13TH CANADIAN MASONRY SYMPOSIUM
HALIFAX, CANADA
JUNE 4TH – JUNE 7TH 2017

IMPROVING ON-SITE STORMWATER MANAGEMENT WITH PERMEABLE INTERLOCKING CONCRETE PAVEMENTS

Sehgal, Kirti[1] and Drake, Jennifer[2]

ABSTRACT

Urbanization and increased hardscape surfaces (walkways, parking lots and roadways) contribute to a range of environmental problems for urban streams and rivers including flooding, erosion, poor water quality and habitat degradation. Sustainable solutions are increasingly required by municipalities across Canada and United States as a means of providing on-site stormwater management. Masonry products like Permeable Interlocking Concrete Pavers (PICP) are a pioneer technology that offers a "green" alternative to traditional stormwater management and treatment by infiltrating stormwater directly to native soils. Much of Southern Ontario, however, has low permeability soils making it difficult to infiltrate stormwater. It has been suggested that stormwater infiltration to low permeability soils provided by a PICP systems may be substantially increased by temporarily detaining stormwater within the PICP reservoir after rain events. The excess stormwater can subsequently be discharged to receiving surface water systems by way of under drains after achieving the desired volume reductions. The University of Toronto is currently testing this hypothesis using the newly constructed PICP walkway located at the Canada Masonry Design Centre (CMDC), Mississauga, ON. This paper will evaluate the current state of literature and the construction challenges for small scale PICP installations in Ontario. It will also focus on the infiltration volumes achieved with and without temporary detention of stormwater within the PICP reservoir from summer and fall 2016. Results of this work will be used to develop best management practices for temporary stormwater detention for PICP systems over low permeability soils. By demonstrating the effectiveness of this operational practice, it may be possible for PICP systems to address the increasingly stringent on-site stormwater management criteria required by Canadian municipalities.

KEYWORDS: *infiltration, low permeability soils, masonry materials, permeable interlocking concrete pavements, stormwater management, sustainable hardscape*

[1] PhD Student, Dept. of Civil Engineering, University of Toronto, 35 St. George Street, Toronto, ON, Canada, M5S1A4; kirti.sehgal@mail.utoronto.ca

[2] Assistant Professor, Dept. of Civil Engineering, University of Toronto, 35 St. George Street, Toronto, ON, Canada, M5S1A4; jenn.drake@utoronto.ca

INTRODUCTION

Water resources have become an important economic, cultural and environmental component of our cities. Stormwater management systems have implications on our daily lives and all levels of politics, thus, requiring careful planning and design strategies. Traditionally, stormwater systems were developed for protection against flooding and were designed to get rid of any excess water from the property as quickly as possible. However, with rise in the frequency and severity of instances of flooding, public expectations from our stormwater systems have changed. According to the national disaster database [1], floods have been classified as the most frequent natural disaster in Canada with 241 instances between the years 1900 and 2005. This is almost five times as high as wildfire, the second most frequent disaster. A recent study by the Institute for Catastrophic Loss Reduction & Swiss Reinsurance Company Ltd cited that the most common cause of flooding in Ontario has been rain on snowmelt accounting for 47% of the total disasters [2]. The 'rain only' events contribute an additional 31% and ice jams contribute 17% [2]. According to the Insurance Bureau of Canada, the 2013 floods in downtown Calgary and Don Valley Parkway in Toronto caused insurance damages worth $1.72 billion and $465 million respectively [3]. Thus, floods have become frequent and increasing in damage costs and it has become pivotal to design our infrastructure to meet the increasing expectations.

Stormwater systems also face a growing challenge due to rapid urbanisation that has increased the impervious urban landscape. It has caused visible changes in the hydrological cycle by decreasing the ground water recharge and evapotranspiration while, simultaneously, increasing the surface runoff. Streams downstream of traditional systems suffer from the *urban stream syndrome* characterised by a flashier hydrograph with high contaminant concentrations [4]. It is estimated that watersheds with 10-25% impervious cover are impacted by urbanization demonstrating changes in runoff quality and quantity, decreasing infiltration and evapotranspiration ([5], [6]). Thus, newer stormwater systems draining to downstream water resources are expected to provide water quality benefits, erosion control in addition to flood management.

Permeable pavements are one of the most prevalent Low Impact Development (LID) technologies for onsite stormwater management. Masonry products like Permeable Interlocking Concrete Pavers (PICP) have been found to effectively tie up the urban lifestyle requirements with a similar total impervious area (TIA) like impermeable pavers, but decrease the effective impervious area (EIA) and help in achieving the pre-development site conditions [7]. PICPs can be used in lieu of the existing impermeable pavers for better on-site stormwater management. The units have void space in between them filled with coarse aggregate (e.g. chip-stone). The water percolates through its open joints to the underlying aggregate base [8], providing a continuous path to enhance surface infiltration and, at the same time help in quality control of the infiltrate [9]. For sites with clayey soil, with low permeability, it is difficult to infiltrate the stormwater in the soils beneath. For such conditions, partial infiltration systems have demonstrated that PICPs can still achieve some volume and peak flow reduction and the excess stormwater is discharged to the receiving surface water system through the underdrains [9]. It has been suggested that infiltration to low permeable soils can be enhanced by temporarily holding storm water within a PICP reservoir [9]. In order to explore this observation a series of rainfall events of different sizes were monitored to compare both detention and non-detention strategies. This paper presents outflow data from summer and fall 2016 monitored rain events for four PICP cells located at Canada Masonry Design Center (CMDC), Mississauga.

EXPERIMENTAL SETUP

The University of Toronto, in collaboration with Canada Masonry Design Center (CMDC), is conducting research to explore the operational practices for open jointed masonry pavers. The test site for the project is a pedestrian walkway connecting two building that are a part of the CMDC campus located in Mississauga, Ontario. Figure 1 shows an aerial view of the test site.

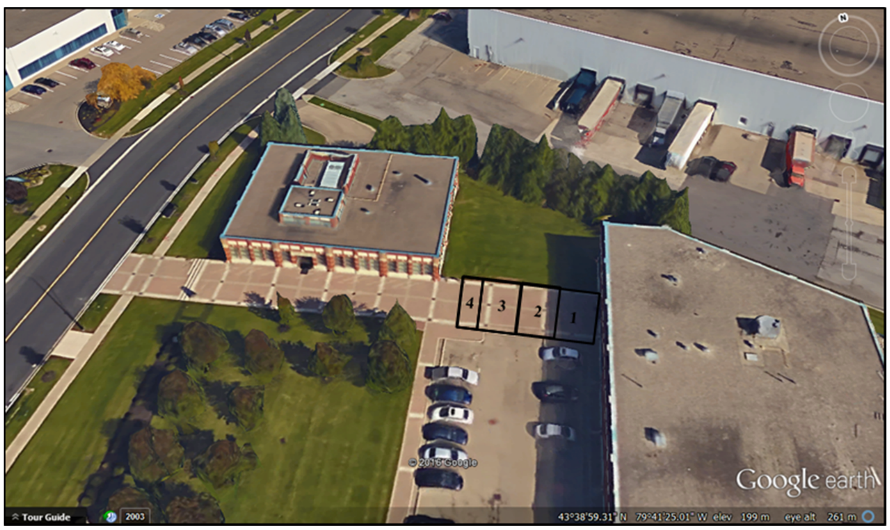

Figure 1: Aerial view of the test site (Courtesy: Google Earth, 2016)

Site Description

The pedestrian walkway at CMDC previously consisted of traditional impermeable pavers. A portion of the walkway was replaced in the fall and winter of 2015-16 with PICP. During this mid construction phase, part of the old impermeable paver sections drains towards the new PICP cells causing additional inflows for PICP 4. The cells are separated by a geo-membrane (described in the subsequent section), thus, till the time the rainfall intensity does not exceed the infiltration capacity of the PICP cell, the effects from the adjacent PICP cells is minimal.

Site specific factors at the CMDC pedestrian walkway makes it a unique location to test PICP operational practices. The CMDC property has silty clay soil [10]. This soils is characterised by a low infiltration capacity and is widely prevalent in southern Ontario. The walkway at CMDC is for pedestrian use only (by office employees) and is not subjected to vehicular traffic. Since the paver sections were new, with a high infiltration capacity, no cleaning or maintenance was performed in the first year of operation. This pedestrian walkway is in close proximity to two

CMDC office buildings which influences the amount of stormwater that the PICP cell receives. Operational evaluation of PICP for such installations in southern Ontario is non-existent.

The four PICP cells consist of different PICP products in a mixed configuration (color, void space etc.), shown in Figure 2. All the cells are constructed as partial infiltration systems with under drains connected to the flow monitoring equipment and fitted with outlet valves. A separate monitoring room was constructed at CMDC to house all the equipment. Table 1 illustrates the design characteristics of the PICP cells.

Table 1: Summary of Pavement Characteristics

Cell number	Dimension	Product
1	4.66m X 7m	Permacon® Subterra
2	4.80m X 7m	Santerra® Terra-Flo
3	4.82m X 7m	Oaks® Hydro'eau
4	2.48m X 7m	Oaks® Enviro Passagio

Figure 2: PICP Products at CMDC

Description of Paver Cross-Section and Function

PICPs consist of up to seven distinct components in its cross-section over the native soils. The typical cross section of the pavers, recommended by the Interlocking Concrete Pavement Institute (ICPI) design guide [11], was adopted at CMDC and is described in Figure 3.

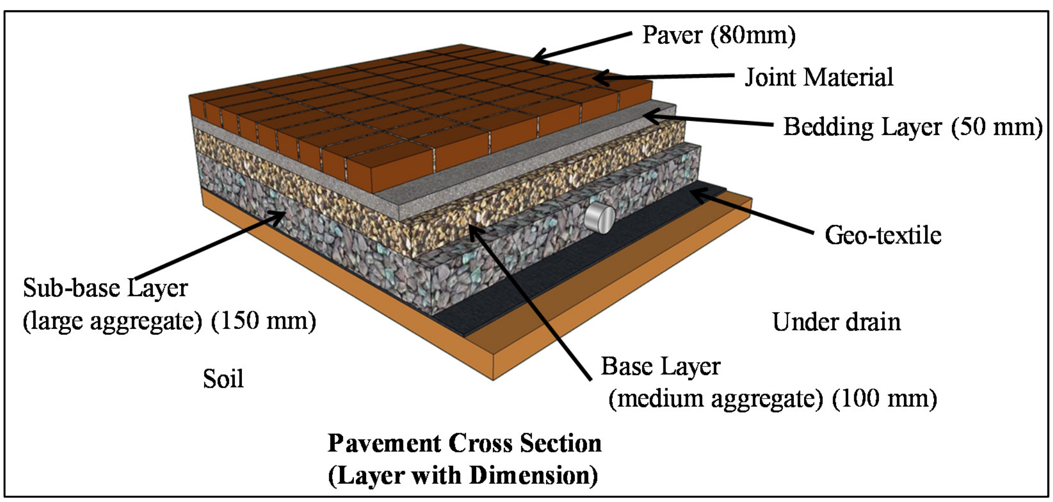

Figure 3: Typical Cross Section of PICP cells at CMDC

The sub-base, base and bedding layers consist of different size of aggregates which act as a reservoir and the filtration media for the water percolating through the pavers. The large aggregate sub-base is 150 mm thick with 50 mm stone, the medium aggregate base is 100 mm in depth using 19 mm aggregate and the bedding layer is 50 mm deep using the 6.7 mm stone. The 6.7 mm stone is also used as joint material for filling in the open joints. The pavers are 80 mm thick and a perforated pipe below each cell drain the excess water. Beneath the underdrain and the aggregate a geotextile, Layfield® LP4 Filter Cloth, is present which prevents the soil from drifting up into the aggregate layer. An impervious geomembrane, Layfield® EPDM Membrane (45 mils), is used between the paver lots which minimises the horizontal movement of water between cells.

Equipment Installation

The PICP underdrains are accessible at a downstream monitoring hut. Each drain is outfitted with a gate valve allowing stormwater to be temporarily held upstream within the aggregate reservoir. During summer 2016, flow and precipitation monitoring equipment were installed for the four PICP cells. The details of the equipment are summarised in Table 2.

Table 2: Equipments installed at CMDC

Measured Characteristic	**Equipment Used**	**Installation Illustration**	**Remarks**
Flow Monitoring	Tipping Bucket		▪ 4 tipping buckets of 1 L capacity ▪ Installed at the underdrain outlet ▪ Data recorded at 5 min interval ▪ Connected to HOBO ® data loggers
Water Level	Pressure Transducers		▪ 5 HOBO® U20 loggers ▪ Fitted in the observation wells and outside ▪ Measures absolute pressure and temperature ▪ Typical accuracy of 5mm ▪ Maximum error of 10mm.
Precipitation	Weighing Precipitation Gauge		▪ OTT Pluvio® installed at 100 m. ▪ Onsite precipitation information ▪ High accuracy precipitation (± 0.05mm) ▪ Intensity of ± 0.1 mm/min ▪ Internal compensation of wind, temperature and evaporation.

METHODOLOGY AND PERFORMANCE EVALUATION

The objective of this study is to evaluate the difference in outflow response for detention and non-detention events for four PICP cells between July 2016 and Dec 2016. Permeable pavements have longer response for precipitation events. Thus, an event is defined when the duration between successive precipitation instances is at least 12 hours to isolate its response from a subsequent event. During a detention event, the outlet valves of each PICP cell are closed allowing storage and slow infiltration of water into the underlying soil. During a non-detention event valves are opened and excess stormwater was allowed to freely drain through the underdrain. Since the area for each cell is different, the inflow from precipitation and outflow recorded by tipping buckets was normalised by the area of each pavement (Equation 1 and 2). Stormwater detention for variable duration was tested for sixteen precipitation events. The duration of detention was affected by the subsequent forecasted rainfall and logistical issues affecting access to outflow valves at the project site. The outflow volumes were recorded using the tipping buckets which record total volume at every 5-min interval.

Unit Output Volume (mm): $$V_{\text{PICP cell}}=\frac{V_{\text{PICP total}}}{\text{Area}} \quad (1)$$

Unit Input Volume (mm): $$V_{\text{Precip}}=\text{Volume of Cumulative Event Precipitation} \quad (2)$$

The volume reduction was calculated as a percentage of total input rainfall volume.

Percent volume reduction (*VR*): $$VR=\frac{V_{\text{Precip}}-V_{\text{PICP cell}}}{V_{\text{Precip}}}\times 100 \quad (3)$$

The pressure transducers record the absolute pressure in the observation well of each PICP reservoir. The barometric compensation utility of Hoboware® software uses the barometric file from the fifth logger for estimation of the water level. This allowed for the monitoring of built-up stormwater in the PICP reservoir.

RESULTS AND DISCUSSION

A total of thirty-one events were monitored between July 13th 2016 and Dec 7th 2016. Detention of water for different time duration was tested for 16 events. The results of the non-detention and detention tests are summarised below in Table 3 and Table 4, respectively which illustrate the volume reduction (VR) and the maximum water level (MWL) observed in each pavement.

Table 3: Volume Reduction for Non-Detention Events

Event Size	Date	Precipitation (mm)	PICP 1		PICP 2		PICP 3		PICP 4	
			VR (%)	MWL (mm)	VR (%)	MWL (mm)	VR (%)	MWL (mm)	VR (%)	MWL (mm)
Small (<6 mm)	8/5/16	0.4	100	8	100	9	100	-	100	11
	7/15/16	0.8	100	10	100	9	100	-	100	10
	8/21/16	0.8	100	34	100	32	100	-	100	36
	12/2/16	1.2	100	46	100	21	100	-	100	28
	8/20/16	1.8	100	36	100	35	100	-	100	38
	7/13/16	3.2	100	10	100	12	100	-	100	13
	12/6/16	3.6	100	52	100	22	100	-	81	29
	7/14/16	4.8	74	13	100	14	100	-	-24	15
	11/30/16	4.8	98	53	100	24	100	-	-2	28
	12/4/16	4.8	100	52	100	22	100	-	21	28
	8/25/16	5.2	81	52	100	29	100	-	-42	38
Medium (6 mm-20 mm)	8/25/16	8.8	92	53	98	31	95	-	51	38
	7/25/16	9.4	66	13	100	11	97	-	60	11
	7/14/16	12.0	67	14	100	13	100	-	-16	14
Large (>20 mm)	8/13/16	32.6	11	83	66	54	66	-	-82	63
MWL for PICP 3 not available due to sensor malfunction										

Table 4: Volume Reduction for Detention Events

Event Size	Date	Precipitation, mm (Detention, hrs)	PICP 1		PICP 2		PICP 3		PICP 4	
			VR (%)	MWL (mm)	VR (%)	MWL (mm)	VR (%)	MWL (mm)	VR (%)	MWL (mm)
Small (<6 mm)	9/23/16	0.6 (69)	100	31	100	22	100	-	100	26
	9/10/16	1 (37)	100	34	100	35	100	-	83	32
	10/16/16	1.2 (20)	100	31	100	25	100	-	100	43
	10/29/16	1.2 (26)	97	40	100	31	100	-	95	45
	9/17/16	5.8 (48)	100	39	100	26	100	-	100	29
Medium (6 mm-20 mm)	10/8/16	6.6 (73)	84	51	100	28	100	-	72	46
	11/19/16	7.6 (40)	100	35	100	25	100	-	100	27
	11/23/16	9 (77)	100	48	100	19	100	-	100	26
	10/1/16	9.4 (39)	95	51	100	31	100	-	59	46
	10/27/16	10.2 (25)	69	49	97	28	99	-	51	43
	9/26/16	11.4 (48)	72	48	95	26	95	-	48	63
	9/29/16	12.4 (16)	73	64	99	30	100	-	51	68
	9/7/16	15 (11)	78	74	88	45	89	-	57	100
	8/16/16	15.4 (19)	92	73	92	45	96	-	55	105
	10/20/16	15.8 (67)	85	63	100	30	100	-	62	48
Large (>20 mm)	11/2/16	26 (25)	87	134	88	95	91	-	77	158
MWL for PICP 3 not available due to sensor malfunction										

Non-Detention events

Fifteen non-detention events were observed during the monitoring period. The results (Table 3) for PICP 2 and PICP 3 demonstrated great agreement with the previous research [9] with no runoff for small events (i.e. less than 6 mm of rainfall). The volume reduction obtained was highly variable. The results of paired t-tests demonstrated no significant difference ($p=16.43\%$) between PICP 2 and PICP 3 based on their overall volume reduction. Though different products, PICP 2 and PICP 3 showed almost similar behaviour with volume reduction of 66% to 100%. PICP 2 and PICP 3 demonstrated significant difference from PICP 1 and PICP 4 ($p<5\%$). The small event observed on 7/14/16 demonstrated volume reduction response (for PICP 1 and PICP 4) different from previous events of similar intensity. This event was preceded by an event on 7/13. Thus, the antecedent moisture in the soil is expected to have caused less volume reduction. Similar observations were found for the two events on 8/25. For small and medium sized events, the volume reduction for PICP 1 and 4 was lower than PICP 2 and PICP 3. The lowest volume reduction was obtained for the highest precipitation (32.6 mm) event during the monitoring period. During high precipitation events, PICP 1 and PICP 4 recorded very low volume reduction. Negative volume reductions of -82% was recorded for PICP 4 during this event. It was observed that PICP 1 receives flows from the Ontario Masonry Training Center building on its east, where as PICP 4 receives flows from the old impermeable pavers, which slope towards PICP 4 as well as the Canada Masonry Center building on its North-west. The current calculations do not take into account the additional inflows from neighbouring infrastructure which would have resulted in the low volume reduction for PICP 1 and PICP 4. The actual area draining to PICP 1 and PICP 4 is currently not available and would be computed in the future stages of the research.

Detention Events

It was observed that all four permeable pavements responded with larger volume reduction to detention events of almost similar intensity, even in the presence of excess surface flows. Sixteen detention events were recorded. In the absence of surface overflows from adjacent infrastructure, PICP 2 and PICP 3 demonstrated similar volume reduction. Similar effect of lower volume reduction was observed for PICP 1 and PICP 4 during detention events (Table 4) as in non-detention events (Table 3). The detention event showed a volume reduction of 77% for PICP 4 during a large precipitation event of 26 mm. This was in stark contrast to the volume reduction of -82% for a large non-detention event. The volume reduction for PICP 2 and PICP 3, which don't have additional surface water inputs, also demonstrated improvement over a similar non-detention event with just 25 hours of detention. An influence of the effect of detention can also be observed for a medium intensity event of 16.4 cm on with a detention of approximately 67 hours. This event produced 100% volume reduction for PICP 2 and PICP 3 during detention.

Detention vs Non-detention

The processes of detention and non-detention were compared using independent t tests. Since the small events did not produce any runoff, sample for independent t-test consisted of detention and non-detention processes for medium and large size events. The data for both PICP 2 and PICP 3 was analysed as a single group (non-significant difference from paired t-tests) in both the processes. The results of independent t-tests (Table 5) demonstrated significant difference between the two processes. The results also highlighted a higher mean volume reduction for detention events when compared to non-detention events.

Table 5: Independent T tests

	Non-Detention	Detention
Mean	90.25	96.77
Standard Deviation	15.07	4.37
T tests Results		
Significance (p-value)	0.0357	
Degree of freedom	28	
T-score	2.21	

Figure 4 shows the water level during a non-detention event which shows a sharp change at the beginning of the precipitation. In contrast, from Figure 5, the change in water level for a detention event was gradual in PICP 1,2 and 4. The gradual decrease also illustates the steady infiltration into the underlying soils during detention event, increasing the overall infiltration. A maximum water saturation of upto 29% was observed during non-detention and 56% for detention events. During the largest precipitation non-detention event (Figure 4), all the observation wells demonstrated almost similar maximum water level, PICP 1 being the highest. The drawdown was at a similar rate for each of the observation well. It is important to note that the accuracy of the pressure transducers is 5 mm. During the highest precipitation detention event(Figure 5), PICP 1 and PICP 4 demonstrated the highest maximum water level. This may be attributed to the additional surface flows received from adjacent infrastructure. The rate of drawdown had a similar trend for the PICP 1 and 4. This trend was different for PICP 2, which experienced less volume of water per unit area compared to PICP 1 and PICP 4. PICP 2 reached the steady state earlier that the other pavements after infiltration of the detained water.

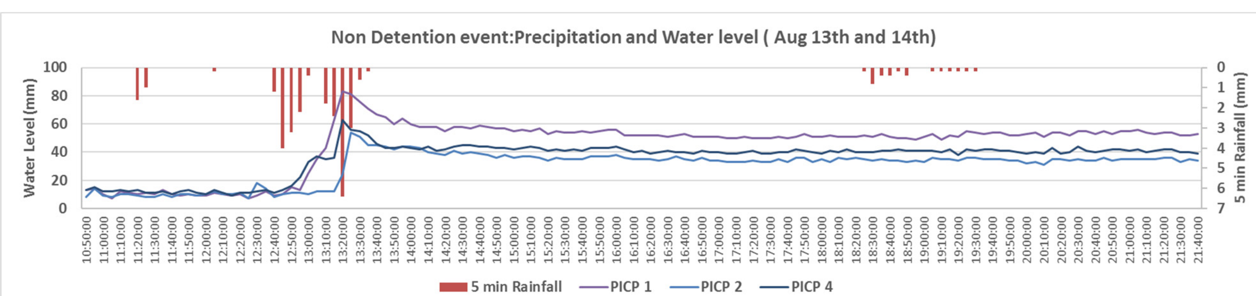

Figure 4: Water level in PICP during non-detention event

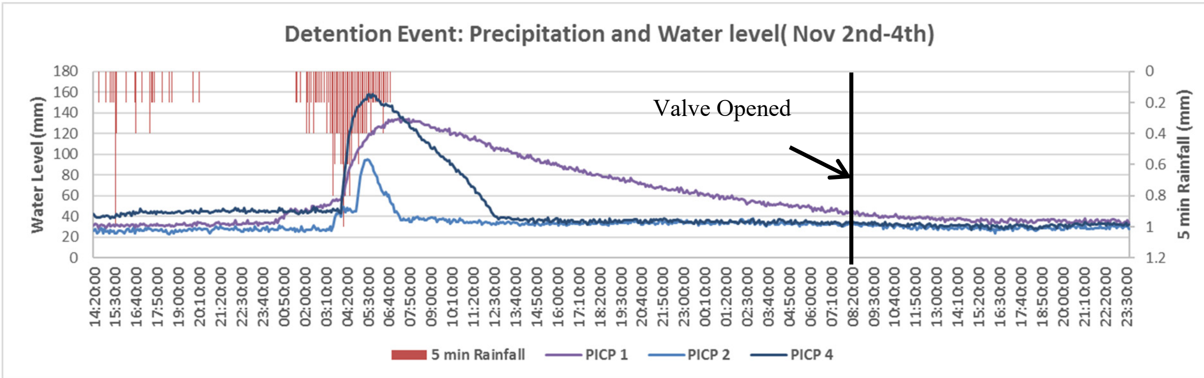

Figure 5: Water level in PICP during detention event

CONCLUSIONS

Though the research in permeable pavement systems started in the 1970s they are still fairly new with mainstream commercial use limited to the last decade of the 20th century. The presence of low permeability silty clay soil has been seen as a deterrent in the acceptability of open-jointed masonry pavers in Southern Ontario. Thirty-one precipitation events were monitored during summer and fall 2016 with sixteen detention and fifteen non-detention processes for the infiltrated stormwater in the PICP reservoir. Two PICP cells (PICP 2 and PICP 3) had similar response to volume reduction. For these cells, it was observed that detention of stormwater significantly enhanced the volume reduction for medium and large scale events when compared to non-detention events. The duration of detention had a positive effect on the volume reduction. These results present a possibility of achieving a pre-development flow regime and increasing infiltration in low permeability soils by modifying operational practices.

Visual and data backed observations confirmed that two PICP cells (PICP 1 and PICP 4) were subjected to additional surface flows from adjacent infrastructure resulting in lower and negative values for volume reductions respectively. Even with the additional flows, the estimated volume reduction (considering the input from the pavement surface area only) for detention events was 87% and 77% for PICP 1 and PICP 4.

Further research and monitoring of precipitation events would be conducted in the summer and fall 2017. It is important to note that CMDC presents a unique case of LID installation in proximity of and affected by infrastructure. Thus, it may imperative to analyse the actual contributing drainage area for PICP 1 and 4 in the future stages of the research which would give an insight on the effect of adjacent infrastructure. Overall, the detention of stormwater in the PICP reservoir yielded improved volume reduction. The operational practice also contributes positively in maintaining pre-development flow regimes in areas with low permeability soils.

ACKNOWLEDGEMENT

Financial support for the project was provided by the Natural Sciences and Engineering Research Council of Canada (NSERC) and Canada Masonry Design Center (CMDC). CMDC also provided in-kind and staff support during the duration of the experiments. The project also acknowledges the generous contribution of Permacon®, Santerra Stone® and Oaks Pavers® for generous donation of the masonry pavers.

REFERENCES

[1] Public Safety Canada. (2013). *Canadian Disaster Database*. Retrieved 12 13, 2016, from Public Safety Canada: http://cdd.publicsafety.gc.ca/srchpg-eng.aspx?

[2] Sandink, D., Kovacs, P., Oulahen, G., & McGillivray, G. (2010). *Making Flood Insurable for Canadian Homeowners: A Discussion Paper.* Toronto: Institute for Catastrophic Loss Reduction & Swiss Reinsurance Company Ltd.

[3] Insurance Bureau of Canada. (2015). *Weather Story*. Retrieved 12 13, 2016, from Insurance Bureau of Canada: http://www.ibc.ca/nb/resources/studies/weather-story

[4] Walsh, C. J., Roy, A. H., Feminella, J. W., Cottingham, P. D., & M., P. (2005). “The urban stream syndrome: current knowledge and the search for a cure”. *Journal of the North American Benthological Society, 24*(3), 706-723. doi:http://dx.doi.org/10.1899/04-028.1

[5] Dietz, M. E., & Clausen, J. C. (2008). “Stormwater runoff and export changes with development in a traditional and low impact subdivision”. *Journal of Environmental Management, 87*(4), 560-566.

[6] Schueler, T. (2003). *Impacts of impervious covers on aquatic systems*. Ellicott City: Center for Watershed Protection”. Retrieved from http://clear.uconn.edu/projects/tmdl/library/papers/Schueler_2003.pdf

[7] Yang, B., & Li, S. (2013). “Green Infrastructure Design for Stormwater Runoff and Water Quality: Empirical Evidence from Large Watershed-Scale Community Developments”. *Water, 5*, 2038-2057. doi::10.3390/w5042038

[8] Huang, J., Valeo, C., He, J., & Chu, A. (2012). “Winter Performance of Inter-Locking Pavers—Stormwater Quantity and Quality”. *Water*, 995-1008. doi:10.3390/w4040995

[9] Drake, J. (2013). “Performance and Operation of Partial Infiltration Permeable Pavement Systems in the Ontario Climate”. University of Guelph.

[10] McClymont & Rak Engineers, INc. (2007). Geotechical Investigation Report.

[11] Smith, D. R. (2011). *Permeable Interlocking Concrete Pavements.* Herndon, VA: Interlocking Conrete Pavement Institute.