Using permeable pavements to promote street tree health, to minimize pavement damage and to reduce stormwater flows

T. Lucke[1*], T. Johnson[2], S. Beecham[2], D. Cameron[2], and G. Moore[3]

[1] *School of Science and Education, University of the Sunshine Coast, Sippy Downs Campus, Maroochydore, 4558, Queensland, Australia*
[2] *School of Natural and Built Environment, University of South Australia, Mawson Lakes Campus 5095, Adelaide, Australia*
[3]*National Trust of Victoria Significant Tree Register Committee Chair, Melbourne 3000, Australia*
**Corresponding Author e-mail: tlucke@usc.edu.au*

ABSTRACT
One of the guiding principles of water sensitive urban design is mitigating the adverse effects of urban stormwater runoff such as increased urban flooding and deteriorating receiving water quality. Street trees can be used as water sensitive urban design measures and they have been shown to substantially reduce nitrogen and other pollution loads in stormwater. However, urban planners and local council designers have often been reluctant to include trees as part of their urban street designs in the past due to the susceptibility of pavements to damage by tree roots. Permeable pavements may offer a solution to a number of the common problems associated with incorporating street trees into urban landscapes.

This paper reports on a new experimental research project to assess and quantify the long-term performance of permeable pavements in reducing stormwater flows and pollution loads, reducing the incidence of structural damage to pavements by tree roots and in promoting healthier and faster growing trees under typical Australian conditions. Three separate paving configurations were used in the field trials; two pavements were constructed as permeable pavements and the third was constructed as a typical impermeable pavement. Initial experimental results are presented and these suggest that trees planted with permeable pavement surrounds generally have a higher growth-rate than trees planted with impermeable surfaces.

KEYWORDS
Permeable pavements, street trees, stormwater reduction, pollution reduction, root damage.

INTRODUCTION

WSUD and Street Trees
Water sensitive urban design (WSUD) aims to achieve integrated water cycle management for the development or redevelopment of urban areas. One of the guiding principles of WSUD is mitigating the adverse effects of urban stormwater runoff such as increased urban flooding and deteriorating receiving water quality (Lucke, 2011). Local government authorities now routinely incorporate various treatment devices into the urban landscape as stormwater best management practices (BMPs) to assist in achieving WSUD objectives.

One of the main problems associated with stormwater discharge is the negative impacts that its high nutrient levels can have on downstream aquatic environments (Denman et al., 2006). Elevated nutrient levels in stormwater contribute to eutrophication of streams and coastal environments and this can have devastating consequences for aquatic marine life (Islam and Tanaka, 2004). Stormwater treatment by WSUD measures such as biofiltration systems, vegetated swales and other vegetated devices have been shown to significantly reduce the nutrient loadings in stormwater runoff (Hatt et al., 2009; Davies, 2007). However, vegetated WSUD treatment systems generally require a significant footprint to function correctly and this is often difficult to provide in typically congested urbanised areas.

Street trees are a highly desirable part of the urban landscape that can also be used as WSUD measures. As part of their natural growth cycles, they have been shown to substantially reduce nitrogen and other pollution loads in stormwater (Denman et al., 2006; Read et al., 2010). Street trees are also known to significantly reduce stormwater runoff volumes from urban catchments (McPherson et al., 1999). Street trees can therefore offer the same or improved environmental benefits as bioretention and other vegetated systems. However, they do so without taking up excess valuable urban street space. The other significant benefits of urban street trees, such as their aesthetic value and their social and economic benefits are also well documented (Roberts et al., 2006).

Street Tree Issues

In the past, urban planners and local council designers have often been reluctant to include trees as part of their urban street designs as there has been a perception that this increases overall lifecycle costs, particularly due to pavement damage by tree roots (McPherson and Peper, 1996). If the value of trees was considered at all, it was generally only for their amenity value and this was readily discounted against future potential maintenance costs. The economic implications of this damage are substantial and can include infrastructure maintenance and replacement costs, risk of potential injury and associated claims, administrative costs, poor public relations, reduced property values and reduced tree health and longevity.

A study of the infrastructure repair costs of municipal councils in 15 different US cities was undertaken by McPherson and Peper (1996). They reported that the cost for repairing infrastructure damaged by street trees consumed an average of 25% of the total tree budget allocated for these cities. However, they also recognised that these maintenance costs were conservative as sewer repair and other costs borne by home owners were not included in these estimates. Various other studies have reported on the significant structural damage caused by tree roots (Hamilton et al., 1975; McPherson, 2000; Costello and Jones. 2003; Randrup et al., 2003) and the associated economical impacts of that damage.

There are a number of factors that can contribute to preventing healthy street tree growth in urban environments. Air pollution, poor drainage and damage by people and vehicles can shorten the life expectancy of urban trees (Smiley et al., 2006). However, a lack of suitable soil conditions to promote root growth is the most common cause of poor tree health. The high levels of soil and base course compaction required to support the pavement loadings can become problematic for a tree that is planted close to pavement (Grabosky et al., 2009). The compacted soil often hinders or excludes root growth by limiting their access to the water and mineral resources contained in the soil.

To address the issue of compacted soils limiting tree root growth, a variety of structural soils have been developed in recent years (Smiley et al., 2006; Grabosky et al., 2009). These structural soils have been used as alternatives to typical compacted soils and often contain large proportions of aggregate to bear the weight of the overlying pavement and vehicular traffic in urban areas. Other materials have also been successfully used to minimise the effects of soil compaction on urban tree root growth. Smiley et al. (2006) conducted a study on tree growth in a variety of structural soil types and also trialled a method of suspending a pavement on piers above an uncompacted soil. They found that trees planted in non-compacted soil beneath the suspended pavement were generally larger, faster growing, healthier and had more root growth than in the other treatments.

Randrup et al. (2003) suggested that certain pavement construction methods may even promote damage to pavements by tree roots. They explained that a concrete or asphalt pathway can act as a barrier that prevents soil moisture loss by evaporation. This evaporation barrier causes the soil moisture to condense on the underside of the pavement because of temperature differences between the soil and the pavement. Tree roots are therefore naturally attracted to the condensation at the soil/concrete interface and this leads to pavement surface damage through the radial forces generated during root growth. Randrup et al. (2003) proposed that pavements constructed from porous materials that limit condensation and lower the temperature under concrete slabs may reduce the incidence of rooting at the interface and the subsequent damage this can cause.

There has been considerable research on the negative environmental impacts of treeless streets (including enhanced heat island effects) and growing concerns about the impacts of climate change have helped bring about a change in attitude toward urban street trees by town planners and designers (Shashua-Bara and Hoffman, 2000). The considerable economic and environmental benefits that urban street trees provide are now being duly recognised. Recognition of the fundamental role that street trees play in urban environments has led to research into new methods of implementing street trees that have potentially lower maintenance costs and that promote healthier and faster growing trees.

Permeable Pavements and Street Trees

Permeable pavements may offer a solution to a number of the common problems associated with incorporating street trees into urban landscapes. Permeable pavements allow stormwater to infiltrate through the paving surface where it is filtered through the various layers and then either harvested for later reuse or released slowly into the underlying soil or downstream stormwater drainage system (Lucke and Beecham, 2011). Permeable paving can be used as an alternative to the conventional hard, impervious surfaces that typically surround trees in footpaths, roadways and carparks. Providing that permeable pavements are correctly designed and installed, they have the potential to successfully minimise the incidence of pavement damage by tree roots, to promote healthier and faster growing trees and to reduce stormwater runoff and pollution loads from urban areas.

Figure 1 shows a comparison between a typical street tree configuration planted under a concrete or asphalt pavement and a street tree configuration planted within a permeable pavement.

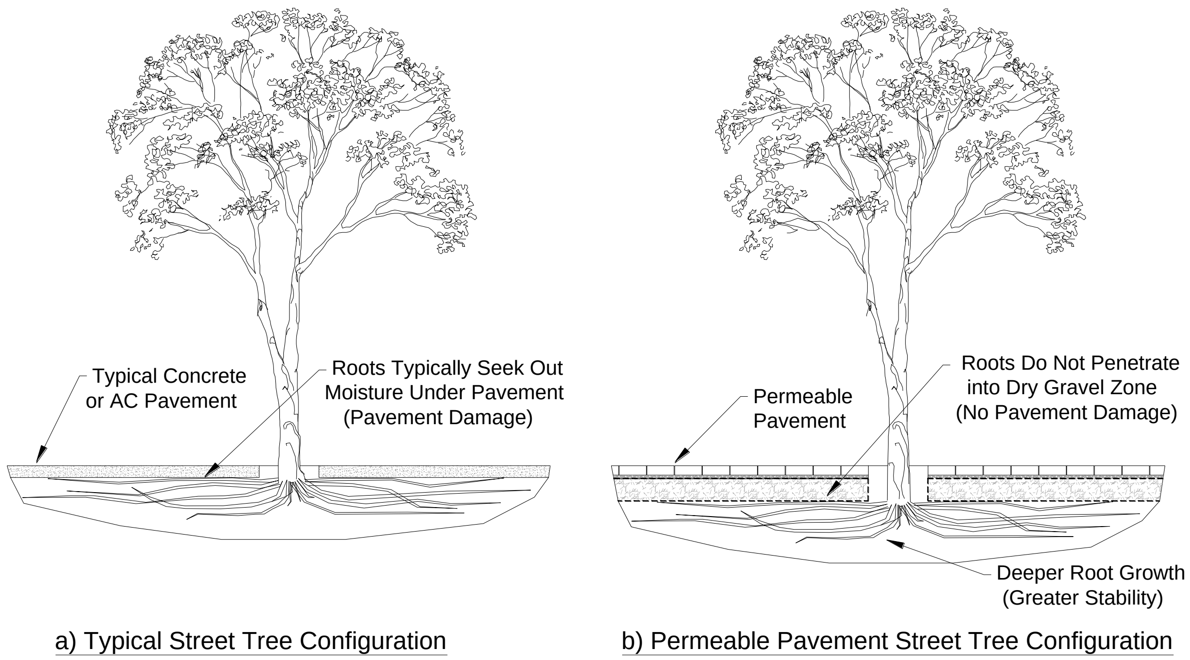

Figure 1. Permeable Pavement with Street Tree Design Concept

Figure 2 shows the concept design for a permeable pavement and street tree system. Rainfall and runoff infiltrate through the permeable pavement layers and are filtered through the various paving bedding and basecourse layers. The treated stormwater then infiltrates further into the tree root zone in the sub-grade loam beneath the pavement. The increased water and air infiltration promotes healthier and faster growing trees and also results in decreased stormwater volumes and pollution loads downstream. The deeper root zone also provides greater tree stability. As the paving base layers are self-draining and contain no soil particles, tree roots should not seek out water and nutrients in this zone. This should minimise the incidence of pavement surface damage by tree roots. Repairing any surface damage that does occur should also be a simple and cost-effective operation.

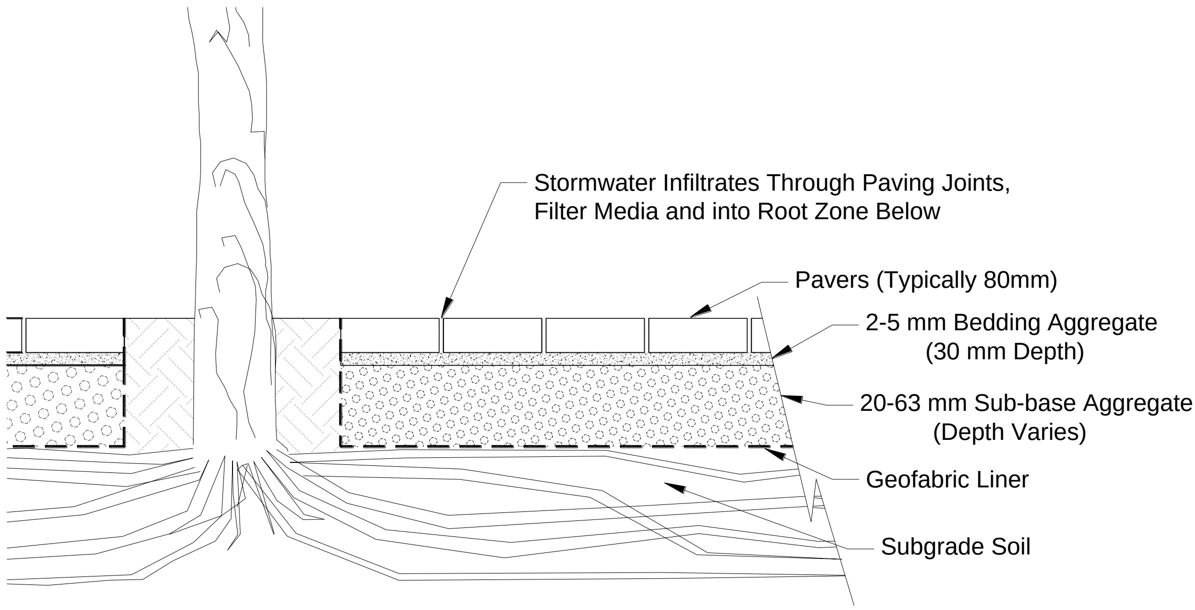

Figure 2. Permeable Pavement with Street Tree Design Concept

EXPERIMENTAL STUDY

A new experimental research project has commenced at the University of the Sunshine Coast (USC) in Queensland, Australia. The research project is sponsored by the Sunshine Coast Regional Council and involves collaboration with researchers at the University of South Australia (UniSA). The aims of this study are to assess and quantify the long-term performance of permeable pavements in reducing stormwater flows and pollution loads, in reducing the incidence of structural damage to pavements by tree roots and in promoting healthier and faster growing trees under typical Australian conditions. The study will also investigate the suitability of various indigenous Australian tree species for use in permeable pavement installations.

The research project at USC was designed to address research needs previously identified by previous investigations. For example, Helliwell and Duncan (cited in Randrup et al., 2001) recommended that fundamental research into the geotechnical and physical conditions that prevent root extension needs to be undertaken. This included the effects that different construction techniques and base materials have on the growth responses of different tree species and an investigation into the interaction between roots and infrastructure, as well as the soil moisture regime under paving systems, for a range of natural and manufactured soils. Randrup et al. (2001) suggested that pavements constructed from porous materials may reduce the incidence of rooting at the interface and the subsequent damage that this can cause.

The field study experimentation at USC has only recently commenced and therefore the experimental results presented in this paper are from the parallel field study currently underway at UniSA. In this study, a total of 18 new street tree-permeable pavement systems were installed in a residential street in Adelaide in September 2009. The study was designed to compare the effects that different paving configurations have on tree health and surrounding soil conditions. All 18 trees planted in the street tree-permeable pavement systems used in this experimental study are Chanticleer pear (Pyrus calleryana 'Glen's Form' Chanticleer) trees. Chanticleer pear was selected for use in the field trials because it is is widely planted by local government authorities in Adelaide and it has proven to have a reliable growth rate under local conditions.

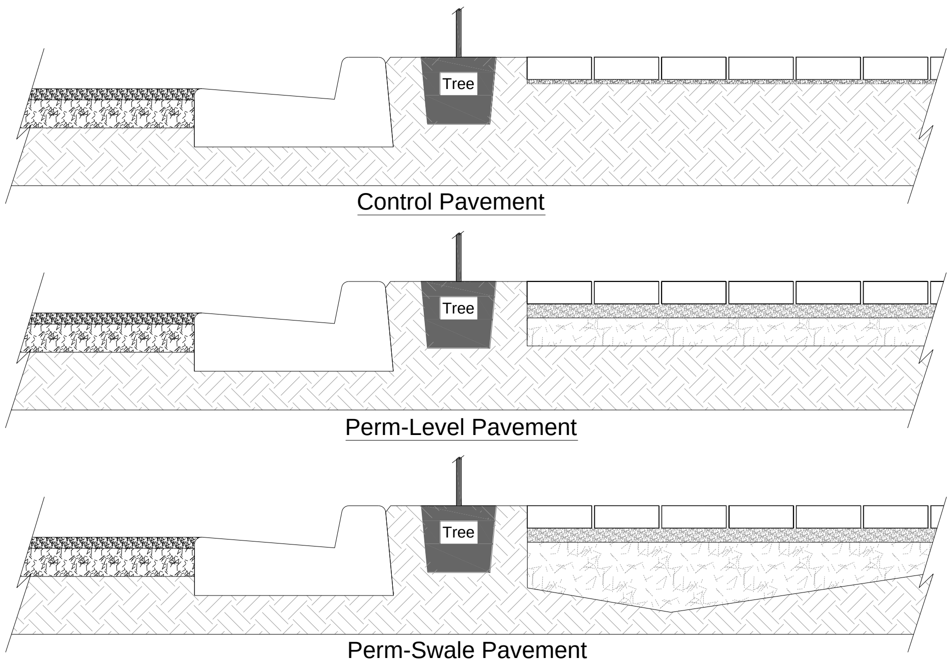

Figure 3. Three Different Pavement Configurations

Three separate paving configurations were used in the field trials, namely, a Perm-Level configuration, a Perm-Swale configuration and a Control configuration. The three different configurations are shown in Figure 3. The Perm-Level Pavement configuration was similar to the pavement structure shown in Figure 2. However, the depth of the 2-5 mm bedding aggregate was 50 mm and the depth of the sub-base aggregate was 100 mm. This gave a total pavement depth of 230 mm (Figure 3). The Perm-Swale Pavement was similar in construction to the Perm-Level configuration except that the subgrade was shaped into a swale and the depth of the sub-base aggregate was 250 mm in the centre of the swale. This gave an overall pavement depth of 380 mm in the centre of the swale. The centre of the swale was one metre in from and parallel to the kerb (Figure 3). The Control Pavement configuration was a typical block paving construction of conventional, impermeable pavers laid on 15 mm of paving sand (Figure 3).

There were six separate Chanticleer pear tree samples for each of the three configurations shown in Figure 3 (18 samples in total). The 18 Chanticleer pear trees were planted in September 2009. The rates of tree growth as well as the soil moisture and oxygen levels were recorded on five different occasions between 15th September 2009 and 25th February 2011. Measurements of the trees' overall heights, canopy spread, leaf area index and trunk diameters at ground level and elevations of 300mm, 1000mm and 1400mm above ground level were taken. The initial tree height measurement results are presented in this paper.

Tree Cell Trials

Another part of the new research study at USC will investigate and evaluate the performance of a new product called StrataCell™. This product was developed to promote healthy tree root growth and to provide support and stability to pavements that are constructed above the tree roots. The new product prevents compaction of the soil underneath the pavement by creating a skeletal support structure that keeps pavement loads off the soil under the pavement. This allows unencumbered tree root growth in the uncompacted soil between the StrataCell™ units. A typical StrataCell™ application under pavement is shown in Figure 4.

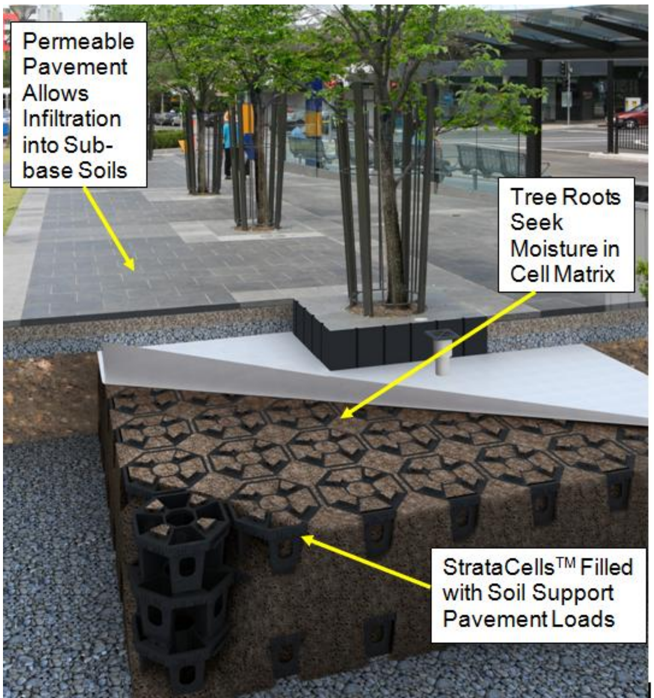

Figure 4. Typical StrataCell™ Application (*http://www.citygreensystems.com*)

A number of street tree-permeable pavement systems will be planted in the USC study to evaluate the effect that the StrataCell™ has on tree health and root growth. Tree and root growth will be monitored together with the soil moisture conditions under the pavement. Grabosky et al. (2009) suggested that infiltration and permeability data of permeable pavement systems may be helpful for stormwater management and hydrological design purposes, particularly for estimating water interception in sheet flows from pavements. They also highlighted the importance of providing a water holding reservoir for plant use in transpiration or deep infiltration below the pavement. The experimental results from this study should assist with the identification of these stormwater management design issues.

RESULTS AND DISCUSSION

Initial experimental results from 18 new street tree-permeable pavement systems installed in a residential street in Adelaide are shown in Figure 5. The heights of each of the 18 trees were recorded on five different occasions between 15th September 2009 and 25th February 2011. Figure 5 shows the average heights of the six trees in each of the experimental groups at the times of measurement.

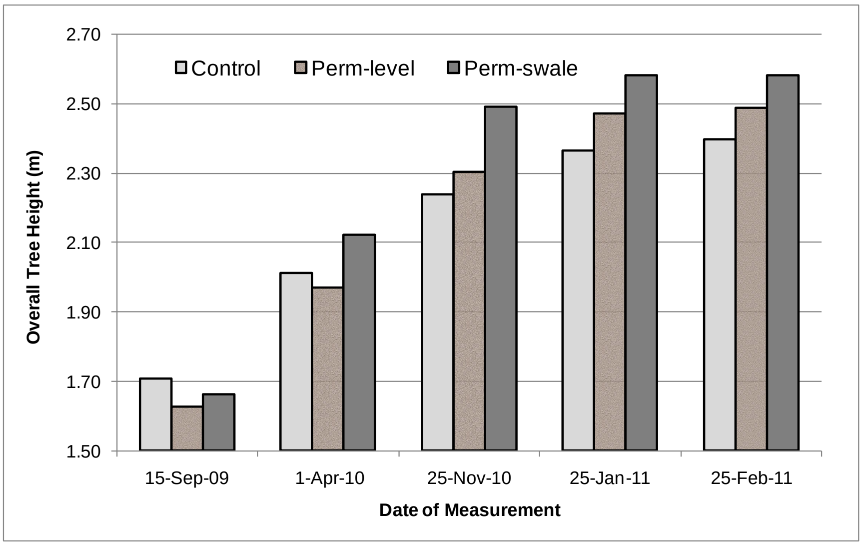

Figure 5. Initial Average Tree Height Measurement Results for the Three Groups

Figure 5 shows that trees planted with permeable pavement surrounds generally have a higher growth-rate than trees planted within the impermeable Control Pavements. Of the two permeable pavement groups, it appears that the six trees planted in the Perm-Swale Pavement configurations are growing faster than the trees planted in the Perm-Level pavement configurations. The reasons for this cannot be confirmed at this early stage of the study. As this experimental trial has only been running for less than two years, it is too early to make any long-term predictions on the effects of the different permeable pavements on the growth rates of the trees. It is expected that future results from this study should significantly increase knowledge in this area.

Moisture readings were taken at a variety of depths at three different positions in each of the 18 test pavements. Initial results indicate that the soil directly under the permeable pavement test pavements generally has less moisture than the soil under the Control pavements. This is thought to be due to evaporation through the permeable pavements. This could mean that tree roots that grow under the pavement will suffer during high temperature events due to lack of moisture. This could also mean less pavement damage due to tree root growth. However, further testing is required to verify these hypotheses.

CONCLUSION

This paper reports on a new experimental research project that has been designed to assess and quantify the long-term performance of permeable pavements in reducing stormwater flows and pollution loads, while reducing the incidence of structural damage to pavements by tree roots and in turn promoting healthier and faster growing trees under typical Australian conditions. Initial experimental results from 18 new street tree-permeable pavement systems have been very promising. Three separate paving configurations were used in the field trials; two pavements were constructed as permeable pavements and the third was constructed as a typical impermeable pavement. The initial results suggest that trees planted with permeable pavement surrounds generally have a higher growth-rate than trees planted within the impermeable control pavements. However, it is still too early to make any long-term predictions on the effects of the different permeable pavements on the growth rates of the trees. It is expected that future results from this study should significantly increase knowledge in this area.

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