

Changes in the filtration rate of a novel stormwater harvesting system: impacts of clogging and moisture content

Evolution de la capacité d'infiltration d'un nouveau système de récupération des eaux pluviales : influence du colmatage et du taux d'humidité

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RÉSUMÉ

Cet article s'intéresse au colmatage dans de nouveaux systèmes de filtration à haute capacité hydraulique pour le traitement des rejets urbains de temps de pluie, développés en Australie. Cette technologie se compose d'un revêtement poreux reposant sur un filtre construit à partir de matériaux artificiels. L'un de ces systèmes a été installé dans une école primaire de Melbourne, afin de collecter et traiter les eaux de ruissellement des surfaces imperméables et les réutiliser pour l'irrigation des terrains de sport adjacents et comme source d'eau non-potable (pour les chasses d'eau). La capacité hydraulique du système a fait l'objet d'un suivi régulier pendant six mois : d'une part, par la mesure du débit sortant (relevés à intervalles d'une minute) et, d'autre part, au moyen de tests de filtration in-situ. Les deux méthodes ont montré une réduction du taux de filtration au cours de l'étude, passant d'environ 3000mm/h à 1000mm/h. Cependant, cette tendance n'était pas constante. Les données prélevées ainsi que les tests de filtration in-situ ont aussi montré un accroissement du taux de filtration au cours du temps, alors qu'une perte d'efficacité hydraulique était attendue. Bien que l'accumulation de sédiments au sein du système ait été identifiée comme facteur principal influençant le taux de filtration, les antécédents de périodes sèches avaient un impact considérable sur les filtres colmatés. Suivant une légère amélioration de la capacité hydraulique après une période de sécheresse prolongée, cette dernière diminuait à nouveau lorsque le volume collecté au cours des 48h précédentes augmentait. Pour l'ensemble du système, l'étude a démontré que le taux de filtration augmentait de manière exponentielle avec la distance par rapport à l'entrée. Une légère baisse en milieu de section suggère un dépôt élevé de sédiments favorisant le colmatage.

ABSTRACT

This paper addresses the clogging of novel high flow stormwater filters, developed in Australia. This technology consists of a porous pavement on top of engineered filter media. A system was installed in a primary school in Melbourne for the harvesting of stormwater for toilet flushing and the irrigation of a sports oval. The hydraulic performance of the system was monitored over six months via two methods: (1) using the flow rate at the outflow (monitored continuously at 1 min intervals), and (2) discrete field filtration tests. Both methods displayed similar trends over the study period with filtration rates decreasing from around 3000mm/hr to just over 1000mm/hr. However this trend was not uniform. Both the event data and field tests also showed occasional increases in filtration rate with time, when a decrease would be expected. Whilst the increase in sediment load was generally found to be the main influence on filtration rate, for clogged filters there was also a significant influence of antecedent dry weather. Filtration rates recovered slightly after a prolonged dry period and decreased again with an increase in runoff received in the previous 48 hours. There was also a general exponential increase in filtration rate with distance from the inlet of the system. A slight decrease toward the middle section of the filter suggests that this section received a higher percentage of the finer sediment that causes clogging.

KEYWORDS

Stormwater, porous pavement, clogging, filtration, stormwater harvesting

1 INTRODUCTION

Urban stormwater runoff, while often a problem, can also be seen as a largely untapped resource. The negative effects of increased frequency and magnitude of peak flows, and the reduced water quality in urban runoff on receiving waters are well known and include problems such as erosion of stream channels and increased pollutant loads (Paul & Meyer, 2001; Leopold, 1968; Novotny & Olem, 1994). At the same time, climate change is increasing the risk of extreme storm events (Hergel et al, 2004; Tebaldi et al., 2006) and thus the risk of flooding. Stormwater harvesting can help to reduce the increasing pressure on the stormwater system and alleviate some of the detrimental effects on receiving waters, as well as provide a valuable source of water. In Australia and many other countries, water resources are being stretched; approximately one-third of the world's people live in countries with at least moderate water stress and every year more than five million people die on account of poor water quality (DEH, 2004; UNESCO, 2003). As the world's urban population continues to increase, a reduction in potable water demand by harvesting and reusing treated stormwater can be a part of the solution. Utilising urban stormwater is attractive because it is generated close to where it is needed and, notably, the amount of stormwater discharged annually in all large cities in Australia is approximately the same, or greater than, the entire annual water demand of these cities (PMSEIC, 2007).

Stormwater harvesting technologies suitable for use in space constrained urban environments remain a limiting factor in this practice being more widespread (Yong et al, 2008). However, a new technology, named *enviss*TM, has recently been developed that has the potential to overcome this constraint. It is a modular technology (Figure 1) that consists of the following;

1. A trafficable porous pavement grate that removes gross pollutants and could be used a part of a path, car park or light trafficable road;
2. A replaceable sediment trap that removes the bulk of the sediment;
3. A filter that removes finer sediment and dissolved pollutants;
4. A drainage layer at the bottom to prevent filter media migration and outlet clogging; and
5. A box that contains the above and is used for the collection of treated water.

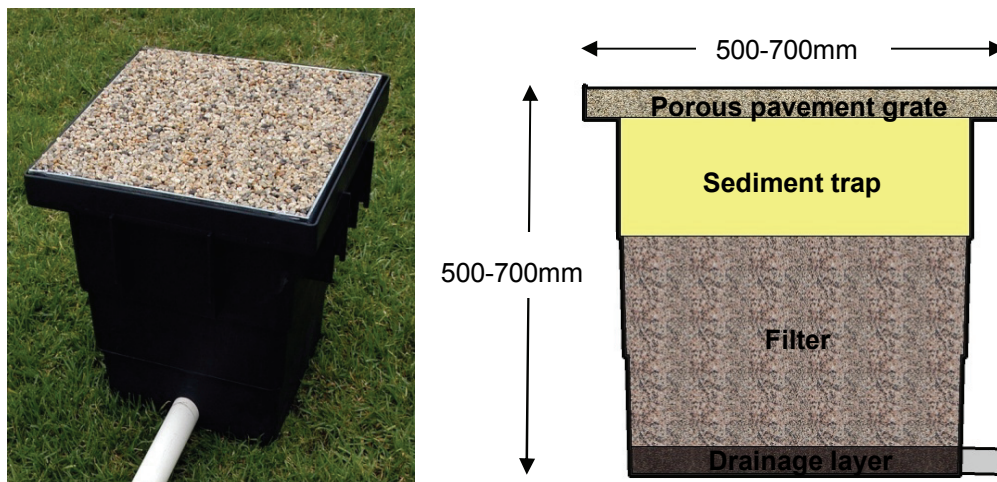


Figure 1: The *enviss*TM stormwater treatment module. Exact size depends on model.

The hydraulic performance of the system is controlled by the granular based filter that has a high initial filtration rate - often greater than 3000mm/hr, but sometimes varies to as low as 2000mm/hr due to the natural variability of the filtration media. The sediment trap is designed to protect the underlying filter from premature clogging by removing most of the sediment and be replaced between one and two times per year, depending on the catchment's properties.

Like all filtration systems, the rate at which the stormwater flows through the filter, as well as the area of the filter and the ponding depth, determine the amount of water which is treated. Maintaining the design filtration rate is thus very important if the filter is to perform optimally. Studies by Lindsey et al. (1992), Schueler et al. (1992) and Le Coustumer et al. (2008), have found that 31%, over 50% and 40% of the biofilters (another common stormwater treatment filter) tested were considered to be clogged, leading to more frequent overflows and therefore, a decrease in treatment capacity. Clogging, and the rate at which it occurs, needs to be understood so that stormwater treatment filters can be designed and maintained appropriately and can therefore, function effectively.

This paper aims to characterise the clogging of a porous pavement stormwater treatment system built at Syndal South Primary School in Melbourne, Australia. The change in filtration rate over time and the spacial variation will be investigated, along with the variations within these trends.

2 METHOD

2.1 Treatment system and site description

The enviss™ treatment system was installed at the Syndal South Primary School for harvesting of stormwater for toilet flushing and irrigation of the school sports grounds.

Runoff from a 5000m³ catchment area consisting of roofs and paved areas is treated by this system. The total filter area is 9.6m³, or 0.2% of the catchment area, and is made up of sixty treatment modules or pits (Figure 2 and Figure 3). These are arranged in two rows of thirty pits with the inlet at one end. At a design filtration rate of 2000mm/hr (conservative estimate) a filter this size is able to treat 80% of flows expected from the catchment. This system has been operational since October 27th 2008.



Figure 2: The stormwater treatment system at Syndal South Primary School.

Treated water is conveyed to underground storage tanks with a capacity of 140m³ and is used within the school for irrigation and toilet flushing, potentially saving the school 1000m³ of potable water annually.

2.2 Monitoring of the hydraulic performance

The filtration rate of the system as a whole was calculated using two methods:

1. *Analysis of the continuously monitored flow rates and rainfall data* – the rainfall data was analysed for large events which would theoretically cause the system to overflow, thus allowing an estimate to be made of the system's overall filtration rate using the monitored flow rates; and,
2. *Field trials* – water was constantly poured through a number of the pits installed at the site, maintaining a constant head over several hours, and the calculated flow rate was used to estimate the filtration rate of the system.

2.2.1 Continuous flow measurements

Flow rate out of the system (i.e. inflows into the tanks), was continuously measured from January to July 2009. A magnetic flow meter (magflow) was used to record the flow rate from the system every minute. Rainfall data (6 minute), from Melbourne Water's Notting Hill gauging station (2.8km south-east of the site) was used.

During wet weather, the filtration rate of the system could be calculated if the event was intense enough to cause the system to overflow, therefore making the filtration rate of the filter equal to the flow rate at the outlet divided by the filter's surface area.

So, when the system is overflowing,

$$\text{infiltration rate (mm/hr)} = \frac{\text{flowrate (L/sec)}}{\text{surface area of filter (m}^2\text{)}} * 60 * 60$$

As no level was recorded to determine whether the system was overflowing, this needed to be determined using rainfall intensity data. The following assumptions/criteria were made:

1. 0.5mm of rainfall was needed to fall on the catchment to create runoff (this value is typically used for roofs or paved areas in rainfall runoff modelling).
2. The void space ratio of the filter was conservatively estimated at 0.5, and with an area of 9.6m² and a depth of 0.45m² the voids in the filter occupy 2.16m³. Another 0.96m³ (or 0.1m depth) can pond above the filter, so another 0.6mm of rainfall is needed to "fill" the filter.
3. Based on the initial filtration rate of 4000mm/hr (calculated in the laboratory), a maximum of 4000L or 0.8mm of rainfall (across the impervious catchment area) could be treated in a 6 minute period. After the field tests in April, a new filtration rate of 2000mm/hr was calculated, reducing the maximum amount that could be treated in a 6 minute period to 2000L or 0.4mm.

Therefore, for the events prior to April 2009, if the rainfall intensity was greater than 1.3mm in 6 minutes (or 2.1mm in 12 minutes, 2.9mm in 18 minutes, etc.) after an initial 0.5mm had wetted the catchment, it could be assumed that the filter was at capacity and the outflow rate was at its maximum. For events after April 2009 the rainfall intensity needed was 1.0mm in 6 minutes, (or 1.4mm in 12 minutes, 1.8mm in 18 minutes, etc.), to reach the filter's capacity. If these criteria were met, then the monitored outflow data was used to determine the maximum outflow rate from the filter. A six minute average was used to estimate this maximum rate, and was then converted to a filtration rate [mm/hr] by using the filter area [9.6m²]. This average was used so that the influence of small (1 minute) spikes in the flow data was reduced.

2.2.2 Field filtration measurements

The field measurements of filtration rate were carried out each fortnight in April and May 2009. They involved individual measurements of the filtration rate of 13 of the 60 pits at various distances from the inlet. Figure 3 shows the modules (cells) that have been measured.

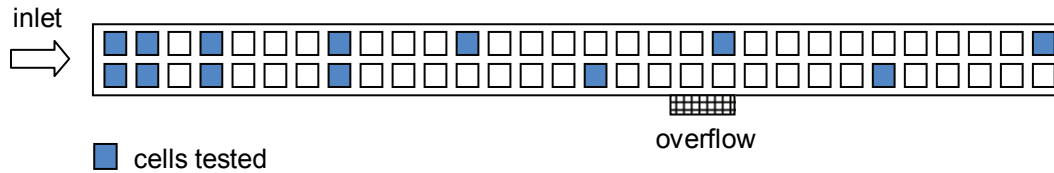


Figure 3: A schematic of the treatment system and the pits tested.

Water was applied to each of the tests pits over 4-5 hours. Maintaining a constant ponding depth, the inflow rate was measured using a bucket and stop watch at least 3 times and up to 6 times and the average taken. As not every pit was tested, the flow rate of an untested pit was assumed to be the same as that of the closest pit tested. This weighted average of the pit tests was used to get an overall filtration rate of the system.

3 RESULTS AND DISCUSSION

3.1 The peak outflow reduction with time

A clear reduction in peak outflow from the treatment system is seen over the period monitored (Figure 4). In these hydrographs, monitored 1 month apart (during very wet period), the rainfall intensities are approximately equal, indicating that it is very likely that the decrease is due to a reduction in the filtration capacity of the filter.

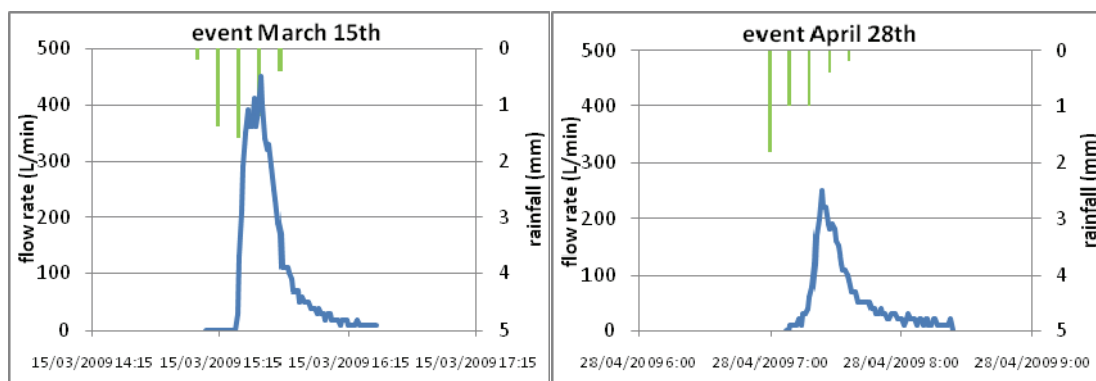


Figure 4: Hydrographs and rainfall of 2 events

3.2 Degradation of filtration rate over time

Figure 5 shows the filtration rate as a function of the load (measured in mm rainfall) that the system has received.

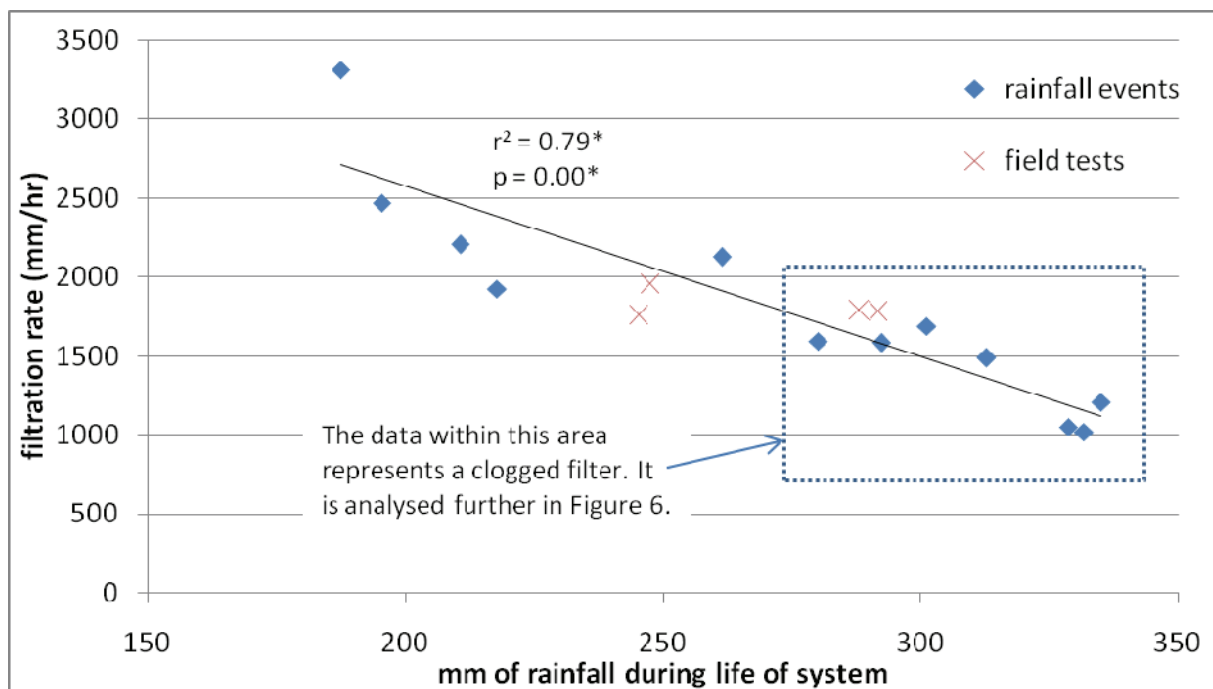


Figure 5: Change in filtration rate as load (measured in mm of rainfall) increases.

*The r^2 and p values were calculated using both the rainfall events and the field tests combined.

As the system receives more runoff which includes more pollutants and sediment, the filtration rate decreases due to the clogging of the filter media. This trend ($p = 0.00$) is observed for both the filtration rates calculated using rainfall events, and those calculated in the field trials. For example, for the two events in Figure 4, there was almost 100mm of rainfall between them and the effect of the associated sediment on their filtration capacity can be clearly seen.

Interestingly, the decrease in filtration rate is not uniform. There are events where the filtration rate increases from the previous event despite the increased sediment load it has received. Possible explanations include uncertainties in the data collected, as well as not correctly identifying which events should be used to calculate the filtration rate. However, there are similar patterns in the filtration rates calculated using the field tests. A conservative approach to the selection of events considered to have overflowed (reaching maximum outflow) was taken to prevent including events which may not have overflowed. Also, using 6 minute averages of the peak flow used to calculate filtration rates smoothed out some of the uncertainties in the data collected.

3.3 Relationship between antecedent dry weather and filtration rate

The filtration rates from the last 7 rainfall events and the last 2 field tests are highlighted in the box in Figure 5. Here, the data is more scattered, and the decrease in filtration rate caused by clogging is less pronounced. The impact of drying may be used as an attempt to explain this variation.

Hatt et al. (2008) found that when the hydraulic conductivity of fine media filters had decreased due to clogging, they increased again or “recovered” after a preceding dry period. It was suggested that the accumulated sediments forming the clogging layer, contain clay and organic material that swells when wet (reducing the filtration capacity), and shrink and crack when dry (increasing filtration).

The relationship between the wetness of the clogged layer, measured in volume of water treated by the system within the last 48 hours, and filtration rate during this period, can be seen in Figure 6. Although not the perfect measure, the flow treated within the last 48 hours was chosen as the x-axis

because it was the most accurately recorded variable that indicated how much of the clogged layer in the filter was wet, which, in turn, has the greatest influence on the filtration rate. Parameters such as antecedent dry weather period (ADWP), while important, did not have as strong a relationship with filtration rate because it did not indicate how much of the filter was wet. For example, a small event shortly before the filtration rate was measured would result in a short ADWP but might not have a significant effect on the filtration rate as only a small proportion of the filter had been wet by the inflow.

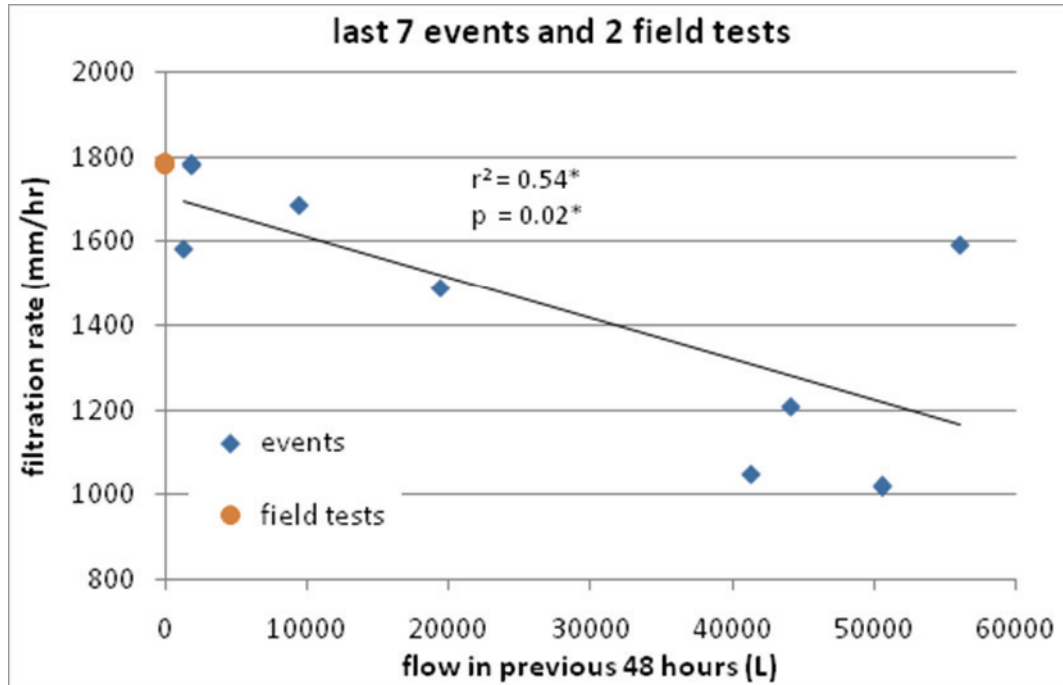


Figure 6: Relationship between filtration rate and volume of runoff system has received within last 48 hours for the events within detail box in figure 5.

*The r^2 and p values were calculated using both the rainfall events and the field tests combined.

The graph shows that filtration rate increases with a decrease of treated volume (i.e. more dry conditions). This trend can be seen in both the filtration rates calculated from events and field trials. This relationship, while not as strong as the one between filtration rate and load, may be an important factor as the system clogs.

3.4 Degradation of filtration rate along the system

The inlet to the system is located at one end of the 2 rows of treatment pits (as shown in Figure 3). As a result, for many events, the sediment will be deposited in the pits closest to the inlet while those at the other end will receive far less sediment. Figure 7 presents data from four filtration tests and clearly demonstrates this. The pits located more than 15 meters from the inlet did not show considerable clogging even after 6 months of operation.

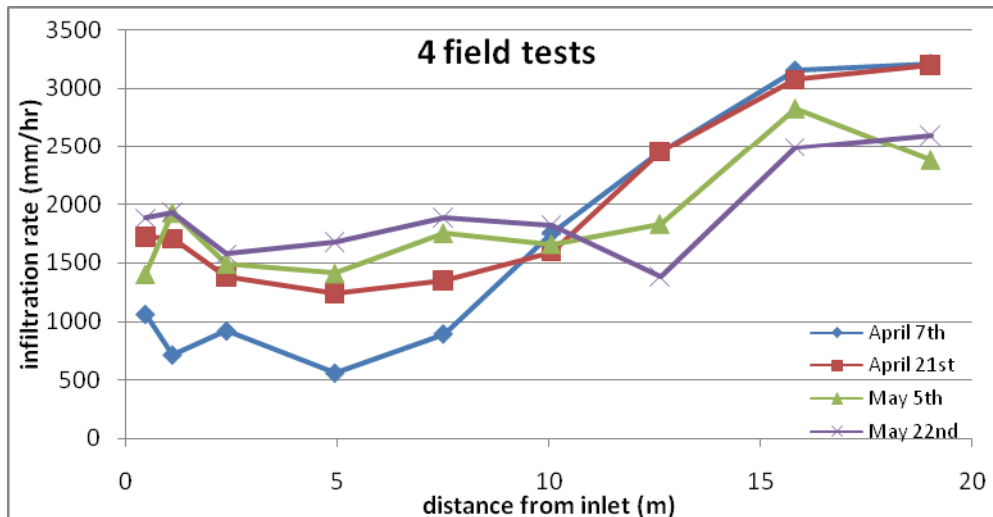


Figure 7: Filtration rate measured along the filter system during two field tests

It might be expected that the filtration rate increases linearly with distance from the inlet. However, the filtration rate does not increase within 13 meters of the inlet. In fact there is even a notable decrease in filtration rates up to this point, before it increases again. It is suspected that these pits between 3 and 13m receive less sediment than those closest to the inlet (<3m), but are actually receiving a higher percentage of finer sediment than the first few rows (because this sediment has a lower settling velocity and hence is transported further down the system). This finer sediment is often considered to cause the majority of clogging in filtration systems (Siriwardene et al, 2007). Exactly where fine sediment (and, in fact, all sediment) is deposited depends on the size of the event. Large events will result in sediment making it all the way to the pits furthest from the inlet while small events will result in sediment deposition only occurring closer to the inlet.

There were several events (with a rainfall total of 40mm including two large/ intense events) recorded between the two field tests in April 2009 and the two field tests completed in May 2009. This appears to have reduced in the filtration capacity of the pits furthest from the inlet, especially those around 13 meters from the inlet where there was previously a significant increase. Again, this may be due to the fine sediment particles settling out in the pits beyond 13 meters from the inlet, especially from the two large/ intense events.

It is also worth noting that there was zero flow recorded in the previous 48 hours for the last three field tests, while the first field test on April 7th had recorded 28,000L in the previous 48 hours. For this first test, the filtration rate within 8 meters of the inlet (an area most likely to be clogged and wetted by the previous inflow), is lower than that observed in subsequent tests even though these pits received additional inflow and sediment load after this. This effect is not observed for unclogged pits further from the inlet. This may be further evidence of the clogged layer decreasing the filtration capacity as a result of previous wetting.

This observation may have implications for the design of these systems. For example, a linear system receiving diffuse sheet inflow would receive more frequent, distributed inflows. This would result in wetting of all the pits throughout the system, compared to the system in this study, where only the pits nearest the inlet would be frequently wet. As a result, systems with such a diffuse inflow may have a reduced filtration rate more often due to the wetting of the clogged layer, whereas the overall filtrate rate for systems like the one studied here may be less affected by small events, because they require large events to wet all the pits.

4 CONCLUSIONS

The filtration rate for the porous pavement treatment system studied was assessed during the first half of 2009. The filtration rates were calculated using continuously monitored outflows from the system and rainfall data, as well as direct field measurements of the filtration rate.

It was found that the overall filtration rate of the system declined over time, as it received more runoff and, therefore, more sediment due to clogging. However, this decline was not always consistent, with filtration rates demonstrating occasional increases with time. It was suggested that some of this variation, especially when the filtration rate had already decreased to lower levels, could be explained by the wetness of the clogged layer. Filtration rates were shown to increase slightly after a prolonged dry period while rainfall within the last 48 hours reduced the filtration capacity. The clogging was also more prominent near the inlet, as expected, with parts of the system furthest from the inlet staying almost unaffected after 6 months of being in operation. However, an anomaly was noticed in that the part of the system nearest the inlet was less clogged than areas 5 meters downstream from the inlet. This was attributed to fine sediment (responsible for clogging), being deposited in this part of the system.

Finally, it should be noted that there are likely to be many factors influencing the filtration rates of these filters and this paper only discusses those highlighted by the data collected in this study. As the field monitoring of the system continues, other influences may emerge. Monitoring will also involve data collection on treatment performance, focusing on the impact of clogging on pollutant removal.

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