measured.



**Figure 1.** Infiltration device indicating parts and arrangement of the media

## Results and discussion

### The relationship between water depth and infiltration rates

In all the experiments conducted, it was observed that as the water level rose, the infiltration rate increased. For LIS, this stopped when the infiltration capacity was reached while for HIS, it continued until the overflow level was reached. The water level above the soil created a positive hydraulic head which pushed the water unto the soil and induced an increase in infiltration rate. When the inflow stopped, the infiltration rates also decreased as the water level decreased further demonstrating the influence of overlying water depth to the flow within the system. Thus it can be inferred that the available depth for water storage within and above soil media can influence the infiltration rates in stormwater treatment systems.

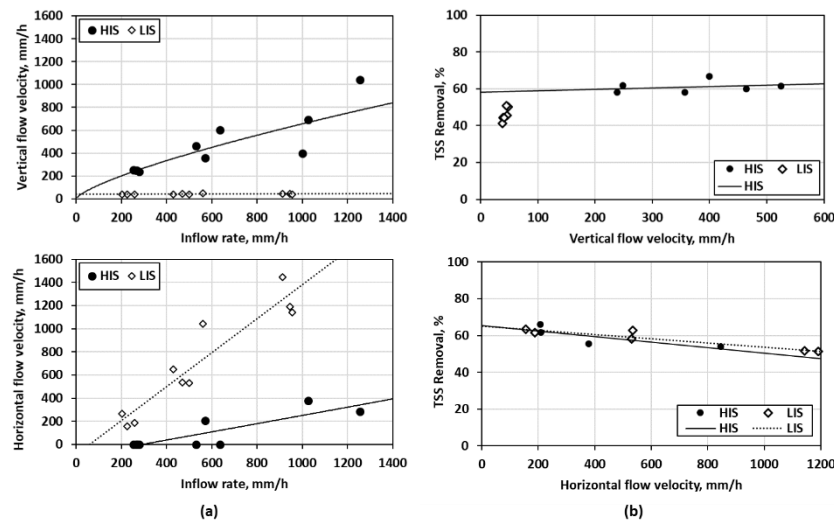
### The effect of runoff capture and infiltration rates in determining media depth

Runoff volume reduction data shows that as the inflow rate increased, the amount of captured runoff also increased in HIS but remained constant in LIS. This signifies that the rainfall depth and intensity influences the amount of runoff capture more significantly in HIS than in LIS due to the limited infiltration capacity in LIS. Using the rational method, it was estimated that to achieve 100% capture of the runoff generated by a 10-mm rainfall in Korea, at least 1 m of gavel media depth is required over a low infiltration soil. This was also confirmed by extrapolating the runoff capture data from the experiments in this study. On the other hand, HIS requires only 0.4 m to achieve the same runoff capture. This is because the rational method does not consider infiltration conditions or assume zero or low infiltration. However, in terms of water quality, a minimum depth 0.9 m is suggested. Moreover, a drawdown time of 9 h corresponding to an infiltration rate of 200 mm/h was estimated to be the optimum condition for pollutant removal.

### The effect of hydraulic characteristics on the removal of suspended solids

Despite the large gap in infiltration capacity between HIS and LIS, the total removal of solids by gravel and soil layer in the two systems are comparable at 91-94% in HIS and 95-98% in LIS. While the gravel layer was able to remove up to 67% of the solids, the rest were removed in the soil layer especially those that were less than 50  $\mu$ m in size. However, a variation in suspended solids removal in the gravel layer was observed with respect to the flow direction and velocity with the infiltration systems. As the inflow rate increased, the vertical flow in LIS remained constant while the horizontal flow rapidly increased (Figure 2(a)) indicating that systems with silty or clay soils are more susceptible to horizontal flow especially during heavy rainfall.

This also induced an increase in the amount of solids escaping the treatment system thereby decreasing the captured TSS as shown in Figure 2(b). Avoiding this phenomenon would require increasing the depth of the facility. However, in areas with site-specific constraints the available depth is limited, the length of the system should be increased to encourage treatment through horizontal flow.



**Figure 2.** (a) Variation in vertical and horizontal flow with respect to inflow rate and (b) corresponding TSS removals

## Conclusions and future work

The major findings in this study as well as recommendations for future work are as follows:

- Aside from the rainfall depth and inflow rates, the water depth can influence the infiltration rates in stormwater treatment system. Infiltration rates are found to increase with water levels until either the infiltration capacity or overflow level is reached.
- High infiltration systems can capture and treat larger volumes of runoff as compared to low infiltration systems but low infiltration systems can capture and treat a consistent amount of runoff that can be infiltrated or released to the storm drains.
- For optimum runoff capture and pollutant removal, a minimum depth of 0.9 m and maximum infiltration rate of 200 mm/h was found to be ideal to provide enough retention time.
- Infiltration systems with or built above silty or clay soils are found to be more susceptible to horizontal flow. Therefore, the length of the media bed is more critical than the depth in this condition and should be considered in the design process.

## Acknowledgements

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