Managing Stormwater Productively Using Pervious Pavements

Gérer efficacement les eaux pluviales avec des revêtements poreux

Jayasuriya N[1], Kadurupokune N..[2], Othman M.[3], Jesse K[4]

School of Civil, Environmental and Chemical Engineering, RMIT University, POBox 2476V, Melbourne 3001, Victoria, Australia.

E-mail: 1. nira.jayasuriya@rmit.edu.au ; 2. S3144302@student.rmit.edu.au ; 3. maazuza.othman@rmit.edu.au 4: Keith@ceres.org.au

RESUME

Traditionnellement, la gestion des eaux pluviales repose sur la construction de réseaux de drainage pour l'évacuation rapide des eaux afin d'éviter les inondations. L'objectif principal de cette recherche est d'identifier les relations entre l'intensité des précipitations, le taux d'infiltration et les ruissellements sur revêtements urbains jusqu'aux avaloirs, et enfin d'examiner l'amélioration de la qualité des eaux pluviales après infiltration au travers des revêtements perméables. Cet article décrit l'expérience en laboratoire destinée à déterminer les parcours d'infiltration et l'amélioration de la qualité des eaux pluviales pour des orages simulés sur des revêtements perméables. Ensuite, la mise à échelle d'essai sur site est expliquée. Les résultats préliminaires de ce travail destinés à démontrer le potentiel d'utilisation des revêtements poreux en Australie sont présentés.

ABSTRACT

The traditional approach to stormwater management has focused on constructing drainage networks to carry stormwater away from developed areas quickly to avoid flooding. The main aim of the research project is to establish relationships between rainfall intensity, infiltration rate and pervious pavement runoff to urban drains as well as to examine the improvement to stormwater quality after infiltrating through the pervious pavement. The paper describes the laboratory experiment set-up to determine the infiltration patterns and stormwater quality improvement for simulated storms precipitating on pervious pavements. Next the scaling-up of the experimental rig to a field trial is explained. Preliminary results from this work presented to demonstrate the potential for pervious pavement use in Australia.

KEYWORDS

Permeable pavements, Stormwater pollutants, Stormwater management, Water Sensitive Urban Design.

1. INTRODUCTION

Melbourne in Australia has high quality drinking water, but like other many urban cities in the world, it's growing population from 3.7 million in 2006 to 4.2 million in 2030 means ever increasing demand for water. Melbourne water authorities recently imposed water restrictions after below average rainfall for 9 consecutive years. The recently developed Central Region Sustainable Water Strategy (Our water Our Future, 2006) has set a 25% and 30% per capita water consumption reduction target by 2015 and 2020 respectively for Melbourne to ensure continuation of a safe, reliable and cost effective water supply that is provided in an environmentally sustainable manner in the long term. Water authorities, planners and conservation professionals are interested where and how water is put to use by the consumers so that they can provide fit-for-purpose supply in the future.

The Victorian Government's White Paper on water, 'Our Water Our Future' (Water Resources Strategy Report, 2003) promotes the use of alternative sources such as stormwater for substituting potable supply to save precious water resources. The Central Region Sustainable Water Strategy has confirmed the 20% water recycling target set for Melbourne to be achieved by 2010. The poor quality of stormwater is one of the factors limiting the use of stormwater for fit-for-purpose productive use.

Urbanization has had a detrimental effect on stormwater quality. The increase in impermeable area due to rapid urban development causes the quantity of runoff to significantly increase at times, stretching the capabilities of stormwater disposal infrastructure. Pollutants carried by stormwater to receiving waters are also a major concern. Receiving waters such as creeks, rivers and the Port Phillip Bay and Westernport in Melbourne are also impacted by poor stormwater quality.

The main focus of the paper is to report on research related to using pervious pavements for managing stormwater efficiently and productively. The infiltration of storm runoff through pervious pavements reduces peak flows and removes contaminants improving the water quality. The infiltrated water could recharge groundwater or if harvested, could be used for fit for purpose productive use. This application can help return the urban water cycle close to its natural condition, increasing groundwater recharge and decreasing the pressure on new and existing urban drainage infrastructure.

Although the benefits of using pervious pavements are many, a number of issues need to be investigated before promoting pervious pavements as a suitable means of managing stormwater. Since 1980's, European countries have gradually increased the use of pervious pavements. However, research into managing stormwater using pervious pavements is at an early stage, especially in Australia. More laboratory and field tests are needed before practicing engineers; land developers; regulators and urban councils adopt pervious pavements as a standard feature in water sensitive urban design.

The introduction of a pervious pavement addresses all principles in Water Sensitive Urban Design. Water Sensitive Urban Design is the integration of water cycle management into urban planning and design. The key principles of Water Sensitive Urban Design as stated in Urban Stormwater – Best Practice Environmental Management Guidelines (Victorian Stormwater Committee, 1999) are to: protect natural systems; integrate stormwater treatment into the landscape; protect water quality; reduce runoff and peak flow and add value while minimising development costs.

A pervious pavement is a load bearing pavement structure that is permeable to water overlying a reservoir storage layer. The main difference between a pervious pavement and a conventional pavement structure is the permeability of the surface and the water holding capacity of the sub-base. Pervious pavements reduce the flood peak as well as improve the quality of stormwater at source before it is transported to receiving waters. The water infiltrates through the pavement to a sub-base reservoir, from where it infiltrates slowly to the soil or to drains. By reducing peak flow rates and volumes in downstream receiving waters, pervious pavements decrease overflows and recharge groundwater. Similarly, pervious pavements also reduce nutrients and toxicants in stormwater runoff. These pollutants if left un-trapped will contaminate the drainage system and groundwater. Stormwater infiltration can help return the urban water cycle to somewhat like its natural condition, increasing groundwater recharge and evapotranspiration whilst decreasing the pressure on existing urban infrastructure. The scaling-up of the experimental rig to a field trial is also explained.

The paper will cover types of pervious pavements and address issues related to adopting pervious pavements in the field. The paper will also summarise the research carried out in the laboratory to investigate the infiltration capacity through the pavement and present preliminary water quality improvements achieved for the ROCLA Ecotrihex laboratory pavement.

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.

The classification on 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 (2006), Argue and Pezzaniti (2005) defined porous pavements and permeable pavements as follows. Porous pavements are 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, permeable pavement surfaces are 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.

Current issues related to pervious pavements include:

Groundwater contamination - Runoff from streets and car parks contains pollutants like heavy metals and hydrocarbons that can pollute soil and groundwater.

Pavement clogging - Particles in storm runoff can clog pores in the pavement material. To retain infiltration capacity effectively surfaces must be cleaned from time to time.

Durability – Pervious pavements are currently limited to areas with low traffic volume, low axle loads and low speed zones, i.e. car parking and recreational areas. Pavements should be designed on an individual basis to satisfy criteria set by experienced geotechnical and pavement engineers. If properly installed, pervious pavements have similar load bearing and design performance to conventional pavements (Melbourne Water; 2003). These issues are addressed in the rest of the paper.

3. PREVIOUS RESEARCH ON PERVIOUS PAVEMENTS

Zhang (2006) reported that permeable surfaces are more suitable in car parks and driveways than the porous pavements. The voids between the paver materials are more widely open and can infiltrate higher rainfall intensities than porous pavements. Shackel and Pearson (2004) indicated that infiltration capacity of porous pavements are not sufficiently high for Australian rainfall conditions and can easily clog within a short period. According to above authors, permeable pavements are more suitable for Australian hydrological conditions.

Urban Water Resources Centre (2002) reported the hydraulic performance of three types of permeable pavements named BORAL, ROCLA and grass subject to certain sediment loads through in-situ and laboratory tests. Four test beds were set up in the laboratory and sediment loads were applied with the input water before the tests started. The results revealed with 35 years simulated sediment loads, the hydraulic conductivity reduced by 59%, 68% and 75% from BORAL, ROCLA and Grasspave respectively. Furthermore, the sediment retention rate of different paver surfaces did not decrease significantly according to the long term simulation. BORAL, ROCLA and Grasspave can retain up to 94%, 89% and 97% of sediment loads when compared to the new constructed status respectively.

According to a number of studies carried out (Melbourne Water 2003; Fletcher 2003; Booth 2003) if pervious pavements are correctly designed and maintained, they can retain up to 80 % of sediment, 60 % of phosphorus, 80 % of nitrogen, 70 % of heavy metals, and 98 % of oils and greases in the stormwater.

Legret and Colandini (1999) and Dierkes et al. (2002) examined the possibility of groundwater contamination through infiltrated water from porous asphalt and porous concrete pavements respectively. Both above studies concluded that pollutants such as lead (Pb), zinc (Zn), copper (Cu) and cadmium (Cd) were retained in the porous pavement within the top 30 cm. Dierkes et al. (2002) also stated that the use of pervious pavements is sustainable, if adequate planning, construction supervision and maintenance were in place.

Newton (2001) reported that the stormwater quality varies greatly between locations depending on land use practices. Duncan (1999) carried out a detailed literature review on urban stormwater quality characteristics generated from different sources. Table 1 provides the typical range of concentrations in pollutants observed across Australian urban areas compared to values elsewhere in the world (Newton, 2001). On average, the level of stormwater contamination observed in Australia is greater than data recorded in other parts of the world.

	Australian data set (mg/L)		World data set (mg/L)	
Pollutant	Mean	Range	Mean	Range
Suspended solids	141	42-478	148	45-490
Total nitrogen	2.63	1.29-5.37	2.51	1.12-5.62
Total phosphorus	0.24	0.08-0.72	0.32	0.12-0.82
Lead	0.1	0.01-0.74	0.12	0.03-0.5
Zinc	0.63	0.23-1.7	0.25	0.08-0.78
Cadmium	0.007	0.003-0.018	0.003	0.0007-0.01
Chromium	0.03	0.01-0.11	0.02	0.005-0.08
Copper	0.06	0.012-0.18	0.05	0.02-0.17
Nickel	0.02	0.01-0.04	0.03	0.02-0.07
Biological oxygen demand	15.1	7.9-28.8	12	5.6-25.7

Table 1: Urban stormwater pollutant concentrations (mg/L) in Australia compared to world data

Booth (2003) examined the long-term effectiveness of a permeable pavement as an alternative to a traditional impervious asphalt pavement in a parking area.

Four commercially available permeable pavement systems were evaluated after six years of daily parking usage for structural durability, ability to infiltrate precipitation and impacts on infiltrated water quality. All four permeable pavement systems showed no major signs of wear.

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 friction between particles when saturated. The choice of materials for use in capping and in the sub-base layers below the pervious pavements is therefore a compromise between stiffness, permeability and storage capacity.

4. LABORATOR APPLICATION OF PERVIOUS PAVEMENTS – PRELIMINARY RESULTS

In Australia Shackel et al. (1996) carried out a series laboratory and field tests on the surface layer and bedding layer to determine the optimal structure of pervious pavements. Zhang (2006) adopted the thicknesses of the pavement layers and aggregates sizes recommended by Shackel et al (2003) in designing a laboratory scale permeable pavement test model to examine the rainfall and infiltration relationships.

The designed permeable pavement test rig was constructed in a 1.5m*1.5m steel box with holes on the bottom plate for water to pass through. Zhang (2006) showed that algorithms in the PCSWMMPP model (James et al., 2003) can be successfully used in hydraulic calculations when designing permeable pavements. The PCSWMMPP model uses the Green and Ampt algorithm and Darcy's equation to calculate the infiltration and percolation through the pavement respectively. Zhang (2006) successfully estimated all parameters of Green and Ampt algorithm and Darcy's equation in the laboratory from aggregates physical properties. Different rainfall intensities were applied to the experimental rig to obtain rainfall and infiltration relationships. According to above authors when the rainfall intensity is larger than the saturated hydraulic conductivity of the material, the volume of water infiltrated varies until surface saturation. The total volume of water infiltrated is independent on the rainfall intensity after the surface is saturated.

Laboratory rig used by Zhang et al (2006) will be used to estimate the water quality improvement with stormwater passing through the laboratory pavement test rig. Sansolone and Buchberger (1997), Hsieh et al (2005) have prepared synthetic stormwater samples in the laboratory. All above authors have multiplied the typical stormwater quality parameters by a factor when preparing the laboratory sample. Current study followed the instructions given by Hsieh et al (2005) when preparing the stormwater samples and multiplied the typical stormwater quality parameters given in Table 1 by a factor of 2 to prepare the laboratory sample.

The synthetic stormwater sample was prepared to obtain the concentrations given in Table 2. The chemicals used in lieu of the pollutants when preparing the sample is also given in Table 2. The synthetic stormwater sample was sprayed uniformly over the surface of the laboratory pavement model and rainfall was simulated over the permeable pavement. The rainfall was simulated at a rate of 90 L/hour for 15 mins. The outflow was collected from the bottom of the pavement and analysed for pollutant concentrations. Table 3 depicts the input and output concentrations of the pollutants and the percentage reductions of the pollutants from four storm events. 85% of the total suspended solids (SS) and up to 95% of total Nitrogen (TN) and total

Phosphorus (TP) were retained on the pavement when rainfall events were simulated. Copper (Cu) and lead (Pb) levels in infiltrated water were below detectable levels. However, the concentration of zinc (Zn) was more than the input concentration levels in the first two trials. This could be due to the zinc in the galvanised metal pavement structure. Further investigations are currently being carried out to examine this.

Hsieh et al (2005) during their laboratory studies observed that 56% and 3% of input Pb and TP respectively were absorbed onto the SS particles of the influent stormwater sample. Sansalone and Buchberger (1997) also reported that 55–82% of total input Pb was absorbed onto SS in the runoff sample during their experiments. They also observed absorption of TP by SS in runoff. The pollutant distribution is expected to play a major role in the removal of pollutants during filtration by the media. (Hsieh et al, 2005). This is evident from the Pd and TP levels obtained from the current experimental study.

The next step in the study program was to scale-up the experiment to a field trial to determine whether the effectiveness of pervious pavements shown in the laboratory is replicated under field conditions.

Parameter	Concentration (mg/L, except pH)	Source of pollutant
pH	7	HCl or NaOH
Total Suspended Solids	281	Local soil sieved through a
Total Phosphorus	0.48	Na_2HPO_4
Total Nitrogen	5.26	$NaNO_3$, NH_4Cl
Lead (Pb)	0.2	$PbCl_2$
Copper (Cu)	0.12	$CuCl_2$
Zinc (Zn)	1.26	$ZnCl_2$
Cadmium (Cd)	0.014	$CdCl_2$

Table 2: Pollutant concentrations in the synthetic urban stormwater sample

5. FIELD APPLICATION OF PERVIOUS PAVEMENTS – PRELIMINARY RESULTS

A pervious pavement car park has been built in the field with two types of surfaces namely ROCLA Ecotrihex pavers and Atlantis Turf cells (4.8m*10.5m each). The water quantity and quality infiltrated through the surfaces will be bench marked against the surface runoff from the Asphalt surface. Three on-line flow meters are installed to measure the surface flow from the control surface and infiltrated water from the two pervious surfaces. The flow meters were calibrated to activate when the depth of water in the channel is only 10 mm. Three water quality auto samplers are also installed in special pits in the field to collect event based water quality samples from the three types of pavements. The quality of the infiltrated water will be benchmarked against the surface water quality flowing through the conventional asphalt car park. The auto samplers will not activate automatically. As it is not possible to manually activate the auto-samplers during a storm event, the auto samplers were connected to the flow meters by a special cable. This will ensure the activation of the auto-sampler and the flow meter simultaneously. The rainfall will be collected from a rain gauge installed at the site. It is planned to analyse the stormwater quality samples for the following water quality parameters: SS, ph, total Nitrogen, total Phosphorous, Oil and Greases, Cr, Cu, Cd and Pb. It is also planned to investigate the effect of pervious pavements on the flow hydrograph. Figure 1 shows the hydrographs obtained from the Asphalt and Ecotrihex pavement surfaces during a stormevent with 13 mm of rainfall. There was no runoff generated from the grass pavement for this particular stormevent. Results from this initial event shows a reduction of 0.116 L/s peak discharge with 60 mins of lag time. It also shows a reduction of SS and TP by 75% and 50 % respectively.

The data collection began at this site in September 2006 and will continue until December 2007. Results from the study will be presented elsewhere once the data is collected and analysed.

Pollutant	Input (mg/L)	Output (mg/L)				% Retention
		Sample 1	Sample 2	Sample 3	Sample 4	
Total Nitrogen	5.26	0.25	0.15	0.25	0.25	95.2
Total Phosphorus	0.48	< 0.06	<0.06	0.02	0.02	95.83
Total SS	281	50	48	48	47	82.2
Copper	0.12	<0.003	<0.003	<0.003	<0.003	
Cadmium	0.014	0.004	0.003	0.003	0.001	71.4
Zinc	1.26	2.51	2.12	1.01	0.476	
Lead	0.2	<0.02	<0.02	<0.02	<0.02	

Table 3: Input and output pollutant concentration levels through the pervious pavement

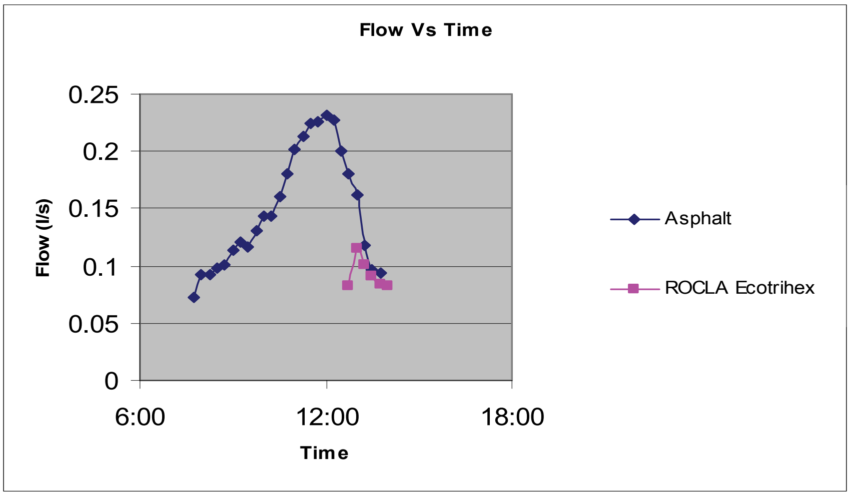

Figure 1: Stormwater hydrographs produced by the Asphalt pavement and the Ecotrihex pavements

6. CONCLUSIONS

Pervious pavements could play an important role in Water Sensitive Urban Design as it helps to reduce peak flows, improved stormwater quality and if properly designed, permits the infiltrated water to be harvested to be put to productive use. Preliminary pervious pavement studies conducted in the laboratory and in the field yielded positive results. The outcomes from the study will provide useful insight to design environmentally friendly car parks, pedestrian paths, light traffic driveways, sporting grounds and public areas in the future.

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