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# Effects of Vacuuming Pervious Concrete on Infiltration Rate

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## ABSTRACT

The objectives of this research were twofold: test the infiltration rate of pervious concrete before and after vacuum cleaning, and assess infiltration variability over time. Infiltration tests were performed on a 558.2 $m^2$ area of pervious concrete, divided into sixteen 0.35 $m^2$ test areas in a parking area at the Science Museum of Virginia in Richmond, Virginia on five dates from November 4-December 30, 2013. Average infiltration rates (avg.= 22.8 and 36.3 L/$m^2$/min) immediately after vacuuming were lower than those (avg.=30.7 and 41.3 L/$m^2$/min) before vacuuming. We hypothesize that the vacuuming lifted materials towards the surface from deeper crevices of the lower profile of the pervious concrete, which clogged interstices in the upper portion of the pervious concrete, and impeded infiltration. Over time, however, average infiltration rates recovered, increasing significantly from 22.8 -44.1 L/$m^2$/min (93% increase) from November 4 through December 30, 2013 (56 days). Ergo, over time, the infiltration capability of the pervious concrete increased as rains likely washed sediments to lower profiles and allow for increased infiltration rates, consistent with the findings of other studies. Infiltration rates on the leading edge of the pervious concrete area receiving runoff from adjacent impervious asphalt surfaces were significantly lower than those furthest away from the leading edge. In contrast to recommendations specifying that pervious concrete be regularly vacuumed monthly, we propose that annual or semiannual vacuuming of pervious concrete would allow adequate infiltration, and reduce costs significantly for pervious concrete areas located in the mid-Atlantic region.

## INTRODUCTION

Urban runoff containing sediments, nitrogen, and phosphorus have contributed to eutrophication of the Chesapeake Bay (Frazer, 2005). New technologies such as pervious concrete have been demonstrated to reduce runoff volume, and nitrogen and phosphorus pollutants by 78.5 % and 70.7 %, respectively (Maurakis and Janeski, 2013). Absence of finer sands in the mix of pervious concrete increases porosity and infiltration capacity, allowing stormwater to infiltrate the pervious pavement and underlying soils, minimizing runoff from a site (Obla, 2007). Infiltration rate varies with soil type, the texture, structure, and uniformity of pervious concrete (Reynolds et al., 2002). The accumulation of the *schmutzdecke* (dirt cover), an active biological layer responsible for pollutant removal, exists in the upper seven cm as reported by Hunt and Collins (2008) and Unger (2006). Sediment from runoff does not penetrate pervious concrete more than 2.54 cm (Mata, 2008).

Wanielista and Chopra (2007) and Bean et al. (2004) suggested that the effectiveness of pervious concrete depends upon the methods and frequency of maintenance. Bean et al. (2004) stated that a lack of maintenance of pervious concrete would eventually result in a decline in infiltration, ultimately leading to an increase in runoff. In a study of 55 sites of 1-12 year-old permeable pavements that had never been cleaned, Boogaard et al. (2014) found that infiltration decreased over time. However, Mullaney and Lucke (2013) point out that there were inconsistencies in the frequency and degree of maintenance required to clean pervious pavements.

Suozzo and Dewoolkar (2012), Chopra et al. (2010), and Boogaard et al. (2014) described the primary methods for maintaining pervious concrete: high-pressure washing, vacuuming, and a combination of both. High-pressure washing is less desirable because it forces sediments deeper into the pervious concrete, potentially clogging underlying layers (Fassman and Blackbourne, 2010). Boogaard et al. (2014) indicated that vacuuming improves infiltration of pervious pavements. However, in a study of the rejuvenation methods (i.e., vacuuming and power washing) of pervious concrete, Chopra et al. (2010) indicated that power washing was more effective in increasing infiltration by pushing clogging materials deeper into the pervious pavements.

In February 2011, the Science Museum of Virginia in Richmond, Virginia (Fig. 1) installed an area of pervious concrete covering 24 parking spots within an existing asphalt parking lot, but did not measure its average infiltration rate after installation and did not perform maintenance. The objectives of this study were to test the infiltration rate of pervious concrete before and after vacuum cleaning, and assess its infiltration variability over time.

## MATERIALS AND METHODS

Infiltration tests were conducted in a 558.2 $m^2$ (18.3 m x 30.5 m) pervious concrete parking area at the Science Museum of Virginia (37.5614° N; -77.4657° W). The pervious concrete of this area is 15.2 cm thick and sits on top of a reservoir composed of a 22.9 cm layer of Solite™ (lightweight, high porous aggregate) supported by a 15.2 cm base layer of #57 gravel size stone (illustrated profile in Sample et al., 2014). The 558.2 $m^2$ area of pervious concrete was divided into four columns (A, B, C, and D) and four rows (parking spaces 2, 5, 8, and 11) (Figure 2). Column A is on the upstream edge that receives surface flow from 9,442 $m^2$ of impervious asphalt surface parking area. Column D is furthest from surface flow.

The four longitudinal columns and the four rows of parking spaces, resulting in 16 test locations, which were used to conduct (1) pre-vacuuming (control) and post-vacuuming infiltration tests on November 4 and December 21, 2013; and (2) long-term infiltration tests on each of five dates: November 4 and 24; and December 15, 26, and 30, 2013, where the control group was composed of the 16 un-vacuumed sites on November 4, 2013.

A single ring infiltrometer (open bottom area of 0.35 $m^2$) was made by cutting and removing the bottom of an 18.93 L bucket. Pliable weather stripping and plumbers putty were attached around the bottom perimeter of the infiltration bucket to form a seal between the pervious concrete and the infiltration bucket to prevent leakage.

A 2-gallon (7.6 L) dispensing bucket was used to pour 3.78 L (1 gal) of water into the infiltrometer using the falling head test procedure in Boogaard et al. (2013) and Lucke et al. (2014) at each test site. A stopwatch was used to time the infiltration rate of 3.78 L of water through the 0.35 $m^2$ open bottom of the infiltrometer. The stopwatch was started as soon as water hit the concrete and stopped when water inside the infiltrometer had drained. This procedure was repeated for all tests. Infiltration rates were recorded in L/$m^2$/min as described in Obla (2007).

A new Billy Goat™ industrial duty hard surface vacuum machine manufactured by Billy Goat Industries in Kansas City, MO was used only to vacuum (2,090 CFM @ 3,600 rpm) the total surface area (9.09 $m^2$) of the four rows of pervious concrete for a minimum of ten times or more until no additional particles were collected. The total sand and debris material from the vacuum bag was removed, labeled, and weighed after each vacuuming of the test areas on November 2 and December 21, 2013. The ratio of g/$m^2$ was calculated by dividing the amount of debris by the area (9.09 $m^2$) vacuumed. The daily rate of sediment accumulation in g/$m^2$/day was calculated by dividing the ratio by the total number of days between vacuuming. No winter surface treatments (i.e., sand) were applied.

Relationships between variables were analyzed using Pearson's *r*-correlation analysis at p=0.05 (SAS, 2014). Average infiltration rates among sampling locations by columns and rows and by date were analyzed with a general linear model procedure followed by Duncan's Multiple Range Test at p=0.05 (SAS, 2014).

## RESULTS

There was a positive correlation between increased distance from column A to D and the infiltration rate (correlation coefficient= 0.2163; p=0.0343) (Table 1; Figs. 1 and 2). There was a significant negative correlation between infiltration rate and increased distance from row one to row four (correlation coefficient=-0.1917; p=0.0429)(Table 1; Figs. 1 and 2).

Average infiltration rate before vacuuming (30.7 L/$m^2$/min) did not differ significantly from the average infiltration rate (22.8 L/$m^2$/min) after initial vacuuming (Table 2). Before the second vacuuming on December 21, 2013, the average infiltration rate (41.3 L/$m^2$/min) did not differ significantly from post-vacuum average infiltration rate (36.3 L/$m^2$/min) (Table 2). However, infiltration rates (avg. range=36.3-41.3 L/$m^2$/min) in December, 2013, 47 days after the initiation of testing, were significantly higher than those (avg. range=22.8-30.7 L/$m^2$/min) in November, 2013 (Table 2).

Over time, infiltration rate increased steadily from 22.8 to 44.1 L/$m^2$/min (Table 3; Fig. 4). Infiltration rates (avg. range=37.3-44.1 L/$m^2$/min) at 20, 47, and 56 days after testing began were significantly higher than the average infiltration rate (22.8 L/$m^2$/min) after post-vacuuming on the first day (Table 3). Pre-vacuuming rate (43 L/$m^2$/min) on the first day (November 4, 2013), however, did not differ significantly from the rate (44.1 L/m$^2$/min) on the final day (December 30, 2013).

Infiltration rates varied over columns and rows. The average infiltration rate increased from 28.1 L/m$^2$/min at column A to 44.2 L/m$^2$/min at column D (Table 4; Fig. 5). Average infiltration rate at column A (28.1 L/m$^2$/min) was significantly lower than those (avg. range=42.4-44.2 L/m$^2$/min) at columns C and D (Table 4). Average infiltration rates within rows 5 and 8 (mean range=26.2-26.3 L/m$^2$/min) were significantly lower than those in rows 2 and 11 (avg. range=44.5-48.4 L/m$^2$/min)(Table 5; Fig.6).

The amount of debris and sand vacuumed on the first day after 20 months from installation of the pervious concrete was 8,845 g (avg.=2,211.25 g/row over 260 days). On day 360 (Dec 26, 2013), a total of 1,842.72 g (avg.=460.7 g/row over 52 days) had been vacuumed from the pavement after the initial vacuuming on November 4, 2013. This resulted in an average daily accumulation per area per day rate of 0.4 g/m$^2$/day for the 260-day period (total 243.3 g/m$^2$), and an average daily accumulation per area per day rate of 0.97 g/m$^2$/day (50.7 g/m$^2$) for the 52-day period. Total rainfall during November and December, 2013 were 77.7 and 155 mm, respectively (Table 6).

## DISCUSSION

Infiltration rate increased steadily from 22.8-44.1 L/m$^2$/min from November 4 through December 30, 2013 (56 days), a 93% increase in infiltration rate after vacuuming over the period. However, when compared to the initial infiltration rate before vacuuming at the start of the study, infiltration rate increased only 43.6% (cf. 30.7 and 44.1 L/m$^2$/min). Both increases in infiltration rate are consistent with the findings of Mata (2010), Bean et al. (2007), Chopra et al. (2010) and others who found that vacuuming increased infiltration rate in pervious pavements. However, immediately after vacuuming, average infiltration rates (avg.= 22.8 and 36.3 L/m$^2$/min) were lower than those (avg.=30.7 and 41.3 L/m$^2$/min) before vacuuming. This is contrary to the results of Bean et al. (2007) who reported that infiltration rates increased immediately after vacuuming. We hypothesize that materials from deeper crevices of the lower profile of the pervious concrete were drawn upwards during vacuuming, essentially clogging the pores in the upper portion of the pervious concrete, and thus impeding infiltration. Clogging allowed seepage to occur underneath the seal between the bottom of the infiltrometer and the pervious concrete), and resulted in an effect described by Chanson (2009) where water seepage follows a flow net under and away from the infiltrometer and then up to the surface, similar to the commonly observed behavior at a dam (Fig. 7). This was evident by the extensive water plane flowing downhill on the surface of the pervious concrete away from the infiltrometer. Over the 56-day period, however, infiltration rates increased, consistent with other studies that found that infiltration rate increased after vacuuming. This is probably related to the flushing of clogging materials by rains that occurred after vacuuming dates as infiltration rates continued to increase over time (Table 6).

Infiltration rates on the leading edge (column A) of the pervious concrete area receiving runoff from the adjacent impervious asphalt surface were significantly lower than those furthest away from the leading edge (columns C and D)(Table 4). These findings are consistent with Al-

Rubaei et al. (2015) and Brown and Borst (2014) who reported clogging of the leading edge of pervious pavement where infiltration is affected by more sediment input from impervious pavement. Similarly, average infiltration rates (44.5-48.4 L/$m^2$/min) in rows 2 and 11 were significantly greater than those (26.2-26.3 L/$m^2$/min) in the middle of the pervious concrete area (i.e., rows 5 and 8). This is probably related to differences in uneven distribution of pervious concrete material during construction. Row 11 was the most distant area from surface runoff streaming off the impervious asphalt and primarily entering the center areas (rows 5 and 8) of the pervious concrete parking area.

The daily rate of debris/sediment accumulation (0.97g/$m^2$/day) for the 52-day period was over twice that (0.4 g/$m^2$/day) for the 260 day-period, assuming similar conditions and rates of vehicle tire abrasion throughout the year. However, this difference may be related to the transport time of material moving from the pervious concrete to rock reservoir sub-layers during longer periods of time. This is consistent with the findings of Welker et al. (2013) and Mata (2010) who reported that sediment is transported and stored in water storage layers of rock underlying pervious concrete.

We recommend that pervious concrete should not be regularly vacuumed monthly or as needed as recommended by Kresge (2010). Even if the pervious concrete is not vacuumed, we determined that water still infiltrates as was noted by Lucke and Beecham (2011), and the more frequent vacuuming plan proposed by Kresge (2010) would be costly. For example, Terhell et al. (2015) indicated annual vacuuming costs for a 0.5 acre pervious parking lot is $400. Our recommendation is consistent with conclusions of Shackel (2010) who reported that frequent maintenance of pervious surfaces (three or more times per year) are often unnecessary. We propose that annual or semiannual vacuuming of pervious concrete is adequate for the pervious concete parking area at the museum, a facility located in the mid-Atlantic region. This approach is consistent with site specific considerations discussed by Mullaney and Lucke (2013).

One variable that could not be controlled in these experiments was the porosity of the pervious concrete. Wanielista and Chopra (2007) and Chopra et al. (2010) indicated that the mixture and pouring of pervious concrete can affect infiltration. If the mixture and pours are not consistent, then there can be a greater density of concrete with fewer pores in some areas when compared to other areas where the concrete mixture is drier, resulting in variation in porosity and subsequently, infiltration rates. We recommend that infiltration tests be conducted immediately after the pervious concrete has cured to characterize average baseline infiltration rates for different areas of the pervious concrete as part of a post-construction protocol. An examination of collected cores of concrete taken at random from pervious concrete pavements could help determine where sand and debris particles are distributed before and after vacuuming, and is recommended for future research. Additionally, as the goal of pervious concrete is to promote infiltration rather than runoff, tests should be conducted to determine the infiltration rate limitations of pervious concrete during heavy and extended duration rain events..

## ACKNOWLEDGEMENTS

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**Table 1**. Results of correlation analyses of day, column, row, infiltration rate ($L/m^2/hr$), and air temperature (C) for pervious concrete studies at the Science Museum of Virginia parking lot section from November 4- December 30, 2013. An asterisk (*) indicates significance at p=0.05.

| | Day | Column | Row | Infiltration Rate | Air Temp. |
|---|---|---|---|---|---|
| Day | 1.00 | 0.00 | 0.00 | 0.3145 | -0.428 |
| | | 1.00 | 1.00 | 0.0007* | <0.0001* |
| Column | | 1.00 | 0.00 | 0.3050 | 0.00 |
| | | | 1.00 | 0.0011* | 1.00 |
| Row | | | 1.00 | -0.1917 | 0.00 |
| | | | | 0.0429* | 1.00 |
| Infiltration Rate | | | | 1.00 | -0.1338 |
| | | | | | 0.1597 |
| Air Temp. | | | | | 1.00 |

**Table 2**. Results of Duncan's multiple range test for average infiltration rates ($L/m^2/min$) before and after vacuuming of the pervious concrete parking area at the Science Museum of Virginia from November 4-December 26, 2013. Underscored means do not differ at p=0.05.

| Vacuum | Before | After | Before | After |
|---|---|---|---|---|
| Date | Nov.4 | Nov.4 | Dec. 21 | Dec. 26 |
| Day | 308 | 308.1 | 355 | 360 |
| Average | 30.7 | 22.8 | 41.3 | 36.3 |
| F=3.72 | | | | |
| p=0.0160 | | | | |

**Table 3**. Results of Duncan's multiple range test for average infiltration rates ($L/m^2/min$) at test locations in the pervious concrete parking area at the Science Museum of Virginia from November 4-December 30 2013. Underscored means do not differ at p=0.05.

| Date | Nov. 4 | Nov. 4 | Dec. 15 | Dec. 26 | Dec. 30 |
|---|---|---|---|---|---|
| Day | 308.1 | 308 | 328 | 355 | 364 |
| Average | 22.8 | 30.7 | 37.3 | 41.3 | 44.1 |

F=3.10
p=0.02

**Table 4**. Results of Duncan's multiple range test for average infiltration rates ($L/m^2/min$) by column in the pervious concrete parking area at the Science Museum of Virginia from November 4-December 30 2013. Underscored means do not differ at p=0.05.

| Column | A | B | C | D |
|---|---|---|---|---|
| Avg. infiltration | 28.1 | 30.7 | 42.4 | 44.2 |

F=3.60

**Table 5**. Results of Duncan's multiple range test for average infiltration rates ($L/m^2/min$) by row in the pervious concrete parking area at the Science Museum of Virginia from November 4-December 30 2013. Underscored means do not differ at p=0.05.

| Row | 8 | 5 | 11 | 2 |
|---|---|---|---|---|
| Average infiltration | 26.2 | 26.3 | 44.5 | 48.4 |

F=8.99
p<0.0001

**Table 6.** Rainfall (mm) at Richmond International Airport from November 4-December 29, 2013.

| Date | Rainfall (mm) |
|---|---|
| 11/4/2013 | Vacuuming |
| 11/7/2013 | 1.78 |
| 11/15/2013 | 0.51 |
| 11/16/2013 | 6.86 |
| 11/17/2013 | 1.52 |
| 11/18/2013 | 1.52 |
| 11/26/2013 | 33.27 |
| 11/27/2013 | 32.26 |
| Total Nov. | 77.72 |
| | |
| | |
| 12/4/2013 | 1.524 |
| 12/5/2013 | 1.27 |
| 12/7/2013 | 9.144 |
| 12/8/2013 | 24.638 |
| 12/9/2013 | 9.398 |
| 12/10/2013 | 6.096 |
| 12/14/2013 | 24.892 |
| 12/17/2013 | 11.684 |
| 12/21/2013 | Vacuuming |
| 12/22/2013 | 17.018 |
| 12/23/2013 | 15.24 |
| 12/29/2013 | 34.29 |
| Total Dec. | 155.194 |

**Figure 1**. Pervious concrete parking area sampled at the Science Museum of Virginia from November 4-December 30, 2013.

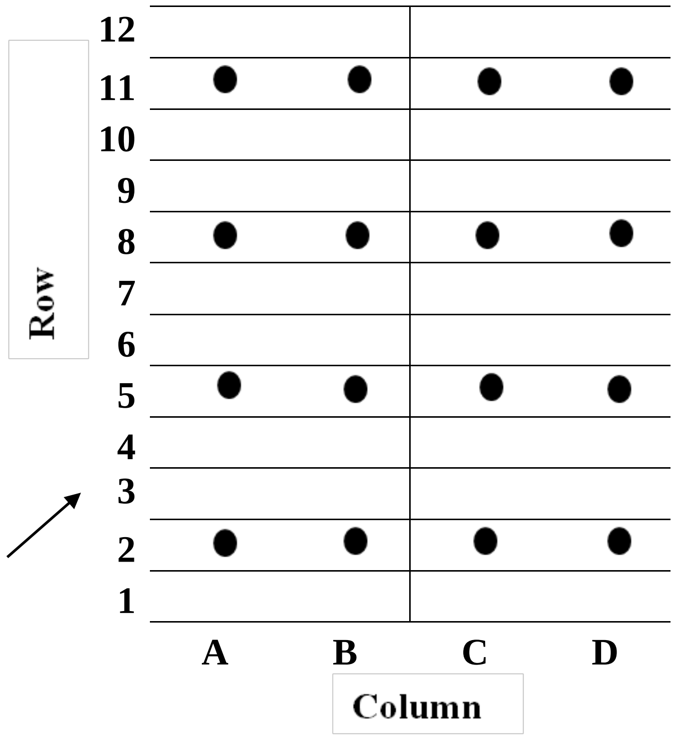
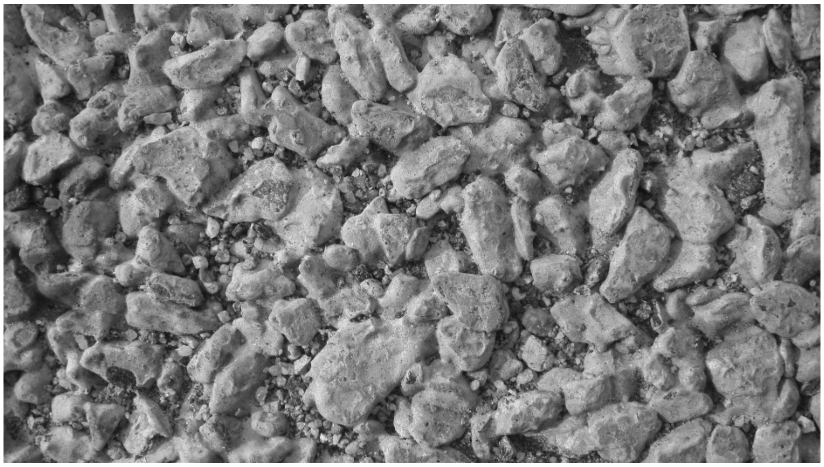



**Figure 2.** Illustration of infiltration testing sites (●) by column and row in the pervious concrete parking lot at the Science Museum of Virginia from November 4-December 30, 2013. Arrow indicates drainage direction. Not drawn to scale.

A.



B.

**Figure 3**. Un-vacuumed (A) and vacuumed (B) areas of pervious concrete in the parking lot at the Science Museum of Virginia in Richmond, VA on November 4, 2013.

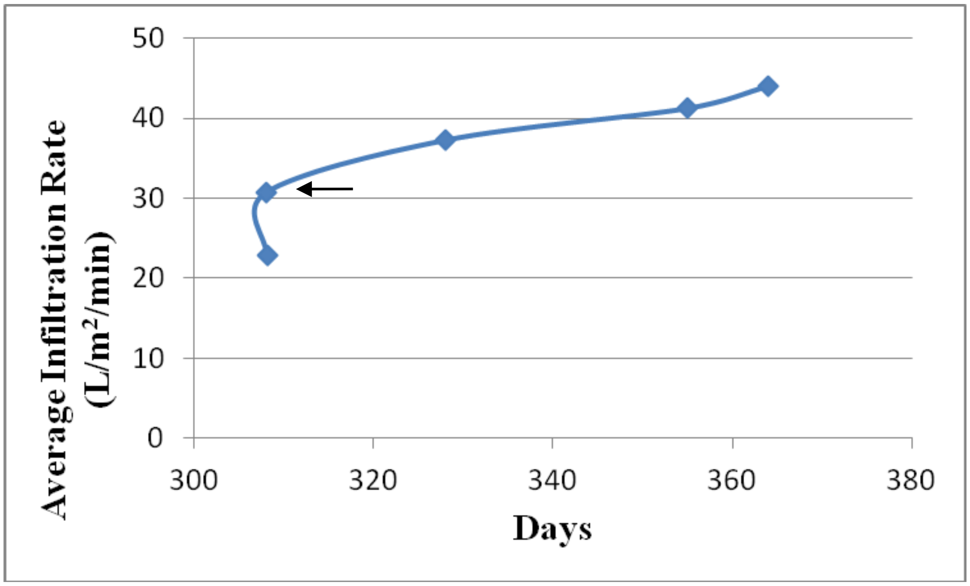



**Figure 4.** Average infiltration rate (L/m$^2$/min) by day at testing sites in the pervious concrete parking lot at the Science Museum of Virginia from November 4-December 30, 2013. Arrow indicates initial un-vacuumed infiltration rate.

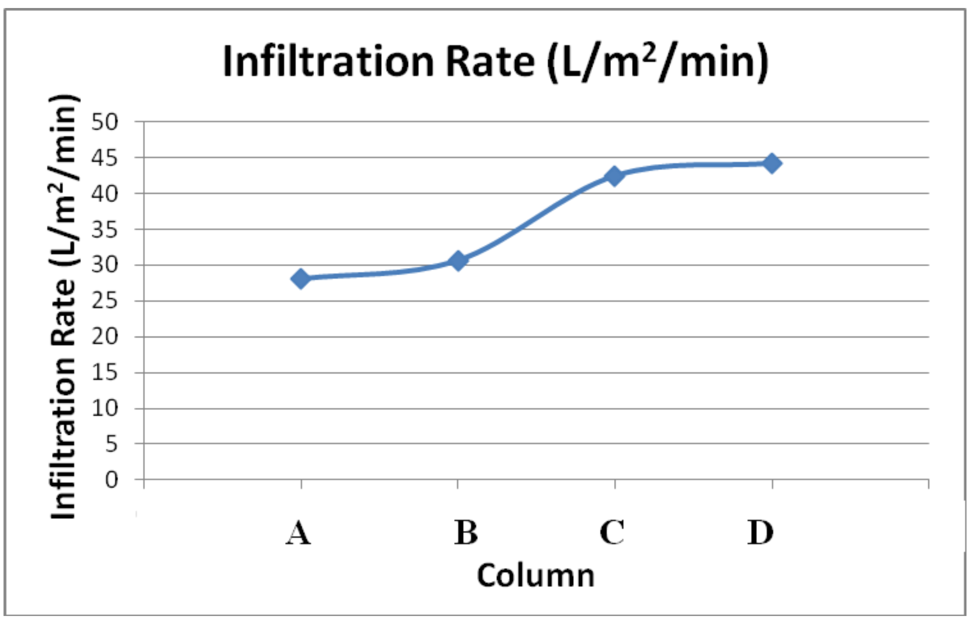



**Figure 5.** Average infiltration rate (L/m$^2$/min) by column in the pervious concrete parking lot at the Science Museum of Virginia from November 4-December 30, 2013.

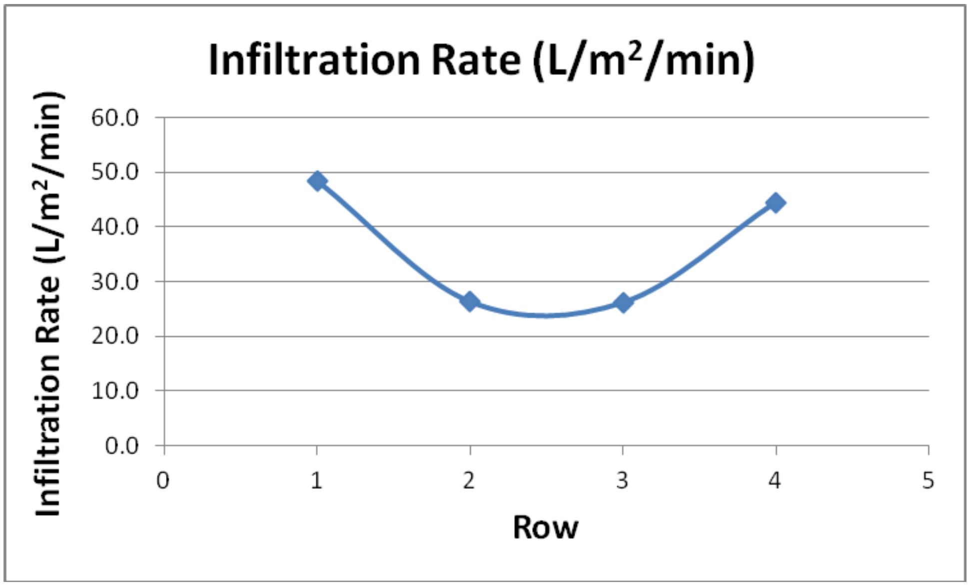



**Figure 6.** Average infiltration rate (L/m$^2$/min) by row in the pervious concrete parking lot at the Science Museum of Virginia from November 4-December 30, 2013.

**Figure 7.** Extensive water plane flowing downhill on the surface of the pervious concrete away from the infiltrometer immediately after vacuum cleaning of pervious concrete at the Science Museum of Virginia on November 4, 2013.