COMPARATIVE PERFORMANCE OF PERMEABLE AND POROUS PAVEMENTS

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Abstract: The traditional approach to stormwater management is based on the development of urban drainage networks to convey stormwater away from developed areas quickly. With the increase in impermeable areas due to urban development, the quantity of stormwater runoff is significantly increased, overloading existing infrastructure. Pollutants carried by stormwater to receiving waters are also a major concern. Pervious pavements in car parks and driveways have potential to reduce peak discharge and the volume of runoff flowing into urban drains and improve runoff water quality by trapping the sediments in the infiltrated water. The paper focuses on presenting results from field tests carried out in Melbourne, Australia to evaluate reductions in peak discharge and the volume of stormwater after infiltrating through pervious pavement surfaces. The current study examines two types of pervious pavement surfaces: namely C&M Ecotrihex pavers and Atlantis turf cells and compares their performance against a conventional asphalt paved car park. Considerable reduction in peak discharges, runoff volumes, pollutant concentrations and loads were obtained from field tests. These reductions reduce the stresses on hydraulic infrastructures and on the ecosystem of the receiving waters. Furthermore, both C&M Ecotrihex and Atlantis turf cell surfaces reduces the lag-time by at least one hour to the peak discharge compared to the asphalt surface. This would further reduce the pressure on the infrastructure during a big storm event.

Keywords: Pervious pavements, Stormwater management, Stormwater pollutants, Water Sensitive Urban Design, Stormwater quality improvement, Stormwater peak reductions

1 Introduction

Urbanization has had a substantial impact on stormwater quantity and quality. The increase in impermeable area causes the quantity of runoff to significantly increase, stretching the hydraulic capabilities of stormwater infrastructure. Pollutants carried by stormwater to receiving waters are also a major concern. Water Sensitive Urban Design (WSUD) is a practice that is emerging throughout the world as a cutting edge initiative adopted to deliver improved receiving water health and where possible, contribute to producing fit-for-purpose water for use in urban communities. WSUD is a structural initiative that is used for a given set of conditions to reduce the quantity and improve the quality of stormwater runoff in the most cost-effective manner. Pervious pavements have been identified in Australia as a successful element of the WSUD concept.

Pervious pavements in car parks and driveways have potential to reduce peak discharge and the volume of runoff flowing into urban drains and improve runoff water quality by trapping the sediments in the infiltrated water. As a result, the risk to the health of rivers and natural water bodies from pollutants such as suspended solids, phosphorous, nitrogen, heavy metals, oils and hydrocarbons will be reduced. Researchers (Booth et al., 2003; Thomson and James, 1995; Lerget et al., 1996) noted a significant reduction in runoff volume and improvements to water quality parameters when using pervious pavements instead of conventional impervious asphalt type pavements. However, it has been shown that the design and application of pervious pavements is site specific and hence, the need for research on pervious pavements still remain as an urgent need to accelerate the practical adoption of them in the field.

The key objectives of the study reported herein are to quantify the amount of stormwater captured through pervious pavement infiltration and quantify improvements to the quality of stormwater infiltrated through the pervious pavement. The paper focuses on presenting results from field tests carried out in Melbourne, Australia to evaluate reductions in peak discharge and volume of stormwater after infiltrating through pervious pavement surfaces. The current study examines two pervious pavement types: namely C&M Ecotrihex pavers and Atlantis turf cells and compares the performance against a conventional asphalt paved car park.

2 Pervious Pavement Types

Pervious pavements can be classified as either porous pavements or permeable pavements. Although both types of pavements strive to achieve the same benefits, they differ considerably in the way they operate and in their appearance Jayasuriya et al. (2005).

The classification of pervious pavements depends on the surface layout and the surface layer materials. There is a significant difference between porous and permeable pavements. According to Zhang et al. (2006), Argue and Pezzaniti (2005) defined porous pavements and permeable pavements as follows. A porous pavement is a thick porous layer with a strong infiltration capacity. A porous pavement contains a grass or gravel surface with a well compacted graded sand and gravel base. On the other hand, a permeable pavement surface is normally constructed by impervious paver concrete blocks with infiltration voids between the blocks. Infiltration capacities of permeable pavements are high due to the coarse aggregate between concrete blocks.

A number of issues need to be resolved before adopting pervious pavements for managing stormwater. Durability of the pavement material, stormwater permeability of the pavement, traffic load capacity, and maintenance of the pavement are some of the issues that need resolving prior to use of pervious pavements. More laboratory and field tests are needed before pervious pavements are accepted by practicing engineers, regulators and councils.

A typical sub-base of a conventional pavement consists of Class 1 sub-base material with large fines content (VicRoads, 1997). This gives the pavement its strength and stiffness but is adversely affected when the sub-base is in contact with water. Pervious pavements require a single size grading (or open graded) to give open voids. Although it will have a lower stiffness than Class 1 material, stiffness will not be significantly reduced by the presence of water within it provided there is sufficient friction between particles when saturated. The choice of materials for use in capping and sub-base layers below pervious pavements is therefore a compromise between stiffness, permeability and storage capacity (Jayasuriya et al., 2005).

3 Experimental Site

A car park was built with two pervious surfaces namely C&M Ecotrihex pavers (permeable) and Atlantis Turf cells (porous) and an impervious asphalt surface as a control at the Centre for Education and Research in Environmental Strategies (CERES), in Melbourne, Australia. Jayasuriya and Kandurupokune (2008) describe the experimental setup at CERES in detail. The size of the study area was 229m^2 (18m*13m). Agricultural (aggi) pipes were placed around the catchment to prevent stormwater from the surrounding areas entering the experimental site and the three surfaces subject to experimentation (Figure 1). A subsurface geo-membrane structure was introduced to mitigate lateral water flow between experimental sites. Each surface type will consist of 2 car park/entry spaces of 50m^2 (5m*10m). Stormwater will flow through the pervious surface and subsurface media and be drained to the outlet via a geo-sock protected perforated header pipe. Details of the pavement design and structure of the pavements were reported in Jayasuriya et al. (2006a) and Kadurupokune and Jayasuriya (2007).

Three on-line flow meters were installed to measure the surface flow from the control surface (asphalt) and infiltrated water from the two pervious pavement surfaces. The flow meters were calibrated to activate when the depth of water in the channel was 10 mm. Three water quality auto samplers were also installed in special pits in the field to collect event based water quality data. One sampler will collect surface runoff from the impervious surface (control surface). Stormwater from the control pavement surface will flow to the 300 mm*400 mm channel. Another two samplers will be collecting the water infiltrated through the Ecotrihex and the turf cells respectively. Samples will be collected from the drainage pipes laid on the base layer. The stormwater infiltrated through the pervious concrete blocks and the turf cells are captured via a properly designed drainage system and the water is diverted to a small onsite dam for productive recycling use in the future. The quality of the infiltrated water in the car park through the pervious material will be monitored and benchmarked against the surface water quality flowing through the conventional car park. The water quality parameters monitored included Total Suspended Solids (TSS), Total Nitrogen (TN), Total Phosphorus (TP), Oil and Grease, Lead (Pb), Copper (Cu), Zinc (Zn) and Cadmium (Cd).

Rainfall data were collected from a Tipping Bucket rain gauge installed at the site. These rainfall values were compared with the nearby continuous rain gauges operated by Melbourne Water (within a 4 km radius) to determine the rainfall pattern and the intensity of the rain event at the experimental site.

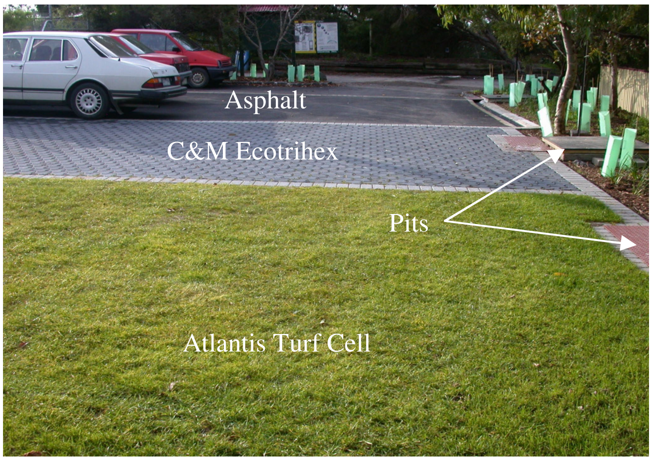

Figure 1 Experimental car park at CERES, Melbourne, Australia; (Jayasuriya & Kandurupokune, 2008)

4 Water Quantity Analysis

The City of Melbourne received below average rainfall for the last fourteen years (1996 – 2009). It was possible to collect stormwater only from 7 storms during the experimental period in 2006 and 2007. Natural storms that produced runoff are presented in Tables 1 and 2. The storms that occurred on 02 November 2006, 24 March 2007 and 18 May 2007 did not produce any runoff from the turf cells. The minimum rainfall required to produce runoff from Ecotrihex and turf cells surfaces are 13mm and 18mm respectively. As expected, asphalt pavement produced runoff with a minimum rainfall of 3mm. The runoff hydrograph produced on 12th July 2007 is given in Figure 2. The area under the hydrograph gives the total runoff produced from each storm.

The detailed hydrograph information obtained for a number of rain events are shown in Table 1. This Table gives the % reduction in runoff from C&M Ecotrihex surface and Atlantis turf cells when compared to runoff from the asphalt surface. Table 1 also present the % reduction of peak and total runoff obtained from the two pervious pavements.

From the hydrographs, it is clear that the runoff volumes and peak discharges from the pervious pavements are much lower than from the asphalt pavement. As presented in Table 1 and Figure 2, the average percentage reduction in peak discharge varied between 40% to 55% for C&M Ecotrihex pavement and 45% to 60% for the Atlantis turf cell pavement. C&M Ecotrihex pavement reduced the runoff volume by 43% to 53% whilst Atlantis turf cell pavement reduced the total runoff between 52% to 62%. From the values presented in the above table and the figure, it is concluded that pervious pavements are effective in managing stormwater flow. The water that is retained within the pavement structure will evaporate back to the atmosphere. Hogland et al. (1987; 1990), Larson (1990), Mantle (1993) and Pratt et al., (1989; 1990; 1995) reported that the percentage reduction in the runoff volume through pervious pavements is between 34% to 47%. It is clear that the results obtained from C&M Ecotrihex are within the range or better than the values observed or reported by previous researchers.

Table 1 Comparison of the two hydrographs from Asphalt and pervious surfaces

Date	Total rainfall (mm)	Difference in time in commencement of runoff (min)		Difference in time to peak (min)		Reduction in peak discharge (%)		Reduction in runoff volume (%)	
		C&M	Turf cell	C&M	Turf cell	C&M	Turf cell	C&M	Turf cell
2/11/2006	13	300	N/A	50	N/A	50	N/A	51.0	N/A
24/3/2007	14	39	N/A	48	N/A	53	N/A	42.0	N/A
18/5/2007	15	330	N/A	25	N/A	44	N/A	43.9	N/A
27/6/2007	18	90		35		55		46.8	
13/7/2007	20	150		85		37		44.5	
4/11/2007	24	150		85		48		53.4	
21/12/2007	25	210		165		42		46.3	

5 Water Quality Data Analysis

The reduction in TN, TP, Oil and greases, TSS and Heavy metals (Pb, Cd, Cu, and Zn) concentrations were investigated analyzing the stormwater infiltrated through both pervious surfaces. In order to obtain the pollutographs, water samples were collected as soon as the flow commenced from the drainage pipes installed within the pavements. The first three samples were collected at 15 minute intervals followed by samples every 30 minutes until the outflow ceases. The collected samples were preserved and analyzed at the laboratory. The pollutograph was also drawn for all pollutants for each storm event. Event Mean Concentration (EMC) was calculated using Equation 1.

$$EMC = \frac{\sum_{t=0}^{T} Q_t C_t}{\sum_{t=0}^{T} Q_t} \quad (1)$$

where,

EMC = Event mean concentration of a particular water quality parameter (mg/L)

Q_t= Discharge at a given time t (L/s)

C_t= Concentration of the water quality parameter at time t (mg/L)

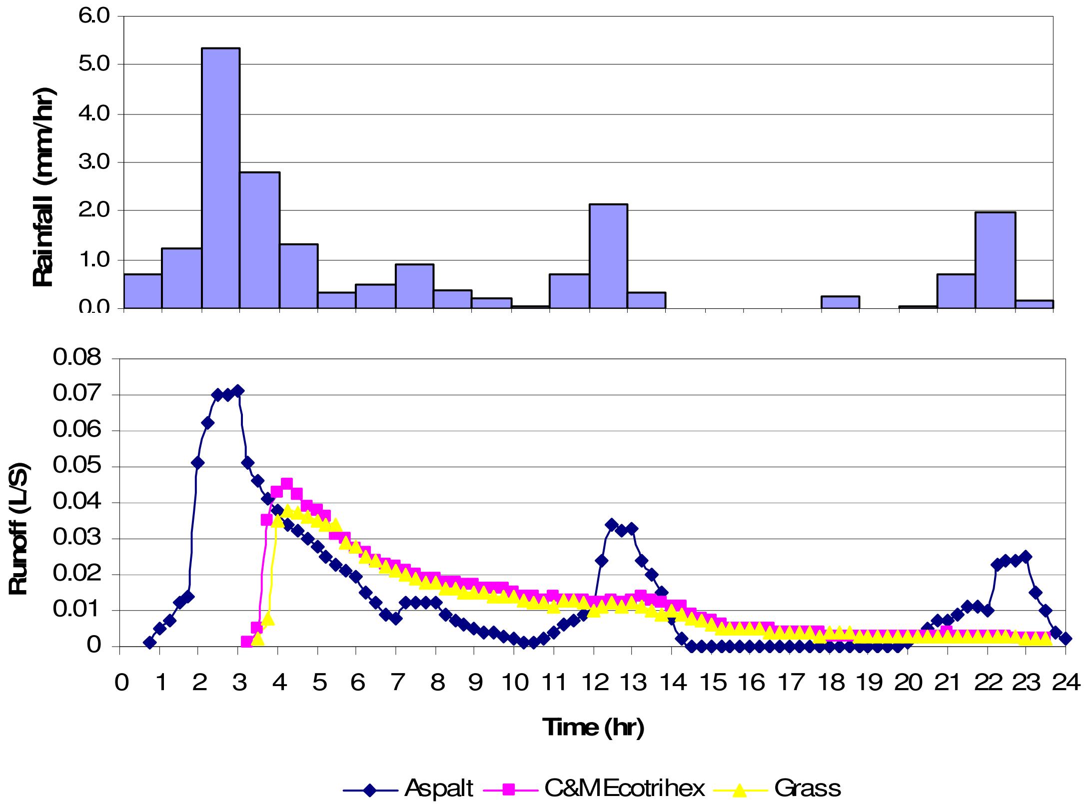

Figure 4.25 Runoff hydrographs produced by the Asphalt, C&M Ecotrihex and Atlantis turf cell pavements from 12th July 2007 storm event

T = Time base of the hydrographs

Tables 2 depicts the EMC of the water quality parameters from the runoff water collected from the asphalt, C&M Ecotrihex and Atlantis turf cell surfaces for the actual storm occurred on 12 July 2007. Tables 3 and 4 depict the removal efficiencies of pollutant concentrations and loads for all the pollutants from the actual storms. The removal efficiencies for Cd and Pb are not reported in Tables 3 and 4 as the concentrations and loads for the above two variables were below the detectable levels.

The removal efficiencies of water quality parameters from C&M Ecotrihex and Atlantis turf cell pavements were calculated by comparing concentrations and loads from the asphalt pavement. On average TSS, TP, Zn and oil concentrations reduced between 87% to 92%, 55% to 62%, 76% to 93% and 89% to 92% respectively from the C&M pavement and 90% to 92%, 50% to 56%, 91 to 92% and 93% to 94% from the Atlantis turf cell pavement. The removal efficiency of Cu is around 40 % and 60% from C&M Ecotrihex and Atlantis turf cell pavements respectively. However, the initial TN concentration levels from the water infiltrated through both pervious pavement types were very high. This was discovered to be due to reducing flow values and leaching of TN from the subbase of the pavement.

Table 2 Event Mean Concentrations (EMC) of the water quality parameters from the storm occurred on 12 July 2007

Parameters	Asphalt (mg/L)	C&M (mg/L)	Atlantis (mg/L)	Removal Efficiency (%)	
				C&M	Atlantis
TP	0.936	0.356	0.41	62.0	56.2
TN	7.1	1.943	2.83	72.6	60.1
Zn	0.076	0.0051	0.006	93.4	91.2
Cu	0.0589	0.0351	0.0238	40.4	59.6
TSS	134.3	10.3	13.2	92.3	90.2
Oil	624	61.6	42.4	90.1	93.2
Cd	BDL	BDL	BDL	BDL	BDL
Pb	BDL	BDL	BDL	BDL	BDL

BDL – Below Detectable Level

Table 3 Removal Efficiencies of pollutant concentrations

Date	% Removal Efficiency in Concentrations											
	Zn		TN		Cu		TP		TSS		Oil	
	C&M	Turf	C&M	Turf	C&M	Turf	C&M	Turf	C&M	Turf	C&M	Turf
02/11/06	N/A	N/A	N/A	N/A	N/A	N/A	50	N/A	88	N/A	80	N/A
24/03/07	76	N/A	37	N/A	-21	N/A	55	N/A	93	N/A	88	N/A
18/05/07	91	N/A	40	N/A	54	N/A	56	N/A	89	N/A	89	N/A
27/06/07	89	91	38	55	73	52	62	50	90	94	89	92
13/07/07	93	92	40	60	73	60	62	56	90	93	92	90
04/11/07	90	91	43	52	74	66	57	63	94	93	91	90
21/12/07	92	92	43	47	63	69	56	60	94	95	91	91

Table 4 Removal Efficiencies of pollutant loads

Date	% Removal Efficiency in Load											
	Zn		TN		Cu		TP		TSS		Oil	
	C&M	Turf	C&M	Turf	C&M	Turf	C&M	Turf	C&M	Turf	C&M	Turf
02/11/06	N/A	N/A	N/A	N/A	N/A	N/A	75	N/A	94	N/A	90	N/A
24/03/07	86	N/A	64	N/A	30	N/A	74	N/A	96	N/A	93	N/A
18/05/07	95	N/A	66	N/A	74	N/A	75	N/A	94	N/A	94	N/A
27/06/07	94	96	67	80	86	78	79	78	95	97	94	96
13/07/07	96	96	67	81	85	81	79	79	95	97	96	95
04/11/07	95	96	74	80	88	86	80	85	97	97	96	96
21/12/07	96	97	69	78	80	87	76	83	97	98	95	96

6 Conclusions

A car park with three different surfaces (two pervious surfaces and one impervious surface as a control) was newly constructed at the Centre for Education and Research in Environmental Strategies (CERES) at Brunswick in Melbourne. The experimental site was fully automated with flow meters and autosamplers to collect flow and stormwater quality data.

Reduction in peak flow from the two pervious surfaces compared to the asphalt surface was comparable with previous studies. The percentage reduction in peak discharge and runoff volume from pervious pavements varied between 45% to 55% and 50% to 60% respectively when compared to the conventional asphalt pavement. From above results, it could be stated that both pervious pavements are effective in managing stormwater flow, although the Atlantis turf cell pavement facilitated more infiltrated water than the C&M Ecotrihex type pavement. The water that is retained within the pavement structure will evaporate back to the atmosphere. The reduction of peak discharge and volume reduces the surcharging stresses on hydraulic infrastructures. Furthermore, both C&M Ecotrihex and Atlantis turf cell surfaces effected at least one hour lag time on the peak discharge compared to the asphalt surface. This would further reduce the pressure on the infrastructure during large storm events.

The results obtained from the field experiments clearly prove that pervious pavements have an ability to reduce peak discharges while filtering the pollutants generated by urban stormwater. Consistent water quality improvements were observed from this pervious paver study, with reductions in TSS, TP and TN of around 70% to 100%, 40% to 80% and 60% to 80% respectively confirming findings by previous researchers. Clogging of pervious pavements and the maintenance required to facilitate continual efficient performance are two areas that require further study.

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