An investigation into the differences in infiltration capacity between porous and permeable concrete pavers installed on sloping sub-catchments

Analyse des différences de capacité d'infiltration entre des pavés de béton poreux et perméables installés sur des sous-bassins versants en pente

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RÉSUMÉ

Cet article décrit des essais expérimentaux des taux d'infiltration sur un lit de pavage perméable en pente à l'échelle prototype de 18m2. Des pavés poreux et des pavés imperméables en béton avec joints d'infiltration étroits ont été testés sur ce lit, avec des pentes de 5 à 10 %. S'il y a des différences entre les performances sur les deux pentes différentes, les effets les plus notables sont l'évolution de la répartition spatiale de l'eau infiltrée avec les systèmes de pavés poreux, par rapport aux pavés de béton imperméables. Pour tous les débits, l'eau appliquée voyage beaucoup plus loin sur la surface des pavés poreux, alors que pour les pavés de béton imperméables, la plus grande partie de l'eau s'infiltre dans les interstices entre les premiers pavés. La prochaine étape de cette recherche est d'intégrer un simulateur de pluie sur toute la chaussée, et ensuite des sédiments à l'entrée afin d'examiner l'effet de colmatage sur les chaussées perméables en pente.

ABSTRACT

This paper describes experimental testing of infiltration rates on a prototype scale sloping permeable pavement bed of size $18m^2$. Both porous pavers and impermeable concrete pavers with narrow infiltration joints were tested on this bed at slopes of 5 and 10%. While there were differences in performance at the two different slopes, the most noticeable effects were the change in spatial distribution patterns of infiltrated water for the porous paver systems, compared with the impermeable concrete pavers. For all flowrates, the applied water travelled much further down the surface of the porous pavers while for the impermeable concrete pavers, most of the water infiltrated into the gaps between the first few pavers. The next stage for this research is to include a rainfall simulator over the entire pavement bed and then to introduce sediment to the inflow in order to examine the effect of clogging on sloping pervious pavements.

KEYWORDS

Infiltration, Permeable pavement, Porous paver, Water sensitive urban design

1 INTRODUCTION

Pervious pavements can be used in water sensitive urban design (WSUD) as an alternative to conventional impervious hard surfaces, such as roads, carparks, footpaths and pedestrian areas. Use of these pavements can have several stormwater management and environmental benefits (CIRIA, 2001; Lucke & Beecham, 2011a). Pervious pavements allow stormwater to infiltrate through the pavement surface where it is filtered through the various layers. The filtered stormwater is then either harvested for later reuse or released slowly into the underlying soil (Yong et al., 2008; Scholz and Grabowiecki, 2009) or stormwater drainage system.

There are four general types of pervious pavements, namely (impermeable) concrete pavers with infiltration joints, porous concrete pavers with infiltration joints, surfaces made of continuous porous concrete or porous asphalt, and concrete or plastic grid pavers (Pratt et al., 2002; Ferguson, 2005; Lucke & Beecham, 2011a). The concrete block paver types are generally referred to as permeable interlocking concrete pavements (PICP). PICPs are designed so that there is a significant open space between the pavers to allow water to infiltrate into the pavement structure. This is either achieved by way of specially designed paving shapes that include small apertures in the paving surface or with slots or spacing lugs that are cast into the perimeter of the pavers (Castro et al., 2007). The joints between PICP pavers are not filled with sand or other binders as they are with conventional pavers. However they are often filled with fine aggregate to allow infiltration through the joints. A typical PICP paving bed cross section is shown in Figure 1.

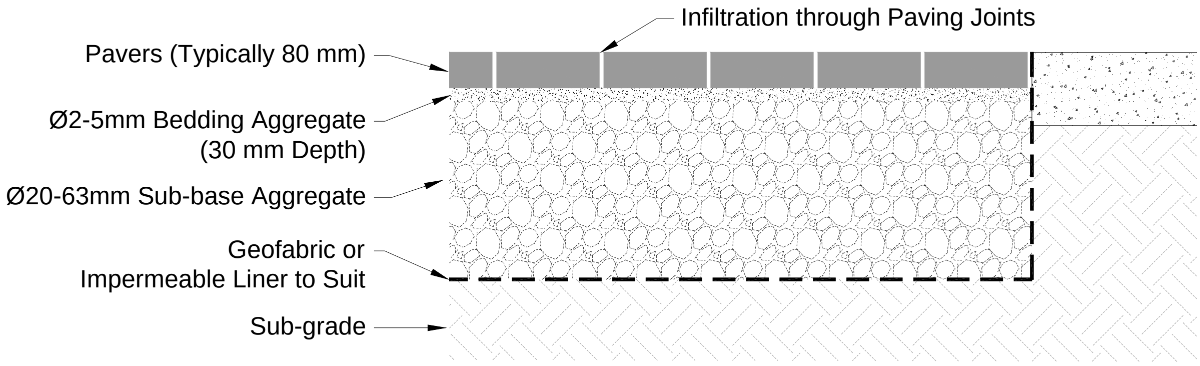

Figure 1. Typical PICP Paving Bed Cross Section

Even for pervious pavement systems not designed for harvesting and reuse, the storage capacity in the basecourse layers can be designed to intercept significant rainfall events. Pervious pavements can therefore reduce runoff volumes and discharge rates from paved surfaces (Fassman & Blackbourne, 2010; Siriwardene et al., 2007; Yong and Deletic, 2012). These volume reductions result in a significantly reduced risk of downstream flooding. Pervious pavements also provide considerable water quality improvements by treating and in some cases retaining stormwater pollutants (Pratt et al., 1989; Dierkes et al., 2005; Yong et al., 2008).

While the significant water quality improvement benefits and flood mitigation potential of installing pervious pavements in appropriate areas are well known and understood, there is still some uncertainty as to how they perform on sloping sub-catchments. Most pervious pavement design guidelines recommend a maximum slope of 5% for the installation of these systems (CASQA, 2003: Melbourne Water, 2011). The reasons for this recommendation are rarely explained and do not appear to be substantiated by any experimental evidence. The most common concern appears to be that at grades greater than 5%, the volume of stormwater that runs off the pavement may exceed the volume that infiltrates into the pavement (Bean at al., 2007; Jayasuria et al., 2005).

There is very limited information available to assist designers of pervious pavement systems to be installed on sloping sub-catchments and the perceived limitation of a maximum 5% slope has undoubtedly restricted more widespread adoption of these effective WSUD systems. Lucke and Beecham (2011b) demonstrated satisfactory infiltration performance of one type of PICP on slopes of up to 20% and suggested that typical PICP design guidelines that recommend a maximum pavement slope of 5% are probably overly conservative.

A number of studies have compared the infiltration and pollution removal rates of different impermeable and porous PICP types (Dierkes et al., 2002; Borgwardt, 2006; Collins et al., 2008; Yong et al., 2010). The results of these studies have generally demonstrated satisfactory infiltration performance of both PICP types. However, the studies also showed that clogging significantly reduces the infiltration performance over time. To date, no studies have been done to investigate the differences in infiltration performance of impermeable and porous PICPs installed on grade.

This paper presents the experimental results of a study undertaken to investigate and compare the infiltration performance of impermeable and porous PICPs installed on sloping sub-catchments. A full-scale, variable-slope, experimental rig was constructed at the University of South Australia and this was used to evaluate changes in the infiltration performance of the two PICP types installed on grades of 5% and 10%. The results of this study will be of practical value to engineers and designers of permeable pavement systems.

2 METHODS

2.1 Experimental Testing Rig

In order to quantify the effects that slope has on the infiltration performance of PICP systems, a full-scale, variable-slope, experimental test rig was constructed. The test rig was designed with similar dimensions to a single residential car space and is shown in Figure 2. The length and breadth of the test rig paving area are approximately 6 m x 3 m respectively and this provided a potential infiltration area of approximately 18 m^2.

The test rig pavement structure is of a similar design to that shown in Figure 1. However, the depth of the basecourse aggregate on the rig is 100 mm. The aggregate is held in place by 25 mm square galvanised mesh laid on top of 75 mm diameter steel joists suspended between the two outer support beams of the tilting paving bed (Figure 2). This allows water to completely infiltrate through the pavement structure.

Figure 2. Full-Scale, Variable-Slope, Experimental Test Rig

The test rig was designed with the capability to test the infiltration performance of PICPs on slopes of between 0% and 30%. The slope is adjusted via two long threaded screws either side of the rig and a spirit level is used to ensure the rig was level. An electromagnetic flowmeter is installed within the water supply line to accurately measure total flowrates onto the rig. The rig can supply steady flowrates of up to 30 L/s to the pavement surface through a supply tank and weir arrangement at the upstream end of the pavement (Figure 2). Roof sheeting with 200 mm pan spacing is suspended underneath the test rig to collect the water infiltrating through the pavement (Figure 3a). There are 24 individual pans along the length of the rig. Pan No. 1 is at the downstream end of the rig and pan No. 24 is at the upstream end (Figure 2). The fall of the roof sheeting directs all infiltrated water into a gutter running along the front of the rig (Figure 3b). This allows accurate measurement of the individual flowrates from each of the roof sheeting pans. The longitudinal infiltration profile of the PICP surface could therefore be calculated in 200 mm wide strips of pavement.

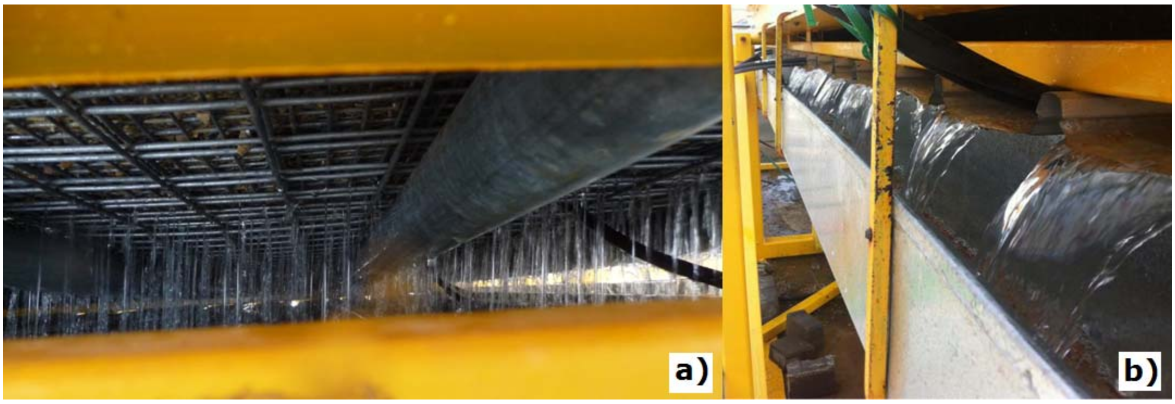

Figure 3. Water Infiltrating through Pavement Structure (a) into Drainage Gutter (b)

A number of methods were trialled to accurately measure the flowrates from the individual roof sheeting pans. Initially, a pipe drainage system with an electromagnetic flowmeter (EMF) was tested. A spout was used that fit around the perimeter of each pan and directed the water over the gutter and into a funnel in the top of the pipe system (Figure 4a). The EMF measurement system was finally rejected after numerous test results showed inconsistencies and errors. At high flowrates the funnel arrangement struggled to capture all of the water flowing from the pans and this caused spillage and inaccurate flow measurements. It was also observed that when the flow rate from the pans was very low, the EMF often registered a zero flow rate. This system was also time consuming to set up and difficult to move along the gutter to measure the next pans. Due to these problems an improved flow measurement system was developed.

Ultimately, while labour-intensive, the volumetric method was shown to be the most accurate, reliable and repeatable method of measuring the flowrates. The spout was simply directed into a large bucket of known volume (Figure 4b) and the time taken to fill the bucket was recorded. The average flowrate from each pan was then calculated based on these filling times.

Figure 4. (a) Measuring Individual Pan Flowrates using EMF; (b) Volumetric Method

Both the impermeable and porous concrete pavers tested in this study were rectangular in shape (approx. 230 mm long x 120 mm wide x 80 mm deep) and both were laid in a herringbone pattern on the deck of the test rig (Figure 5a) This is the pattern generally recommended by paving manufacturers to ensure the greatest structural strength. Both paver types have slots or nibs cast into the sides and ends to allow infiltration through the joint openings. The total area of the impermeable paver joints was slightly greater than the porous paver joint area. These openings were also filled with 2 to 3 mm bedding aggregate (Figure 5b).

Figure 5. (a) Herringbone Pattern Installation, (b) Bedding Aggregate in Paving Joints

2.2 Testing

In order to obtain a general understanding of the hydraulic sheet flow conditions and the infiltration performance that occurred with the two different paver types, eight different flowrates were tested at two different slopes. The flowrates and slopes tested in the study are shown in Table 1.

Table 1 – Infiltration Tests Performed on the Two Paver Types

Paver Type	Slopes Tested	Flowrates Tested (Q L/s)
Impermeable PICP	5% and 10%	4.2, 3.3, 2.8, 2.2, 1.9, 1.7, 1.4 and 1.1.
Porous PICP	5% and 10%	4.2, 3.3, 2.8, 2.2, 1.9, 1.7, 1.4 and 1.1.

These flowrates equate to a contributing area of four times that of the experimental rig receiving runoff from storms varying in intensity between a 2 year and a 100 year average recurrence interval event (for Adelaide).

The testing methodology was as follows:

1. The impermeable PICPs were first laid in a herringbone pattern on the deck of the testing rig;
2. Once the pavers were laid the required slope was set using the slope adjustment screws and a surveying level;
3. The first test flowrate was set using the inflow valve. The test rig flow was left running for five minutes before any testing commenced to ensure equilibrium conditions were met;
4. The sheet flow conditions on the pavement surface was then observed and recorded;
5. The bypass spout was then fit to each pan and the flowrate from each pan was then measured in turn (Figure 4);
6. The flowrate to the rig was then adjusted and the next set of measurements were undertaken;
7. Once all tests were undertaken on the impermeable PICPs, the porous PICPs were then laid and the tests were repeated for this paver type.

3 RESULTS AND DISCUSSION

Figures 6 and 7 show the infiltration testing results for the two different PICP types when the test rig slope was set at 5%. Figures 8 and 9 show the infiltration testing results of the two different PICP types when the test rig slope was set at 10%. It should be noted that Pan 1 is at the upstream end and Pan 10 is at the downstream end.

It is clear from Figure 6 to 9 that there is a significant difference in the infiltration behaviour of the two paver types. For both the 5% slope and the 10% slopes tested, the water flowed much further down the porous PICP surface than it did for the impermeable PICP surface.

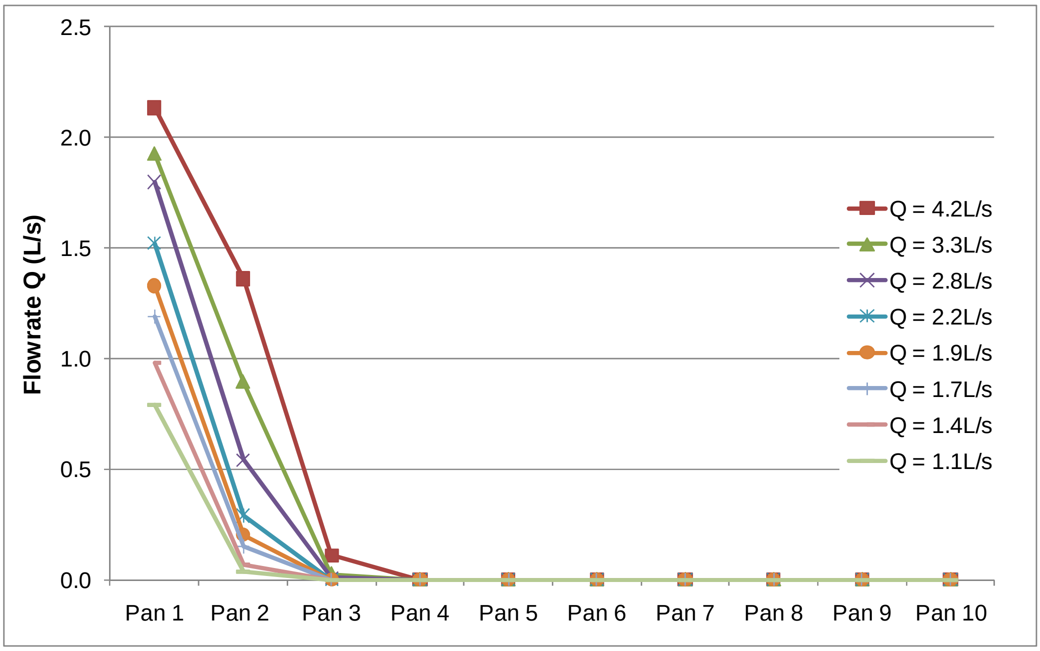

Figure 6. Impervious Concrete Block Pavers 5% Slope

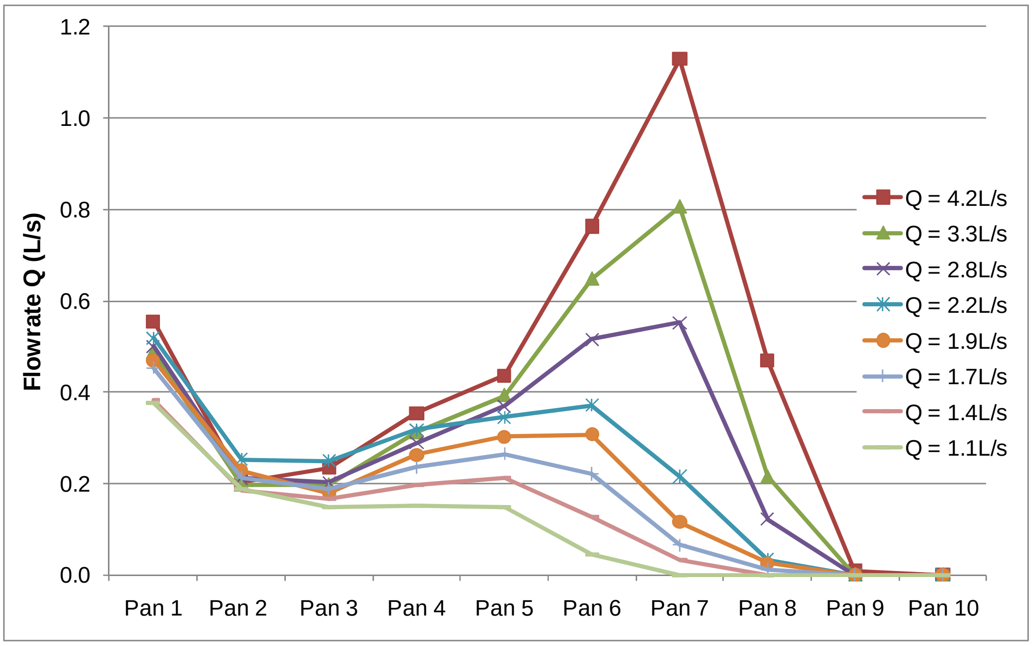

Figure 7. Porous Concrete Block Pavers 5% Slope

It can be seen from Figure 6 that for all test rig inflow rates up to and including Q = 3.3L/s, at the 5% slope, all of the infiltrated water was collected in Pans 1 and 2. Pan 1 outflow was significantly greater than Pan 2 in all cases. Pan 3 had a significant outflow only when the test rig inflow was Q = 4.2L/s. This means that the majority of the water infiltrated into the impermeable pavement surface within the first 0.4m of the total 6m pavement surface length.

In contrast, Figure 7 clearly shows that the water moved much further down the surface of the porous PICPs at all flowrates, with outflows generated in Pans 1 to 8 at the 5% slope. After an initial spike at Pan 1, the greatest outflow rates were generally observed from Pans 6 and 7. This meant that the water ran along the porous PICP surface for a distance of between 1.2m and 1.4 m before it infiltrated through the surface into the pans below.

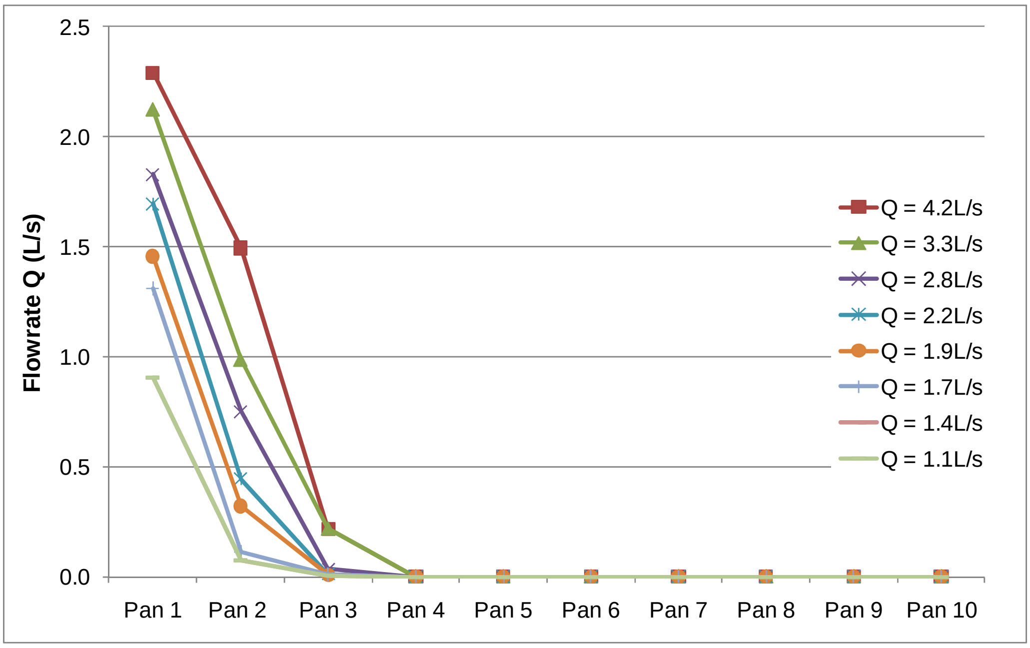

Figure 8. Impervious Concrete Block Pavers 10% Slope

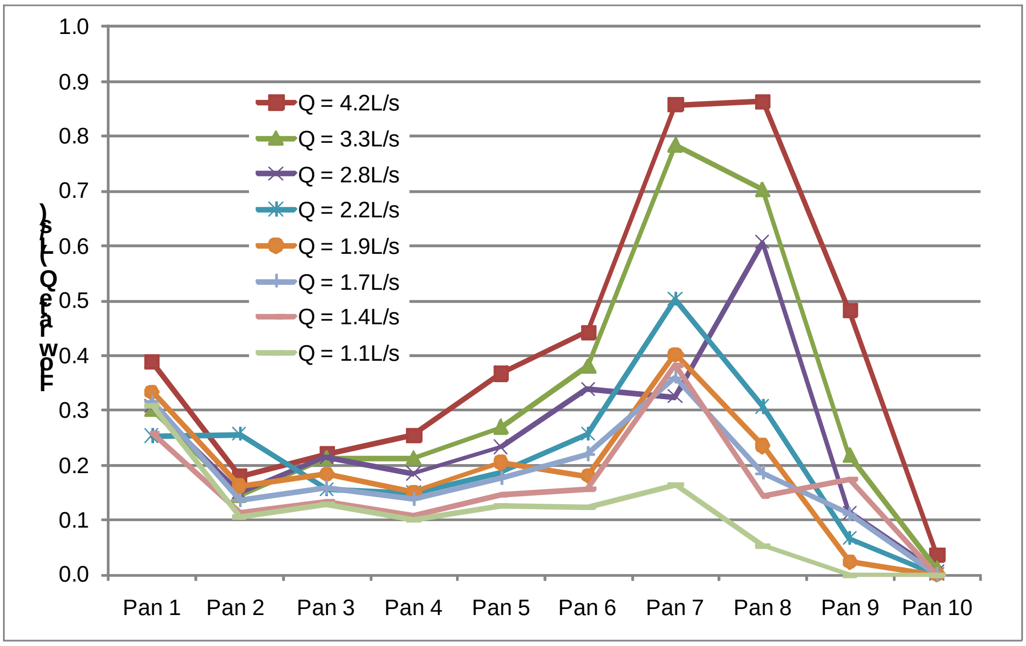

Figure 9. Porous Concrete Block Pavers 10% Slope

Figure 8 shows that for all test rig inflow rates up to and including Q = 2.8L/s, at the 10% slope, all of the infiltrated water was collected in Pans 1 and 2. Pan 1 outflow was significantly greater than Pan 2 in all cases. Pan 3 had a significant outflow only when the test rig inflow was greater than Q = 3.3L/s. This means that at the 10% slope the majority of the water infiltrated into the impermeable pavement surface within the first 0.4 m of the total 6 m pavement surface length.

Figure 9 clearly shows that the water moved much further down the surface of the porous PICPs at all flowrates at the 10% slope. Figure 9 shows the outflows from Pan 1 were less at the 10% slope than was the case for the 5% slope (shown in Figure 7). However, Figure 9 clearly shows that greater volumes of water moved further down the rig at 10% slope and there were higher outflows from Pan 8 at this slope. This meant that the majority of the water ran along the porous PICP surface for a distance of between 1.4m and 1.6 m before it infiltrated through the surface into the pans below.

The results of this research are interesting. Although the total area of the impermeable paver joints was slightly greater than the porous paver joint area, it was still anticipated that the porous paver infiltration rate would be greater. Figures 6 to 9 clearly demonstrate that this is not the case. The reasons for these results have not yet been confirmed. However, further testing is currently underway to identify the causes of the unexpected infiltration behaviour of the porous PICPs.

Although the research results presented here are interesting and informative, it must be pointed out that both sets of testing were undertaken on brand new pavers. Numerous studies (Yong et al., 2008; Pezzaniti et al., 2009: Lucke and Beecham, 2011a: Yong and Deletic, 2012) have show that clogging significantly affects the infiltration performance of pervious pavements and this must be considered before any practical recommendations are drawn from the research results presented in this paper.

The next stage of this research project will investigate the effects of clogging on the infiltration performance of the two different pavement types installed on sloping sub-catchments. It is anticipated that the research into the infiltration performance will also be expanded to include other pervious pavements types.

4 CONCLUSION

This experimental investigation has compared the performance of two types of sloping pervious pavements, namely porous pavers and impermeable concrete pavers with narrow infiltration joints. These were tested at slopes of 5% and 10% for a range of runoff flows equating to design storms of average recurrence intervals varying from 2 to 100 years. The two pavement types displayed quite different infiltration behaviour at both slopes, with the runoff moving much further down the surface of the porous PICPs at all flowrates. The next stage for this research is to include a rainfall simulator over the entire pavement bed and then to introduce sediment to the inflow in order to examine the effect of clogging on sloping pervious pavements.

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