USING PERMEABLE ECO-PAVING TO ACHIEVE IMPROVED WATER QUALITY FOR URBAN PAVEMENTS

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ABSTRACT

This paper describes the planning, design and construction of a permeable pavement as a practical demonstration of the benefits of eco-paving in Australian environmental management. The paper addresses the use of permeable pavements as part of a Water Sensitive Urban Design that allows infiltration of stormwater, reduction of pollutants and slow reticulation of the stormwater to an ecologically sensitive water system.

Management of the quantity and quality of urban stormwater run-off is a major concern for government authorities. The increase in impervious surfaces associated with urbanisation of catchments results in an increase in the volumes of stormwater runoff that must be handled by the stormwater drainage systems and a consequent increase in the ability of the stormwater runoff to transport pollutants from the catchment surface to the downstream receiving waters. These pollutants include those from vehicle exhausts, brakes and tyres, community activities, and atmospheric deposition. Where the stormwater system drains to ecologically sensitive zones, such as beaches, lakes or creeks, communities demand that the quality of the stormwater discharged into these water bodies must not lead to their degradation.

This paper describes how, in a seaside suburb of Sydney, Australia, Manly Council assisted by the Urban Stormwater Initiative of the Commonwealth Department of Environment and Heritage, Environment Australia, has replaced an old impervious asphalt roadway with a Uni-Ecoloc concrete segmental permeable pavement system as part of a stormwater project using the concepts of Water Sensitive Urban Design. Issues covered include the structural design of the pavement to carry traffic and the hydraulic design of the pavement to allow the capture of the storm events, control of water quality at the source, reduction of the volume of storm water reaching drainage system, permeable pavers to ensure traffic flow/frequency is satisfied. Factors influencing the choice of paver and pavement materials are discussed and the construction procedures are described including in-situ assessments of basecourse permeability. The project is now in service and is being monitored on a long-term basis. However, the paper presents preliminary assessments of the impacts and utility of the project.

1. INTRODUCTION

Although established in Europe for more than ten years, permeable eco-paving only began to find application in Australia from about 1998 although tests of both their hydraulic and structural behaviour had been conducted since the early 1990’s (e.g. Shackel, 1996 b, Shackel et al, 1996). When it was decided to reconstruct a suburban residential street, Smith Street, Manly, using permeable eco-paving this represented the first application of this technique to residential paving in Australia i.e. it was a demonstration project.

Local government engineers have long been conditioned to believe that it is desirable to prevent water infiltrating pavements. However, the essential basis of eco-paving is that the pavement should be designed to be permeable and that water infiltration should be actively encouraged. By this simple stratagem eco-pavements are designed to achieve a wide range of environmental benefits (Shackel, 1996 a, b).

These include:

- A reduction in the amount of rainfall runoff from pavement surfaces and, thereby, a decrease or even the elimination of the storm water drainage system necessary.
- A decrease in the size or need for rainwater retention facilities in road works by using the pavement itself for retention.
- A reduction in downstream flooding.
- Assistance in recharging and maintaining aquifers and the natural groundwater.
- Help in trapping pollutants that might otherwise contaminate groundwater or drainage systems (e.g. James, 2002). About 90% of highway pollutants are particulates and these can be retained within the substructure of permeable pavements (Anon, 2002)

Permeable eco-pavements comprise a permeable surfacing overlying permeable base and sub-base materials. The surface that gives the highest infiltration of water comprises concrete eco-paving. Such paving is produced by modification of well-established concrete paver shapes so that, once laid, small openings are provided at intervals along the joints. These are filled with a uniformly graded aggregate to act as vertical drains through the pavement. These permit water to infiltrate the pavement. Because eco-pavers are based on well-proven conventional paver shapes, and are installed on a fully engineered pavement sub-structure, they provide a viable alternative to conventional segmental paving (Shackel, 1996 a, b, Shackel et al, 1996).

In 1994 a program of experimental research into permeable pavements at the University of New South Wales began in which small test sections of permeable paving, 1.5 m square, were examined under laboratory conditions [Shackel, 1996 b, Shackel at al, 1996]. Infiltration data from these studies show that eco-pavers can accept rainfall intensities of up to about 600 l/sec/ha whilst maintaining levels of structural capacity that are comparable with those achieved by conventional paving [Shackel, 1996 b, Shackel at al, 1996]. However, once the water has saturated the surface, any additional water than can be accepted by the pavement depends upon the permeability of the base and sub-base. In general, most conventional bases are relatively impermeable and there is a need to employ new base materials that combine high permeability with good structural properties (Shackel et al, 2001).

2. PROJECT BACKGROUND

The project was known as the Manly Council STAR Project and involved collaboration between Industry, Government and University organisations.

The Water Research Laboratory and the School of Civil and Environmental Engineering at the University of New South Wales (UNSW) provided expertise to the project partners in the following areas of activity:

- Pavement Design - UNSW provided a pavement design for Smith Street which facilitated application of the porous pavers.
- Stormwater Monitoring - UNSW staff have been monitoring the stormwater runoff and associated water bodies from the project. At Smith Street, a gauging station has been installed to sample runoff in the road gutter while a groundwater bore has been installed to sample the groundwater which receives the infiltrated stormwater runoff.

- Application of Catchment Modelling – The particular catchment that includes Smith Street is known as the Pine Street Catchment. A SWMM based model of the total catchment has been developed to enable extrapolation of the results from this project to other portions of the current catchment or to other catchments with similar characteristics.

Each of these activities are now briefly described.

3. PAVEMENT DESIGN

The designs were based on the assumption that Rocla Ecoloc pavers would be used as the pavement surface. These pavers were selected because their structural and hydraulic properties had already been extensively studied in the laboratories of the School of Civil and Environmental Engineering at the University of New South Wales (Shackel 1996 b, Shackel et al, 1996). In addition, there was a substantial history of their successful use both overseas, notably in Germany e.g. at the World Fair, Hannover, 2000, and around Sydney (e.g. Olympics Precinct, 1999, Sydney Sports Ground, Centennial Park, 1999, Kiama, 2000).

The pavements were designed using two computer programs written specifically for permeable eco-paving.

These comprised:
- *LOCKPAVE-PRO 2001 for the Structural Design of Interlocking Concrete Block Pavements* (version 13). This program has been described in detail elsewhere and includes provision for the structural design of permeable eco-paving (Shackel, 2000)
- *PC-SWMM for Permeable Pavements* developed by Professor W James of the University of Guelph, Canada. This program is for the hydraulic design of eco-pavements and is derived from the well-known SWMM program widely used around the world.

A geotechnical investigation established that, beneath the original pavements of Smith Street, the subgrade comprised loose to medium dense sand overlain by silty sandy gravel or silty gravelly sand fills in thicknesses between 0.4 and 1.0m. Two in-situ constant head permeability tests of the subgrade gave coefficients of permeability, k, of 4.1 x 10^{-3} and 6.1 x 10^{-3} cm/s respectively, consistent with the values expected for clean sands.

3.1 Structural Design

For the subgrade, in-situ CBR values measured by DCP tests ranged from 10% to 38%. Four day soaked CBR values measured in the laboratory ranged between 12% and 16%, again consistent with the values expected for compacted clean sands. Based on these data a CBR value of 10% was selected for pavement thickness design.

The design traffic was based on traffic counts conducted in December, 2000. For a 20 year design period and no traffic growth the cumulative design traffic was calculated to comprise just 53000 commercial vehicles.

The LOCKPAVE-PRO 2001 program showed that, for the subgrade and traffic conditions listed above, the thickness of unbound granular base required beneath 80mm Ecoloc pavers was 100 mm. This is the minimum thickness of base normally permitted for use under traffic. In other words, the structural design requirements for the Smith Street pavements were nominal.

3.2 Hydraulic Design

The PC-SWMM program showed that the hydraulic requirements required a greater basecourse thickness than that needed for the traffic loads. The design storm was originally selected as 124 mm/h. The design intent was that, for this storm, there should be no surface runoff from the pavement. To achieve this required the thickness of unbound granular base required beneath 80mm Ecoloc pavers to be 200 mm.

3.3 Pavement Details

In March, 2001, the pavement design was finalised and submitted to Manly Council. This comprised:

80mm	Ecoloc pavers
30mm	2-5mm bedding course
200mm	Open graded granular basecourse
	Bidim filter fabric
150mm	Compacted subgrade

The design given above needed to be varied when the contractor had difficulty locating suitable base material and submitted specifications for a non-conforming basecourse. This comprised 20APS (20mm) base material that recently had been used successfully at Nowra Naval Airport. This material did not, however, meet the eco-paving grading requirements specified in the original design. Moreover, laboratory tests of the material gave permeability values between 1 x 10^{-5} m/s at modified maximum dry density (MDD) and 2 x10^{-5} m/s at standard MDD. Normally, in an eco-pavement, the permeability of a granular basecourse at modified MDD should exceed 2 x 10^{-5} m/s. In other words the non-conforming base had only about half the permeability customarily required in eco-pavements. PC-SWMM analyses showed that the pavement as constructed was capable of accepting rainfall of approximately 60mm/h i.e. about half of the original design storm intensity. Despite this, as discussed below, the pavements have performed well without flooding since being opened to traffic in early 2002.

Details of the pavement construction and the finished project are shown in Figures 1 and 2.

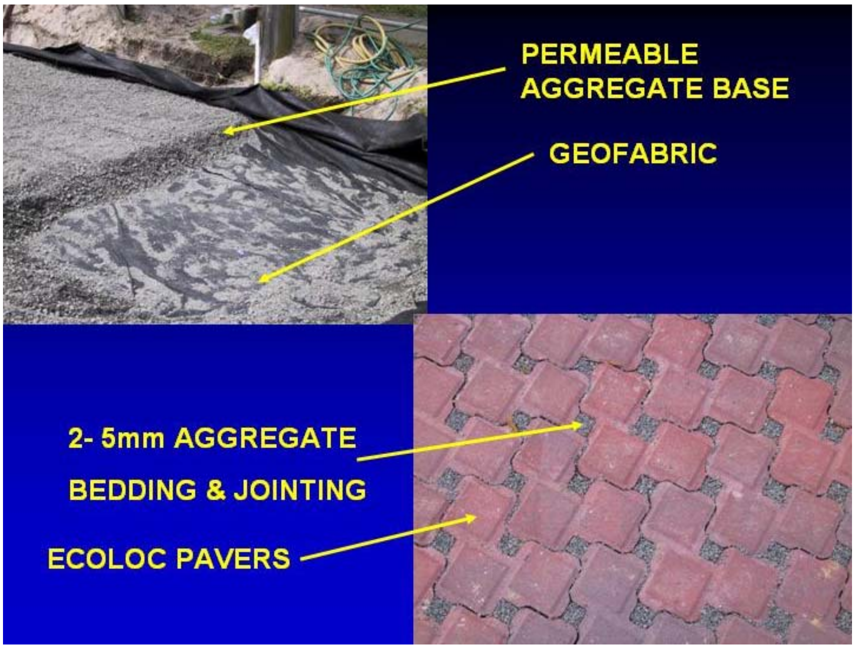

Figure 1. Details of basecourse and surface construction.

Figure 2. The finished pavement.

4. STORMWATER MONITORING

The following equipment was installed to monitor stormwater at Smith Street:

- Pluviometer: A Hydrological Services 0.2mm tipping bucket pluviometer was installed. This instrument recorded rainfall continuously.
- Data logger: A Hydromace 2000 data logger controlled the sensors and stored the recorded signals for downloading to the School of Civil and Environmental Engineering hydrological archives.
- Surface Seeker level sensor: The surface seeker level sensor used to detect the level of the water surface in the gutter at Smith Street was an instrument developed by UNSW for accurate detection and measurement of low flow depths. While this instrument was calibrated to 0.1mm accuracy, the application of this instrument in the field had a lower accuracy due to various field influences such as short period wave motion, irregularities in channel invert, etc. Nonetheless, it was considered that the instrument could measure accurately to 1mm.
- Automatic grab sampler: A Gamet automatic sampler was installed to collect grab samples for subsequent chemical analysis. The sampling protocol was that when the flow level reached 0.008 m, the sampler would be activated. The sample volume collected was 1 L with a maximum of 24 samples collected at constant 10 minute time intervals during an event. Figure 3 is a photograph of a Gamet Sampler and the sample bottles.
- Bore: A borehole to the groundwater system was installed also. This borehole was provided with multi-level peizometers to enable water samples to be collected at different depths within the aquifer underlying Smith Street.

Figure 3. Gamet grab sampler showing sample bottles.

Figure 4 shows details of the gutter in Smith Street. It will be noted that the pavers were laid to the kerb to forms the gutter and that a shed was installed over part of this gutter to house all the instruments listed above except for the pluviometer. The monitoring shed was located on the footpath and tree surround so that it would not disrupt the flow of water in the gutter at the edge of the road.

Figure 4. The stormwater monitoring station at the gutter.

Two other monitoring stations have been set up elsewhere in the catchment and its outfall by UNSW and Sydney Water.

5. CATCHMENT MODELLING

As part of the Manly Council Stormwater Re-use Project, a catchment modelling system was implemented for the Pine Street Catchment to enable assessment of the local impacts of the project and the potential extrapolation of the techniques applied to both other regions within the Pine Street Catchment and other catchments with similar development and hydrological characteristics. The catchment modelling system employed for this was embodied in the software known as XP-SWMM which is distributed by XP-Software. The basis of this modelling system is the US EPA SWMM model which has been developed continuously over the past thirty years for the simulation of the quantity and quality of stormwater runoff from urban areas. (As noted above, the same EPA software provided the basis for the hydraulic design of the pavement structure.)

There were a variety of reasons for selection of the XP-SWMM modelling system. Firstly, this modelling system is capable of simulating both the quantity and quality of stormwater runoff from an urban catchment. Additionally, within this modelling system, it is possible to distinguish between the different types of impervious area that are directly connected to the drainage system. For the Pine Street catchment, the two dominant forms of directly connected impervious areas are the road surfaces and the roofs of houses. Of these two catchment surfaces, the road surfaces will be impacted by the change in pavement type (i.e. replacement of the asphaltic surface with porous Ecoloc pavers) while the second type of directly connected impervious catchment surface is not influenced by the STAR project.

At the present moment, calibration and validation of the results obtained from XP-SWMM is being undertaken.

6. ATTAINMENT OF PERFORMANCE INDICATORS

The project will need to be monitored over some extended time and, at present, there are insufficient reduced data to allow substantive conclusions. Nonetheless, analysis of the initial data suggests the following impacts

- *Catchment Imperviousness* - Initially the Smith Street subcatchment (of area approx 0.6ha) within the Pine Street catchment was 45% effectively impervious with the road contributing 20% of the effective imperviousness within the subcatchment. Following the construction and implementation of the porous pavers in Smith Street, it would appear that the effective imperviousness of the Smith Street subcatchment has decreased to below 20% of the total catchment area. It should be noted, however, that pavement monitoring began under drought climatic conditions.

  For the majority of storm events that occur in the Manly region, the total depth of rainfall will be less than 100mm. At the same time, for generation of stormwater runoff from pervious areas in a catchment, more than 70mm of rainfall is required; for the Smith Street subcatchment, however, the depth of rainfall required to produce surface runoff from pervious areas will be greater than 70mm due to the high permeability of the underlying sandy soils.

  As a result of this preliminary change in imperviousness within the Smith Street subcatchment, it would appear that there is about a 60% reduction in the volume of stormwater runoff occurring in the subcatchment. The importance of this result is that there is a significant decrease in the volume of stormwater runoff and hence a significant decrease in the capacity of the stormwater runoff to transport contaminants.

- *Depression Storage* - The depression storage is a measure of the depth of rainfall prior to the generation of stormwater runoff. For most impervious areas, such as roads, the depression storage is typically 1mm or less. For the Smith Street subcatchment, it would appear from a preliminary analysis that the depression storage has increased to approx 4mm. This increase in the depression storage, like the decrease in imperviousness, will lead to a significant reduction (particularly in the small frequent storm events of, say 5 to 20mm total depth) in the volume of stormwater runoff from frequent storm events.
- *Water Quality* - Stormwater quality has been monitored at Smith Street. Dry weather samples (primarily dust and other gross pollutants) have been collected from the Pine Street catchment and analysed for chemical constituents in the fine dust fraction and for the constitution of the sample.

Stormwater quality at the Smith Street site has been found to be consistent with road surface runoff monitored at other sites such as QANTAS Drive, Hume Highway at South Strathfield, and the Princes Highway at Gymea. Similar to the previous sites, it was found that 90% of the phosphorous in the stormwater runoff is in a particulate form and that between 80% and 100% of the trace metals are in a particulate form also. This contaminant fractionation is shown in Table 1.

Table 1. Trace Metal Levels at Smith Street.

Contaminant	**Fe (μg/L)**	**Mn (μg/L)**	**Zn (μg/L)**	**Pb (μg/L)**	**Cu (μg/L)**	**Al (μg/L)**
Particulate	19600	136	553	354	195	19200
Soluble	36	0.9	16	< DL	18.4	57.6
Ratio of Particulate to Total	1.00	0.99	0.97	N/A	0.87	1.00

DL - detection limit

An initial estimate of the effective imperviousness of the Smith Street subcatchment (area approx 0.6ha) was that 45% of the catchment reacted in an impervious manner with the road contributing 45% of the effective impervious area or, in other words, the road was 20% of the catchment area. Following construction and implementation of the porous pavers in Smith Street, the road surface has been changed from being impervious to a highly pervious surface. This means that the area of impervious surface within the catchment has been reduced from 45% to below 25% (as runoff from the household roofs is transported over the porous pavers where losses may occur prior to entering the underground drainage network).

Rainfall and runoff in the Smith Street catchment have been monitored from June 2002. Because of the drought-like conditions then existing, only two runoff events were recorded. Table 2 details the relevant features of these two events and typical runoff data are shown in Figure 5.

The two events have been analysed to provide a preliminary assessment of catchment runoff characteristics and show that the catchment runoff was less than 1% of the potential catchment runoff. For both events described in Table 2 peak gutter water levels were far below what would normally be expected from an impervious road surface. The results suggest that, for low intensity storm events, the porous pavers acted in a manner analogous to an equivalent pervious area. It should be noted, however, that no significant storm events had occurred at the time of writing this paper due to the climatic drought conditions existing in Sydney.

Table 2. Details of Monitored Runoff Events.

	Event 1	**Event 2**
Event Date	18/8/2002	30/9/2002
Rainfall Prior to Runoff	11 mm	2.4 mm
Rainfall during Runoff Period	1.2 mm	1.4 mm
Total Rainfall During Event	13.4 mm	5.4 mm
Estimated Total Potential Runoff Volume	13.4 m3	5.4 m3
Measured Peak Gutter Water Level	9 mm	9 mm
Estimated Peak Gutter Flow	0.2 L/s	0.2 L/s
Approx. Duration of Flow	10 mins	3 mins
Estimated Runoff Volume	0.12 m3	0.036 m3
Estimated % Runoff	0.9 %	0.6 %

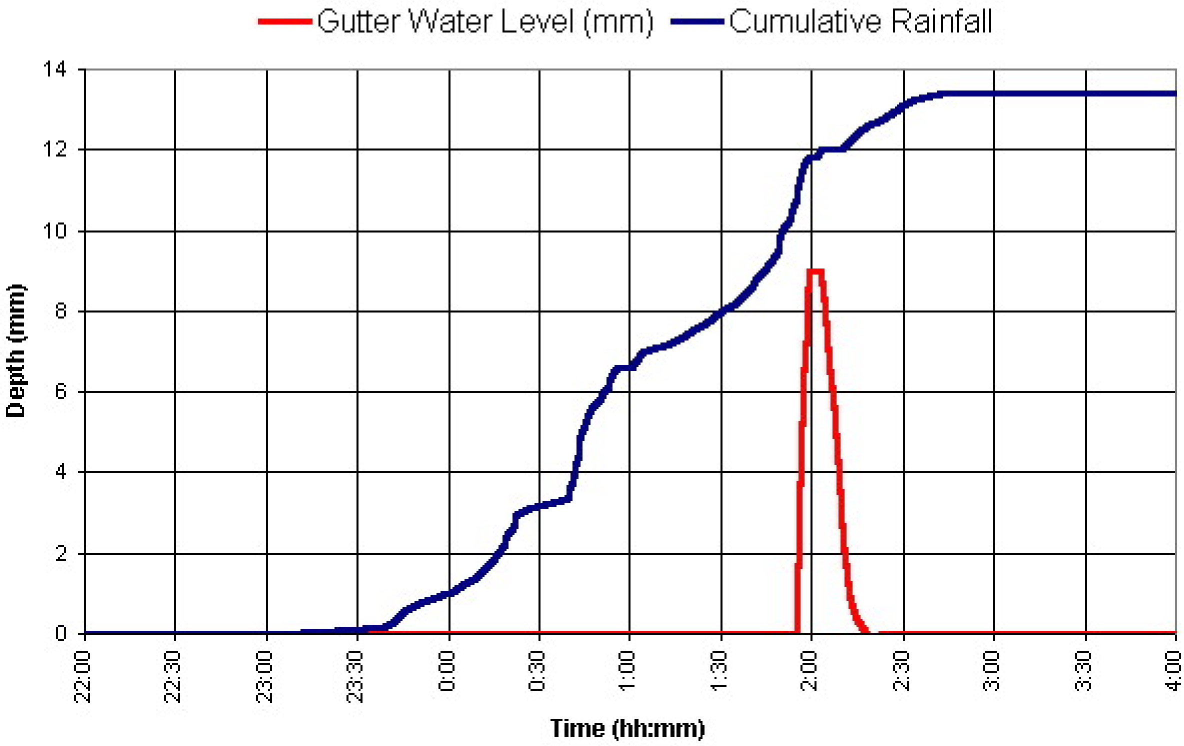

Figure 5. The Runoff Event of 18/8/2002.

As anticipated, as a result of the increased road perviousness, the volume of stormwater runoff occurring within the Smith Street sub-catchment was significantly reduced. This reduction in stormwater volume also resulted in a significant decrease in the capacity of runoff to transport contaminants from the catchment.

7. CONCLUDING COMMENTS

Public reaction to the reconstruction of Smith Street was initially hostile because of the disruption and inconvenience caused by construction operations. However, following completion, this changed to enthusiastic acceptance. In addition to the obvious advantages in reducing or eliminating local flooding and improving water quality, the improved aesthetics of the street led to significant increases in property values and local residents appear pleased with both the concepts and implementation of permeable paving.

Implementation of the permeable pavements posed few problems in design or construction. The principal problem confronting engineers wishing to use permeable paving is to obtain high quality basecourse materials that are adequately permeable. Such materials exist but are not yet generally offered by local suppliers. Further work in developing and marketing such materials is desirable.

Although it will be necessary to continue to monitor the performance of Smith Street for some time, early results demonstrate that the permeable eco-pavement has significantly reduced the runoff from the street and, thereby, has reduced the capacity for pollutants to be carried to the storm water system. Overall, there appears to be about a 60% reduction in the stormwater runoff from the Smith Street subcatchment attributable to the use of permeable paving. At the same time the depression storage has increased about fourfold. This will significantly reduce the runoff from frequent storm events.

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THE CHALLENGES OF CONCRETE BLOCK PAVING AS A MATURE TECHNOLOGY

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