TECHNICAL BRIEF

Sustainable Technologies
EVALUATION PROGRAM

Low Impact Development

Permeable Pavements Maintenance

This study evaluates the capacity of two surface cleaning techniques applied before traditional vacuum sweeping to improve the effectiveness of permeable pavement maintenance. The research, conducted in collaboration with University of Toronto researchers, builds on previous studies at the Toronto and Region Conservation Authority's (TRCA) Kortright Centre permeable pavements research facility on the effectiveness of conventional vacuum sweeping of permeable pavements. While the earlier research showed conventional vacuum maintenance to have provided partial rehabilitation of lost surface infiltration capacity on the permeable interlocking concrete pavers (PICP), the post maintenance surface infiltration rates were much lower than their initial capacity shortly after installation, and some areas remained clogged. The pervious concrete pavement did not show any change following maintenance.

This finding prompted further investigations on the potential for pre-treatment prior to traditional vacuum cleaning using a power brush and pressure washer to help dislodge or loosen densely packed sediment within the pavement joints or pores, and thereby improve overall effectiveness of vacuum maintenance. Results for all treatments combined showed significant improvements in surface infiltration on PICP sections after maintenance, but as observed previously, pervious concrete did not show a significant improvement both with and without pre-treatment. On the PICPs, pressure washing was more effective than the power brush on the wide jointed (approximately 12% open area) permeable paver, but neither technique significantly improved surface infiltration on the narrow jointed (2-4 % open area) paver, likely due to the smaller open area and joint stabilizing aggregate. On a more severely clogged permeable pavement (approximately 12% open area) at the Earth Rangers property

Permeable pavements have been installed on several parking lots, sidewalks and roads throughout Ontario. Like any other stormwater management technology, the pavements need to be regularly maintained in order to operate effectively. As fine sediment and debris accumulates in the joints or pore openings, the capacity of the pavements to infiltrate water declines precipitously. Many older installations that were not maintained have become clogged with fine particles causing runoff to drain to the nearest outlet, rather than through the pavement structure as they were designed to do.

at Kortright, pressure washing was also shown to provide some benefit over vacuum sweeping alone.

Tests were also performed on younger PICPs (12% open space) at the Credit Valley Conservation's (CVC) head office in Mississauga using the same experimental design. Results showed that newer wide jointed pavements with higher pre-maintenance infiltration rates than those at Kortright showed better overall improvements with pre-treatment followed by vacuum cleaning, relative to the control where vacuum cleaning was done without pre-treatment. These findings highlight the importance of regular maintenance as a key factor contributing to the long term success of maintenance practices both with and without pre-treatment.

INTRODUCTION

The stormwater management performance and structural integrity of permeable pavements under various loading conditions have been well documented in previous studies, as has the ability of the pavements to rapidly infiltrate rainwater through the surface. However, the capacity of the pavements to maintain their installed infiltration capacity, and the efficacy of different maintenance methods used to restore infiltration performance has received less attention. This study documents how infiltration rates of three permeable pavements changed over time, and tests vacuum maintenance practices both with and without pre-treatment to better understand how these maintenance practices can be optimized both in terms of cost and overall effectiveness.

STUDY SITES

The primary study site is a parking lot located at TRCA's Kortright Centre in Vaughan, roughly 8 km north of Toronto. The research facility consists of four 230–233 m^2 pavement cells (Figure 1). Two cells are constructed with permeable interlocking concrete pavers (AquaPave® and Eco-Optiloc®, hereafter referred to as AP and EO), one cell is constructed with Hydromedia™ Pervious Concrete (PC) and one cell is constructed with traditional asphalt. The pervious concrete (PC) is estimated to have pore openings consisting of up to 30% of the total surface area. The EO pavement has wide joints (13-14 mm) between the pavers with roughly 12% open space by area and 1-9 mm jointing material. The AP has narrow joints (3-4 mm) with 2-4% open space, and joint stabilizer material ranging from 1 to 3 mm in size. Each permeable pavement cell is drained by a perforated pipe placed 500 mm below the surface at the interface between the open graded granular sub-base layer and the native soil. The asphalt cell is surface drained via a catchbasin in the center of the plot.

Infiltrated water collected from the 3 cells as well as runoff collected in the catchbasin is conveyed separately in sealed pipes to a downstream monitoring vault where automated samplers and flow meters are housed. The pavement cells are hydraulically separated by concrete curbs which extend down to the native soil to ensure the separation of runoff and infiltrated stormwater for each pavement type. Concrete pipe collars at cell boundaries prevent water movement along granular trenches surrounding pipes.

A second study site in Mississauga was also monitored in June 2016 by the Credit Valley Conservation and University of Toronto using the same experimental design to help assess how pavement pre-treatment maintenance practices function across a broader range of conditions. The parking lot was constructed with Unilock Eco-Optiloc® pavers and consisted of a primary parking lot area that received regular traffic (constructed in 2010), and a newer adjacent parking area (constructed in 2012) that was subject to less traffic.

Figure 1.Maintenance tests were conducted on three permeable pavements using three different methods. The three pavements were (from top to bottom) (i) Aqua-pave™ (4% open space); (ii) Eco-optiloc™ (12% open space), and (iii) hydromedia™ pervious concrete (approx. 30% open space). The three methods were (from top to bottom) (i) power brush + vacuum maintenance; (ii) pressure wash + vacuum maintenance, and (iii) vacuum maintenance only (control).

STUDY APPROACH

Surface infiltration rates of the permeable pavements were conducted using ASTM C 1701 and ASTM C1781M - 15, Standard Test Method for Surface Infiltration Rate for Permeable Unit Pavement Systems to assess changes in surface infiltration over time. The measurements were initiated in early June 2010 and were repeated during the spring (May/June) for the following three years. Approximately 18 measurements were conducted on each of the plots. The interlocking concrete permeable pavement (PICP) and pervious concrete plots were constructed in November 2009 and April 2010 respectively; hence the PICP plots were exposed to a longer period of sediment buildup than the PC pavement prior to the first surface infiltration measurement. Hence the first measurement on the PICPs is not representative of the expected rate immediately following installation.

In 2012, surface infiltration measurements were also conducted before and after vacuum maintenance to evaluate the effect of maintenance on surface permeability. The number of surface infiltration measurements for these tests was reduced from 18 to 12 in each of the before and after tests, which still provided a reasonable indication of changes in infiltration performance.

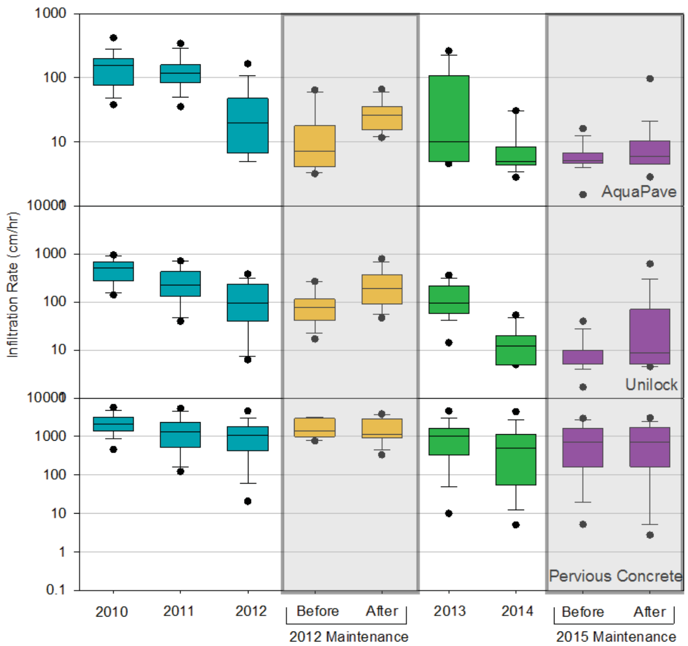

Figure 2.Box plots of surface infiltration rates from 2013 to 2015. Shaded areas show surface infiltration test results before and after maintenance.

In November 2015, a second set of experiments was conducted by TRCA, in collaboration with University of Toronto, using the same methods and materials to evaluate the effectiveness of pre-treatment methods. A power brush and pressure washer (Figure 3) were used to dislodge compacted fines in the pavement joints or pores prior to vacuum cleaning with an Elgin Whirlwind pure vacuum sweeper. For this purpose, each of the three pavement plots were divided into three equal sized sections – one for the two pre-treatment methods, and the third as a control (no treatment). Nine surface infiltration measurements were conducted on each section before and after cleaning, and again after vacuum maintenance. Results before and after were compared to evaluate effectiveness. Similar measurements were conducted on the 2010 and 2012 Mississauga PICPs, but pre and post maintenance surface infiltration tests were limited to 6 on each of the sections.

Maintenance tests were also conducted on an older Unilock eco-stone™ pavement on the Earth Ranger's parking lot at the Kortight Centre. This pavement was installed in 2003 and had undergone vacuum maintenance only once in 2012. Infiltration measurements in 2015 were conducted on two areas. One was pressure washed prior to vacuum sweeping, the other was only vacuum swept. The brusher wheel was not tested on this pavement.

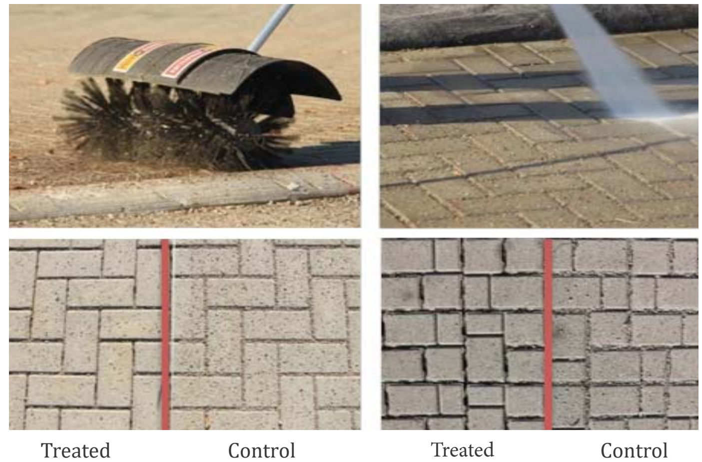

Figure 3.Appearance of pavements after power brushing on the Aquapave pavement (left) and pressure washing on the Eco-Optiloc pavement (right). Pretreatment helped to dislodge sediment and fines embedded in the joints near the surface.

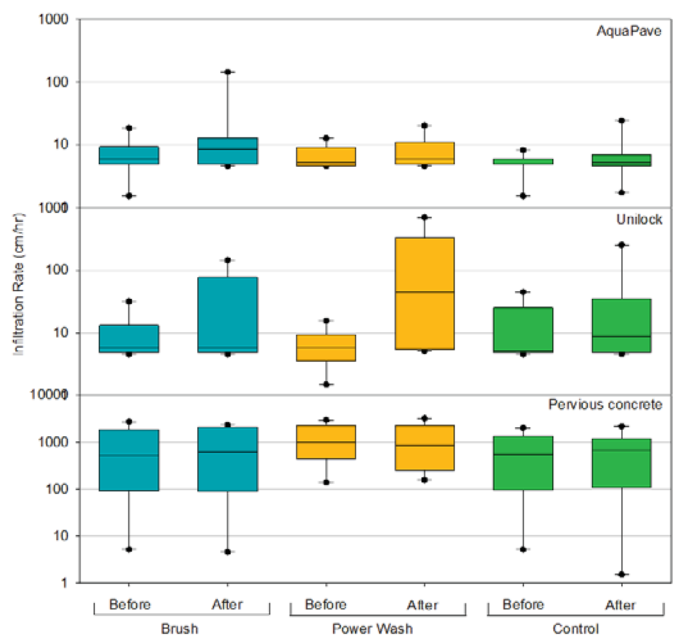

Figure 4.Box plots of surface infiltration rates before and after maintenance. From left to right, treatments were (i) power brush followed by vacuum maintenance; (ii) power wash followed by vacuum maintenance, and (iii) vacuum maintenance only.

FINDINGS

Infiltration testing over a five year period showed a rapid decline in surface infiltration during the first two years after installation and only modest improvements in surface infiltration on the permeable interlocking concrete pavements after vacuum maintenance. Vacuum sweeping did not significantly improve the surface infiltration rates on the pervious concrete, where initial and post installation surface infiltration rates were considerably higher (Figure 2). The surface infiltration tests prior to the test of pre-treatment techniques were conducted from 2010 to 2014. In the initial two years after installation, permeability of the narrow jointed pavement (Aquapave), the wide jointed pavement (Eco-Optiloc) and the pervious concrete (Hydromedia) declined by 87, 70 and 43%, respectively. After maintenance of the PICPs, there was a statistically

Table 1. Average/median infiltration rates, number of failed tests and number that improved by more than 20% for each of the test plots and pavements

Test area	Infiltration rates (cm/h) Average Pre	Average Post	Median Pre	Median Post	Number of failed tests Pre	Number of failed tests Post	Number that improved by more than 20%
AP - B	7	23	6	9	5	4	4
AP - PW	7	8	5	6	6	5	2
AP - CTL	5	7	6	5	8	7	2
EO - B	1	4	1	1	6	5	4
EO - PW	1	17	1	5	5	3	6
EO - CTL	1	4	1	1	5	4	3
PC - B	96	96	51	60	1	2	2
PC - PW	131	130	99	86	0	0	1
PC - CTL	72	73	53	66	1	1	2

significant ($p < 0.05$) increase in median surface infiltration rates from 20 to 94 cm/h on the narrow jointed PICP, and 26 to 187 cm/h on the wide jointed PICP. A reduction in median surface infiltration was noted for the pervious concrete, but the change was not statistically significant. In 2013, one year after maintenance, surface infiltration rates on all pavements showed similar rates to the year before maintenance (2012), but rates continued to decline to critical levels in the following year, signaling the need for repeat maintenance (Drake et al, 2012; Sehgal et al, 2018).

Pretreatment techniques helped remove clogging material within the upper one to two centimeters of the PICP joints. The absence of fines in the joints after pre-treatment was visibly obvious after vacuum maintenance (Figure 3) and was also evident from the large amount of sediment that was removed and remained on the surface of the pavers. However, these techniques were only effective in removing the material close to the surface. Sediment and fines more deeply embedded in the joints remained in place. Since these pavements had been in place for close to six years, the fines likely penetrated much deeper than one or two centimeters, although tests of clogging materials were not conducted. This may help to explain why the second maintenance cycle in 2015 was less effective than the initial maintenance in 2012 in the areas that did not undergo pre-treatment. It should be noted that the pervious concrete did not show any visible signs that clogging material had been removed after pre-treatment. Fines within the pervious concrete appeared to be more deeply embedded and less easily dislodged by surface treatments.

Results after vacuum cleaning showed no significant change in infiltration on the plots cleaned with the power brush, but noteable improvements in 44% of the areas of the Eco-Optiloc plot that was power washed. The pervious concrete plot showed no significant change for any of the treatments (Figure 6 and Table 1), providing further evidence that alternate methods are needed to restore permeability to poured pavement surfaces. These results are consistent with the earlier maintenance trials in showing that the narrow jointed paver with smaller stabilizing aggregate in the joints resists cleaning to a greater degree than the wide jointed paver. The wider jointed paver showed an increase in median infiltration from 7 cm/h before cleaning to 45 cm/h afterwards. However, as shown in Figure 6, the improvements were primarily limited to only four of the nine test areas. The drive lane showed lower permeability than the parking stalls, and these areas were more resistant to improvements through cleaning by all tested methods.

Figure 5. Pavement before maintenance and vacuum sweeper in action.

Pre-treatment on the more severely clogged and older eco-stone pavement showed modest improvements in 50% of the test areas, whereas vacuum cleaning alone showed no improvement both overall and within individual test areas (Figure 7 and Table 2). The power brush was not tested at this site. The increase in average infiltration rates rose from 7 cm/h before power washing and vacuum seeping to 80 cm/h afterwards. This result combined with the noted improvements in infiltration on the Eco-optiloc paver at the permeable pavements research facility suggest that power washing can be an effective measure in loosening and dislodging joints, thereby rendering vacuum maintenance somewhat more effective. However, the practice appears to work only on PICPs with larger joint openings or with drainage cells, as was the case with the Eco-stone product (see Figure 7). Both the Eco-Optiloc and Eco-stone products had similar open areas (approximately 12%).

Vacuum cleaning with and without pre-treatment on newer less clogged wide jointed Eco-Optiloc pavements at the Mississauga site showed better overall infiltration improvements compared to the older PICPs. Median

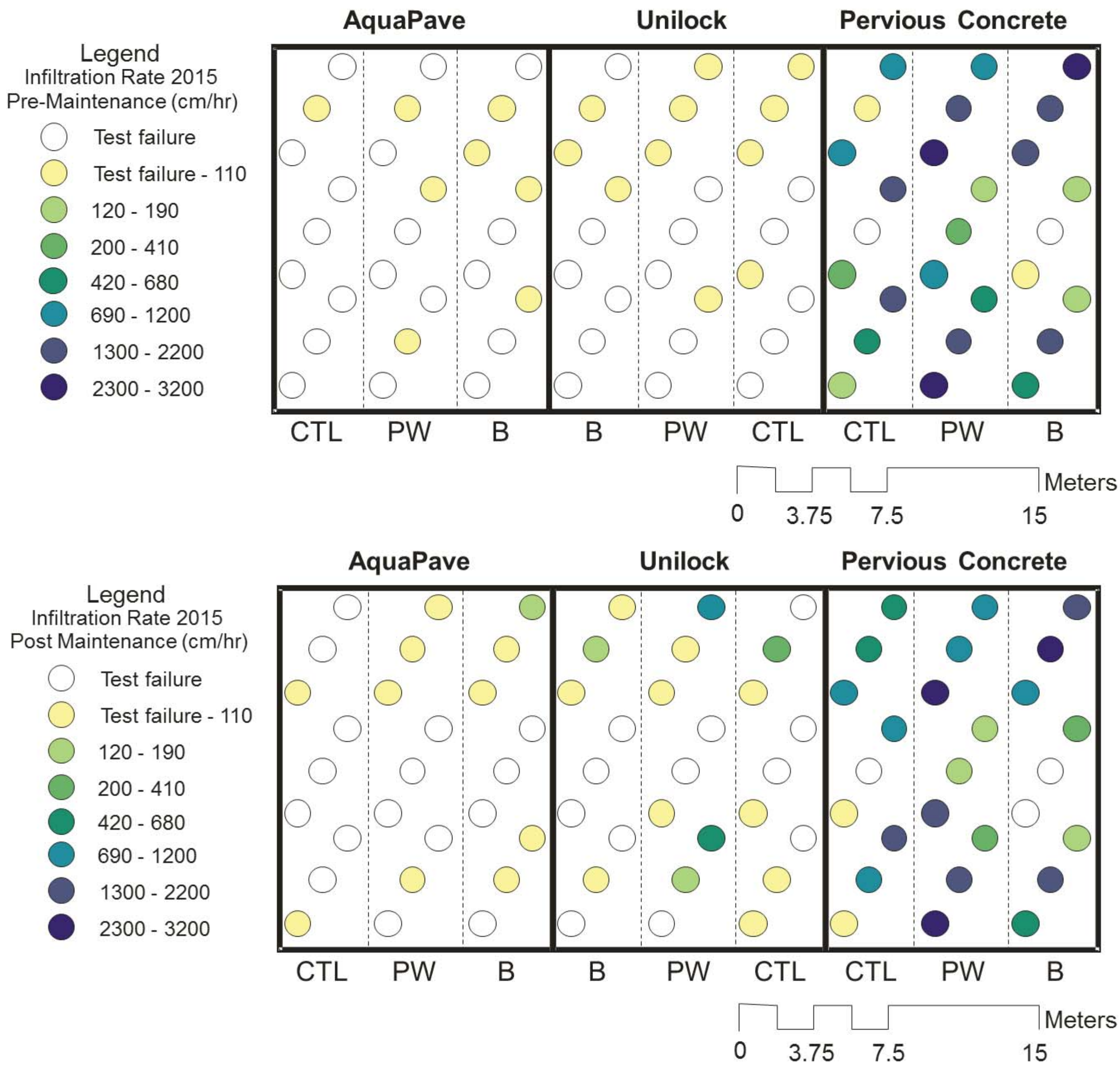

Figure 6.Spatial distribution of infiltration on the three pavements before (top) and after (bottom) maintenance. Note: CTL = vacuum maintenance only. PW = power wash plus vacuum maintenance. B = power brush plus vacuum maintenance. (Drake et al, 2012)

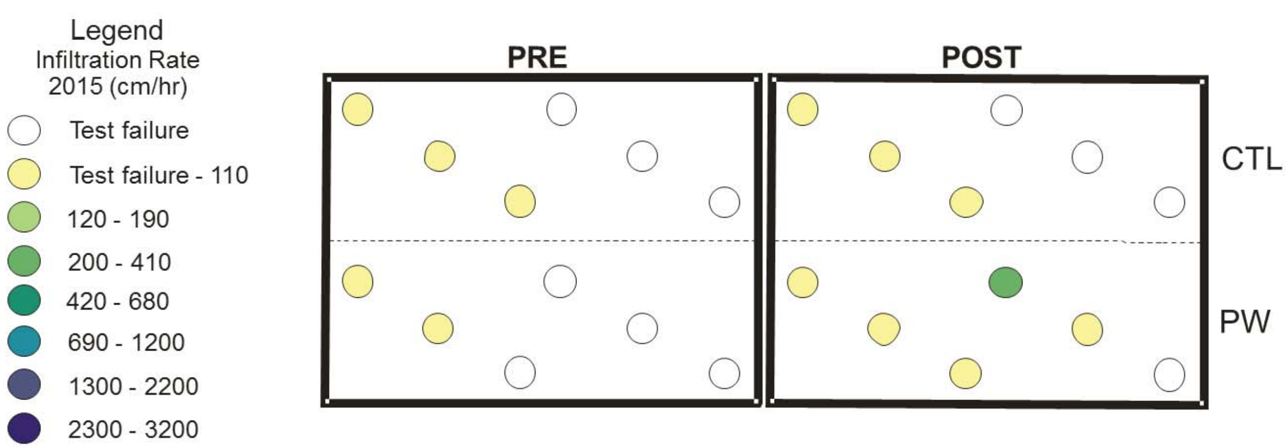

Figure 7.Spatial distribution of infiltration on the older and more severely clogged permeable pavement at Earth Rangers before and after maintenance. Picture shows pavement before maintenance and vacuum sweeper in action. Note: CTL = vacuum maintenance only. PW = power wash plus vacuum maintenance.

Table 2. Average/median infiltration rates, number of failed tests and number that impoved by more than 20% for each of the test plots on the older Unilock Eco-stone (ES) pavement

Test area	Infiltration rates (cm/h)				Number of failed tests		Number that improved by more than 20%
	Average		Median				
	Pre	Post	Pre	Post	Pre	Post	
ES - PW	1	7	1	3	4	1	5
AP - CTL	1	1	1	1	3	3	1

infiltration rates for all test areas combined at the Mississauga site increased from 47 to 619 cm/h on the pavement installed in 2010, and from 1606 to 2595 cm/h on the less used pavement installed in 2012. On the older pavement, sections that underwent pre-treatment did not infiltrate significantly better than the control after maintenance, but on the newer pavement, pre-treatment was found to provide a significant benefit (Sehgal et al, 2018). Although the TRCA and older of the two CVC pavements were of similar age at the time of testing, the CVC pavements showed better response to treatment despite median pre-treatment infiltration rates for all sections at both sites varying within a narrow range (50 to 70 cm/h). After maintenance the range of median infiltration rates was 90, 450 and 160 cm/h on the TRCA site, versus 180, 1290 and 620 cm/h at the CVC site. Vacuum sweeping after power washing pre-treatment showed the greatest change. The difference in response may be explained by differences in the clogging material size distribution or composition, the depth of clogging, or minor differences in cleaning technique.

CONCLUSIONS

Like any other stormwater practice, permeable pavements need to be maintained in order to function effectively. In this research, it was shown that the vacuum sweepers traditionally used to perform maintenance of the pavements are either not effective, as was the case for pervious concrete, or are able to restore surface infiltration to only a fraction of the initial rates, as was the case for the older PICPs. Where the maintenance practices exhibited improvements, these were shown to become less effective after each successive cleaning, likely due to deeper penetration of fine particles into the joint materials over time.

Pre-treament using a power brush and power washer were examined as a means of enhancing the effectiveness of vacuum maintenance. These appeared to be relatively effective in removing clogging debris near the surface, as evidenced from the large amount of sediment that was dislodged after using these techniques. However, tests before and after vacuum maintenance showed pre-treatment to provide only limited benefits, and these benefits were largely confined to the pavers with wider joint openings (i.e greater open area). These same wider joint pavers responded more effectively on the newer Mississauga pavements where the initial median surface infiltration of test plots was greater than 700 cm/h. The results showing degradation of cleaning effectiveness over time, and the improved efficacy of pre-treatment on newer, less clogged pavements highlights the importance of regular cleaning, even when the pavements appear to be infiltrating reasonably well. Regular preventative maintenance prevents fines from becoming densely packed within the joints while also helping to ensure that the clogging sediments and fines remain closer to the surface where they can be more effectively removed.

The pervious concrete tested in this study was still infiltrating rapidly overall, but some areas on the drive lane were shown to be clogged. This study has shown that traditional methods for maintaining PICPs are not effective on pervious concrete. Earlier trials at Kortright have indicated that a method involving simultaneous pressure washing and suction can be an effective cleaning technique, but this practice still needs further research, and the practical challenges of sourcing and disposing of water at remote sites needs to be addressed.

REFERENCES

Drake, J., Bradford, A., Van Seters, T. (2012). Evaluation of Permeable Pavements in Cold Climates – Kortright Centre, Vaughan. Sustainable Technologies Evaluation Program, Toronto and Region Conservation Authority.

Sehgal, K., Drake, J., Van Seters, T, Vander Linden, W.K., (2018). Improving Restorative Maintenance Practices for Mature Permeable Interlocking Concrete Pavements. Water. 2018, 10, 1588. Available at: https://www.mdpi.com/2073-4441/10/11/1588.

This communication has been prepared by the Toronto and Region Conservation Authority under the Sustainable Technologies Evaluation Program (STEP). Funding support was provided by Region of Peel, Region of York, City of Toronto, and the Government of Canada's Great Lakes Sustainability Fund. The contents of this technical brief do not necessarily represent the policies of the supporting agencies and funding does not indicate an endorsement of the contents.

Published 2018. Visit us at www.sustainabletechnologies.ca for more information on STEP's other Low Impact Development intiatives.

About STEP

The water component of the Sustainable Technologies Evaluation Program (STEP) is a partnership between Toronto and Region Conservation Authority, Credit Valley Conservation, and Lake Simcoe Region Conservation Authority. Contact us at STEP@trca.on.ca.

Toronto and Region Conservation Authority