STREET TREES IN PAVED URBAN ENVIRONMENTS – THE BENEFITS AND CHALLENGES

Simon Beecham[1] and Terry Lucke[2]
[1]Centre for Water Management and Reuse
School of Natural and Built Environments
University of South Australia
Mawson Lakes, SA 5095, Australia
Phone + 61 8 8302 5141, email: simon.beecham@unisa.edu.au
[2]Stormwater Research Group, University of the Sunshine Coast, QLD, Australia
e-mail: tlucke@usc.edu.au

Abstract

Street trees have long been associated with increased residential house prices and provide many environmental, economic and social benefits in both residential and commercial precincts. However, increased urbanisation has led to an exponential growth in impermeable surfaces which can increase the environmental stresses on street trees. This can often lead to tree roots spreading to areas that have more favourable growth conditions, which in turn can cause infrastructure damage and pavement uplift. The costly results of this natural growth have led researchers to investigate a range of preventative measures to both reduce pavement damage and to sustain tree health. This paper provides a review of the benefits provided by street trees, their perceived community values, the costs associated with inappropriate root growth and pavement damage, and most importantly the latest research on verified ameliorative measures for preventing pavement damage and improving tree growth.

Introduction

Urbanisation results in increasing areas of impervious surfaces within a catchment and this can change the natural drainage characteristics of the catchment. Pavements are an everyday part of the urban landscape that can have a significant environmental impact. Typically two-thirds of all the rain that falls on potentially impervious surfaces in urban catchments is falling on pavements (Ferguson, 2005), which are responsible for the generation of excess runoff that is often contaminated with heavy metals and hydrocarbons (Fletcher et al., 2005; Hatt et al., 2009). Impervious surfaces also inhibit groundwater recharge and this can result in local water shortages and other water balance problems. Pavements are very much at the forefront of the planning process for developers and local authorities because impervious surfaces can have such a major impact on downstream flooding, receiving water quality and on the health of natural ecosystems.

Street trees are often incorporated into urban developments because of the many environmental, economic and social benefits that they can provide. However, changes in the urban environment, particularly due to increasing impervious surface areas can place increasing stresses on urban forests and ecosystems (Martin et al., 2012). The central function of urban street trees has changed considerably over the last two to three decades. Their primary function has changed from a purely aesthetic role of beautification and ornamentation to a role providing significant environmental, economic or social benefits (Seamans, 2013).

Street trees have an important role in providing healthy urban communities and they can produce significant social impacts by improving human health, reducing crime, increasing community interaction and boosting property values (Burden, 2006). They also provide benefits such as energy conservation, stormwater reduction and increased air quality (Mullaney et al., 2014). Although street trees can provide multiple environmental, social and economic benefits, they can also cause disruptive and costly damage to pavement and other civil infrastructure.

This paper discusses the benefits of street trees and the challenges of growing trees in urban environments. It also describes a current field investigation into street tree irrigation using harvested road runoff. The paper should provide a practical resource for use by urban landscape designers, engineers, and council parks and gardens staff.

Benefits of Street Trees

Street trees improve the liveability of towns and cities in a number of ways including reducing stormwater runoff, increasing air quality, storing carbon, providing shade, and reducing urban heat-island effects. They can also enhance biodiversity by providing food, habitat and landscape connectivity for urban fauna (Burden 2006; Rhodes et al., 2011).

Research has shown that most urban residents have a positive view of street trees, and they believe that the benefits that street trees provide clearly outweigh any detriments (Sommer et al., 1989; Schroeder et al., 2006). Despite identifying potential problems such as falling branches, leaf litter, tree debris and infrastructure damage residents' attitudes to street trees remain positive. The aesthetic and practical attributes of street trees such as beautification, shade provision, increased property values, added privacy and noise reduction are rated highly by most city residents (Summit & McPherson, 1998; Flannigan, 2005; Zhang et al., 2007; Moskell & Broussard Allred, 2013).

Social Benefits

Green space within a city's boundaries can improve the urban environment by providing recreational opportunities and promoting contact between community residents. This encourages physical activity, reduces stress and stimulates social cohesion (Van Dillen et al., 2012). The presence of street trees have also been linked to reduced crime and increased public safety trees (Kuo & Sullivan, 2001; Tarran, 2009). For example, urban areas with higher levels of vegetation can have approximately 50% lower crime levels than areas with low levels of vegetation (Kuo & Sullivan, 2001). Street trees also act as a visual and physical barrier between motorists and pedestrians. Trees can help motorists assess their vehicular speed and provide a physical defence for pedestrians against vehicle injury (Tarran, 2009).

Stormwater Benefits

Increases in impervious surface areas due to urbanisation, can reduce water infiltration into the soil as well as increase stormwater runoff volumes and peak flow rates. Planting street trees in urban environments can significantly improve the overall water balance within a catchment. For example, depending on the site characteristics and the tree species, street trees have been shown to intercept large volumes of rainwater (McPherson et al., 2005; Bonifaci, 2010; Soares et al., 2011) and this can significantly reduce stormwater runoff volumes.

Street trees can also increase soil infiltration as leaves and branches intercept, absorb and temporarily store water before it evaporates from tree surfaces or gradually infiltrates into the soil. Increased soil infiltration due to interception by street trees also reduces stormwater runoff. Lower stormwater runoff volumes also directly reduce downstream pollution levels and minimise the need for stormwater treatment systems, which are often expensive and difficult to install.

Estimated annual reductions in stormwater runoff volumes range from 3.2 kL to 11.3 kL per tree, and the annual values assigned to stormwater reduction vary from A$3.4 to A$58 per tree (Figure 1). Five of the studies place the value assigned to stormwater reduction below A$8.50 per tree per year. However, three of the studies valued the trees at between $18 and $58 per tree. The reasons for these much higher values were not clear but may be due to differences in how the values were assigned. Either way, all of the studies reviewed in Figure 1 demonstrate that street trees can provide a significant reduction in stormwater management costs.

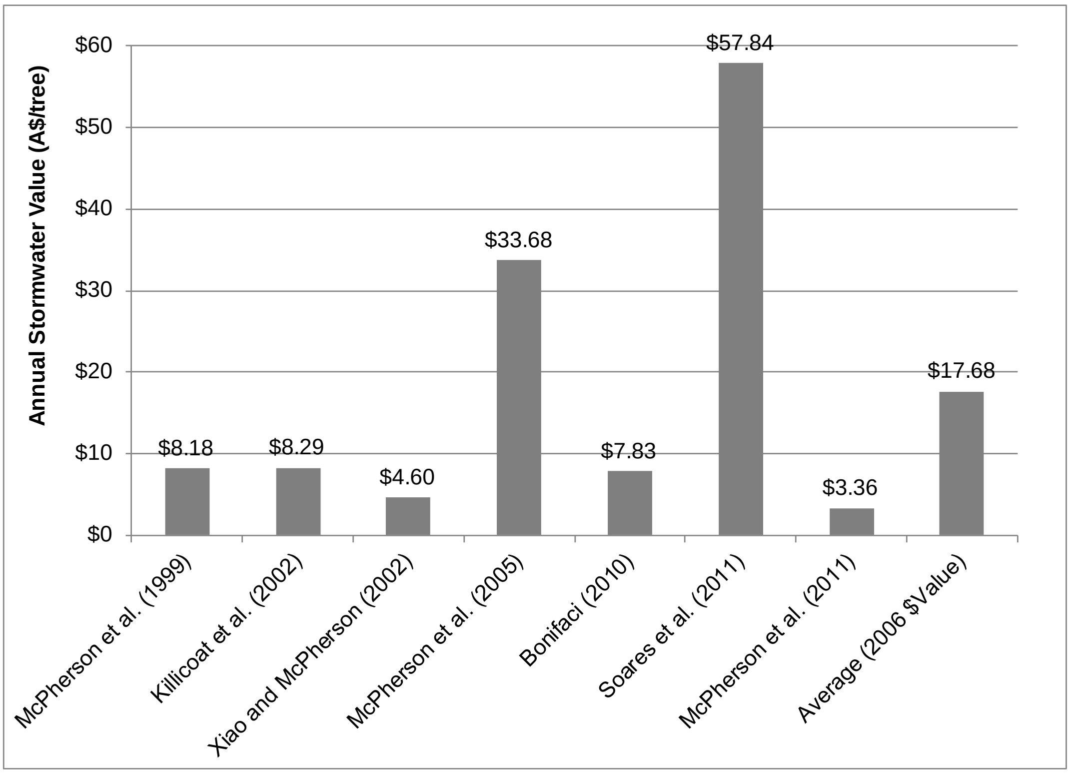

Figure 1 – Estimated Reduction in Stormwater Management Costs due to Street Trees (A$/tree)

Air Pollution Benefits

Traffic emissions and other fine particulate air pollution can cause serious health effects, including premature mortality, pulmonary inflammation, accelerated atherosclerosis, and altered cardiac functions. However, street trees can be particularly effective at capturing airborne pollutants in urban areas (Tallis et al., 2011). Some of the pollutants removed by street trees include ozone, nitrogen oxides, sulphur oxides, sulphur dioxides, carbon monoxide, carbon dioxide (CO_2). It has been estimated that large healthy trees can remove between 60 and 70 times more air pollution than smaller trees (McPherson et al., 1994). Street trees are an effective tool in reducing air pollution and creating healthier urban environments (Nowak et al., 2013). Reduction in energy use due to street trees also leads to reduced emissions of CO_2, nitrogen dioxide, very fine particulate matter and volatile organic compounds.

The economic benefits from removing air pollution range from $0.34 to $42/tree/year (Figure 2). The large variation in the results is possibly due to different locations, tree sizes and tree species.

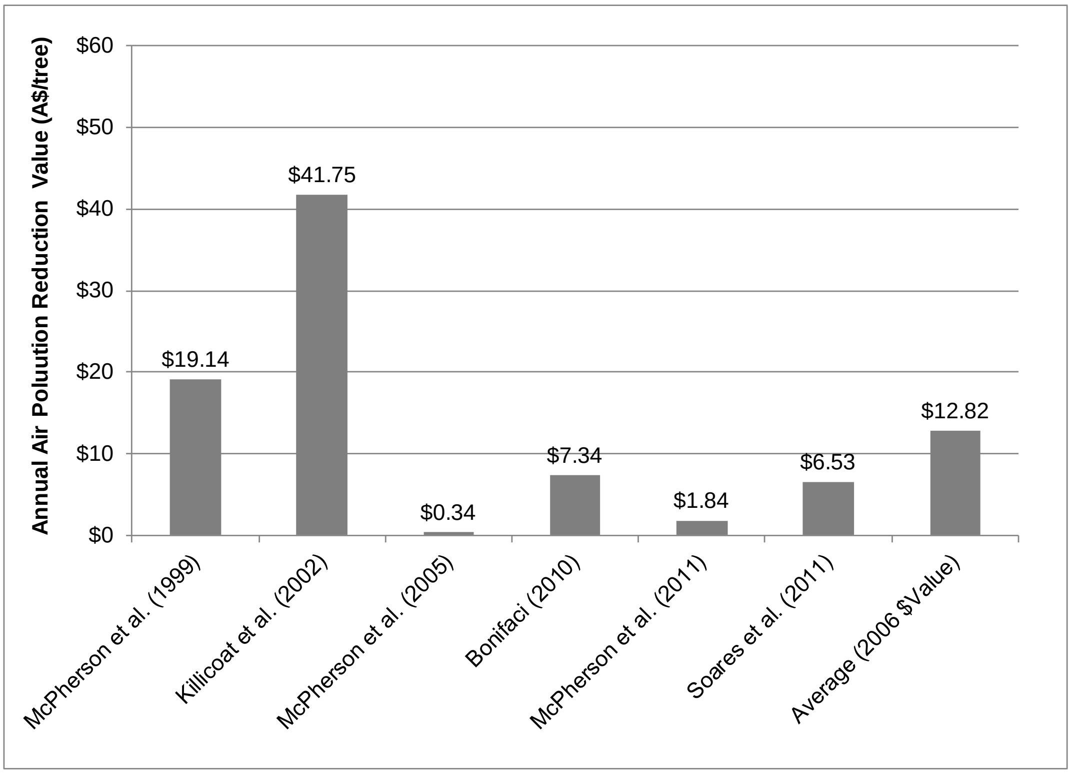

Figure 2 – Estimated Air Pollution Saving due to Street Trees (A$/tree)

Carbon Benefits

The "greenhouse effect" is caused by CO_2 and other gases trapping heat generated from the earth in the atmosphere and prohibiting the heat from being released into space. Urban forests and street trees can help to improve our air quality by removing (sequestering) CO_2 from the atmosphere during photosynthesis (Ferrini & Fini, 2010). This process produces carbohydrates required for tree growth and returns oxygen back into the atmosphere as a by-product. Roughly half of the greenhouse effect is caused by CO_2. Therefore, trees act as carbon sinks, alleviating the greenhouse effect.

To put this into context, Moore (2009) estimated that the inner-city tree population of Melbourne, Australia (~100,000 trees) had sequestered more than one million tonnes of carbon since they were planted. The economic benefit of CO_2 reduction by street trees is less than that of other benefits. However, the values of street tree carbon sequestration still range between $0.4 and $6 per tree/per year (Figure 3).

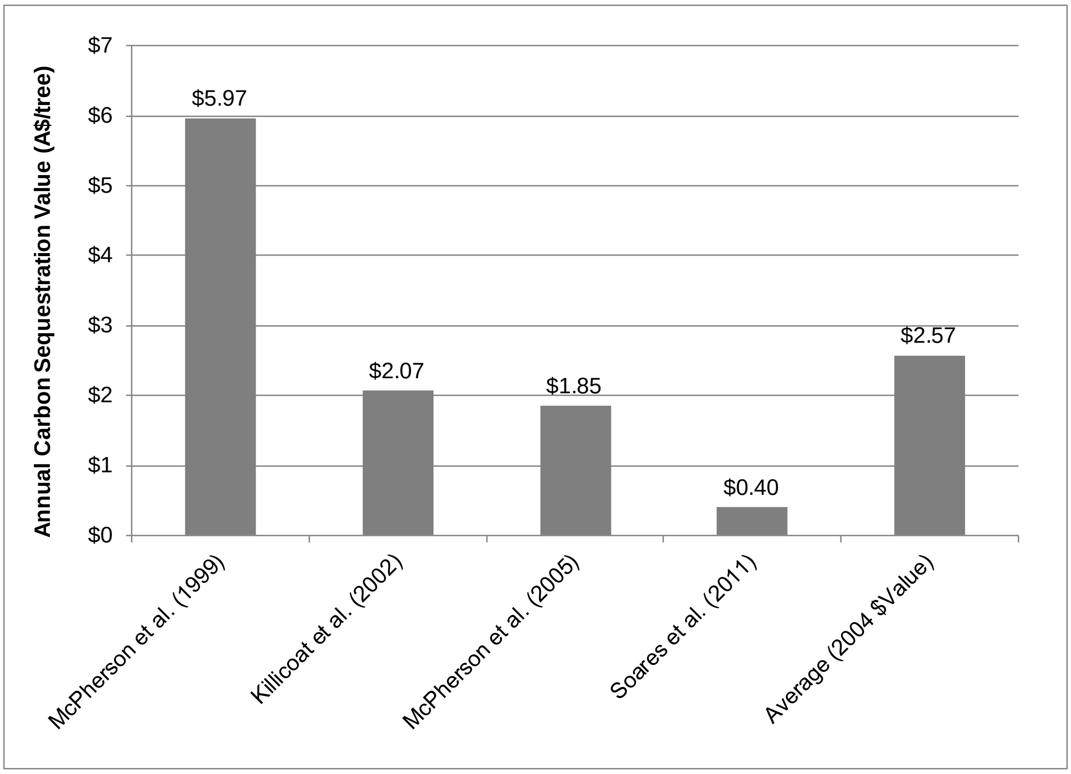

Figure 3 - Estimated Annual Carbon Sequestration Value of Street Trees (A$/tree)

Energy Benefits

Street trees provide energy savings through their shading and cooling effects in summer and the wind-chill protection they offer in winter. The cooling effect provided by trees is directly related to tree size, canopy cover, tree location, and planting density. As much as 80% of the cooling effect of trees results directly from shading (Shashua-Bar & Hoffman, 2009). Street trees can reduce daytime temperatures by between 5°C and 20°C, making everyday activities more pleasurable and healthier (Killicoat et al., 2002; Burden, 2006).

Energy cost reductions due to street trees have been estimated at between $2.6 and $77 per tree/per year (Figure 4). The reasons for the particularly high value of $77.44 by Killicoat et al. (2002) were not clear but may be due to the very-different energy use assumptions and assigned cost values used in the study. Average savings in electricity due to street trees have been estimated at 95 kWh/tree/year, equating to an annual saving of US$15/tree/year (McPherson et al., 2005). A later study calculated a power saving of 30 kWh/tree/year (Moore, 2009).

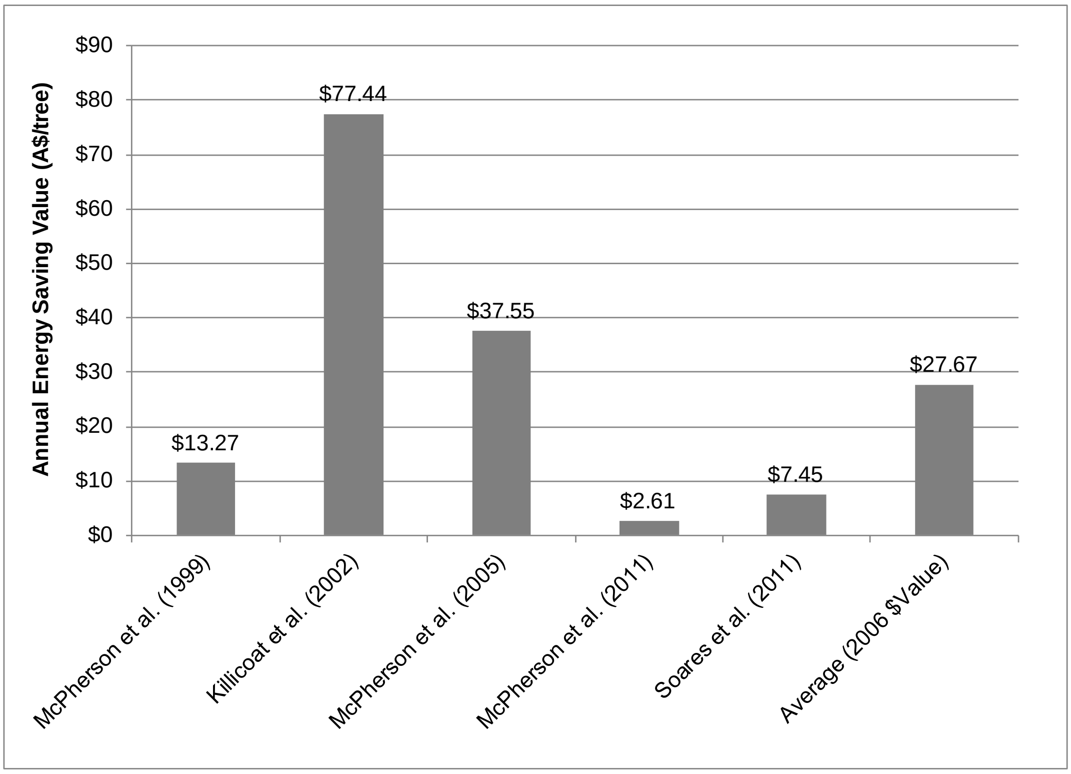

Figure 4 - Estimated Annual Energy Saving due to Street Trees (A$/tree)

Benefit Rankings

The ranked estimated annual street tree benefits are in shown in Figure 5.

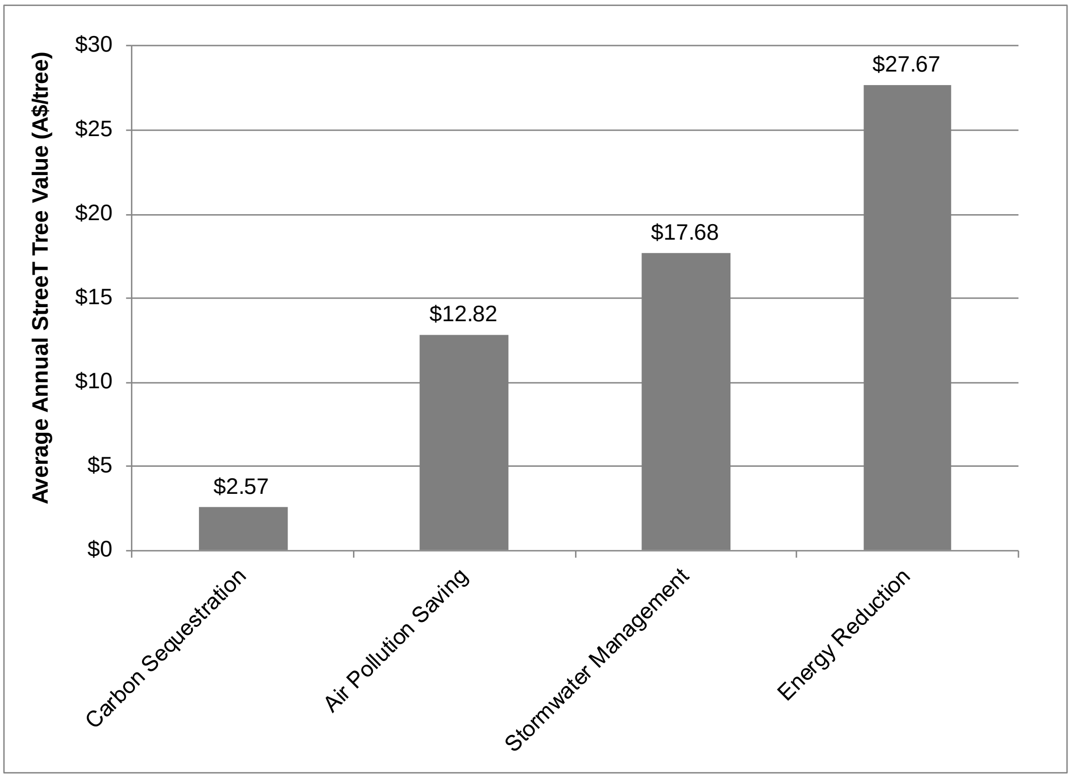

Figure 5 - Estimated Annual Street Tree Benefit Value (A$/tree)

Overall Economic Benefits

Functional benefits of trees such as the removal of air pollution by leaves, and the reduction of stormwater flows through root and leaf uptake, increase as tree canopy cover increases. Therefore, the economic benefits of street trees often correlate with physical tree variables such as trunk diameter and leaf surface area (Killicoat et al., 2002; McPherson et al., 2002; Bonifaci et al., 2010). Figure 6 shows the influence that street tree size has on the general economic benefits of the tree.

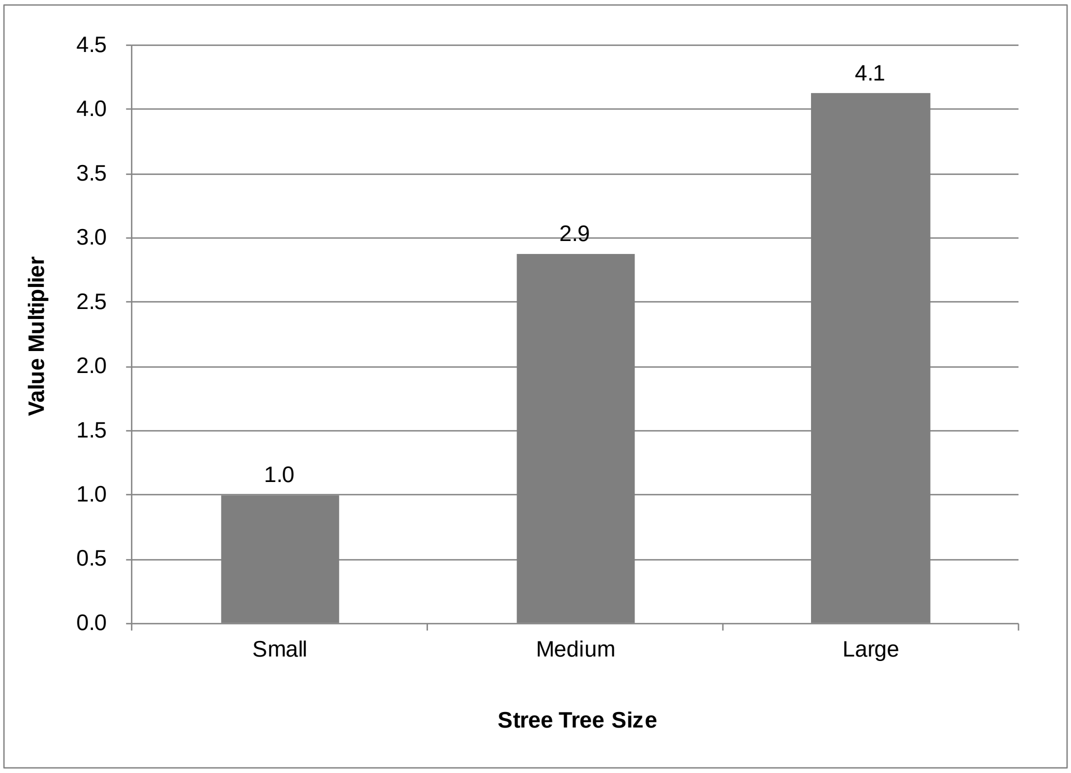

Figure 6 – Relationship between Tree Size and General Economic Benefit

Street trees can also provide other, less expected benefits, For example, treescaping has been shown to increase business income by 20% (Burden, 2006). While this may seem surprising, consumers have been shown to willingly pay more for the same item in a retail development that includes street trees compared with the same item in non-treescaped retail outlets (Wolf, 2005). This amenity value has also been observed for house prices in Perth, Australia, which were shown to be an average of 20–30% higher when there was tree cover on the public space next to, or near, the property (Pandit et al., 2012). Although there are a variety of different ways to assign value to trees, urban street trees clearly generate significant economic benefits for communities and local governments, regardless of the reporting format. Taking estimated values from a range of studies, the annual net benefit per tree seems to lie between $45 and $242 (Figure 7).

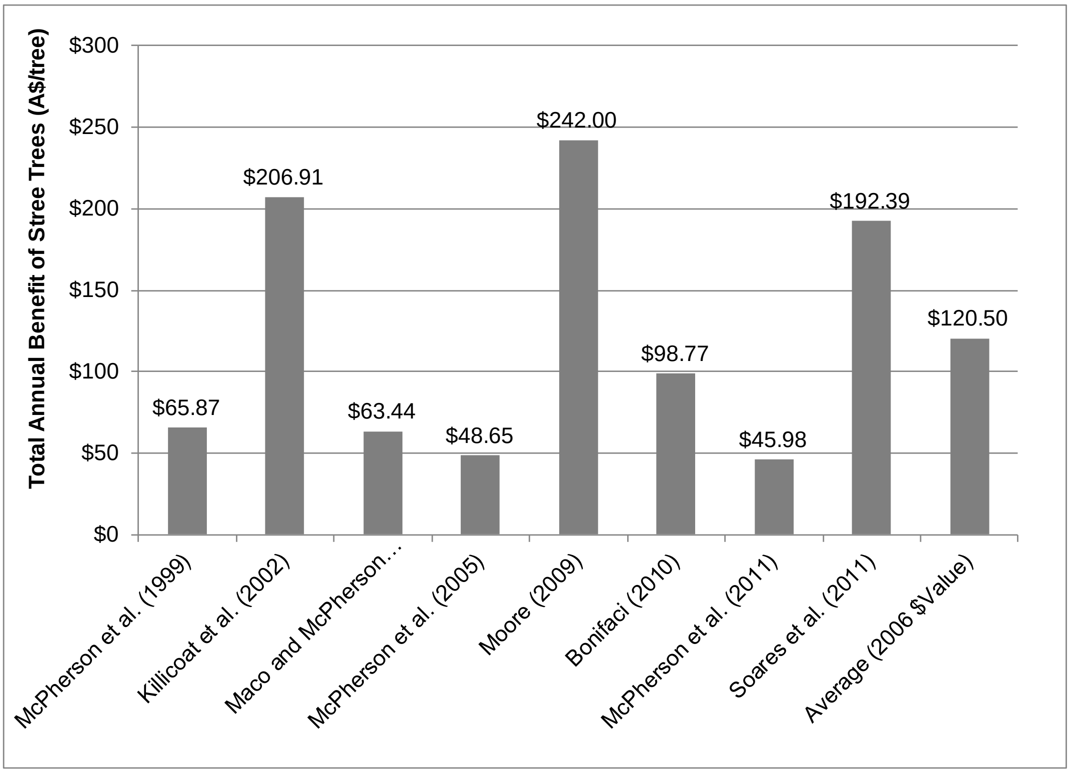

Figure 7 – Estimated Total Annual Benefit of Street Trees (A$/tree)

Challenges of Growing Trees in Urban Environments

Despite the advantages mentioned above, ensuring the survival of street trees is often challenging, and urban designers need to consider critical issues in their landscape design including site conditions, space availability, and maintenance requirements. The healthy growth of trees can be disrupted by a broad range of biotic (living) and abiotic (non-living) factors, and indeed more than one factor can affect the health of a tree at any time. Biotic factors that can adversely affect tree growth include (Boa, 2003):

- Fungi
- Bacteria
- Viruses
- Phytoplasmas

Insects

- Mites
- Parasitic plants
- Weeds
- Larger animals, such as deer and other mammals.

Abiotic factors that can adversely affect tree growth include (Boa, 2003):

- Soil and water chemistry
- Mechanical agents, including poor pruning, construction equipment and malicious human damage
- Soil conditions, including soil type, volume and porosity
- Water availability
- Fire damage
- Weather conditions, including heat and frost

Tree growth is influenced by abiotic factors including air quality, irradiance, soil chemistry, soil moisture, soil volume and soil porosity (Iakovoglou et al., 2001; Morgenroth et al., 2013). A change in availability of these abiotic factors in the urban environment can result in costly damage to infrastructure as tree roots proliferate in otherwise-undesirable areas that provide sufficient water, nutrients and oxygen for tree survival and growth. The use of pervious surfaces to improve the health of urban street trees has been the focus of recent research (Volder et al., 2009; Morgenroth & Visser, 2011; Mullaney et al., 2012). Our research has also investigated whether permeable pavements, which allow water and oxygen to infiltrate through the pavement surface and into the soil, extend the life of street trees (Mullaney & Lucke, 2014).

Some studies have investigated whether permeable pavements minimise damage to pavements and other urban infrastructure (Mullaney & Lucke, 2014). The underlying hypothesis of these studies is that the integral drainage layers required underneath permeable pavements may effectively create a root barrier beneath the pavement surface, forcing roots to grow at greater depths. These layers can potentially also increase the pavement's water storage capacity, promoting tree health directly while minimising pavement damage.

Case Study

A research project is currently underway at the University of South Australia investigating street tree irrigation using harvested road runoff. The study involves the use of "TREENET Inlets" (kerb side tree inlets), which are a relatively new technology introduced by TREENET Inc. The inlets are currently adopted by a number of councils in South Australia and interstate. The inlets form the system by which road runoff can be readily harvested for street tree irrigation. Various back end distribution systems have also been introduced by council engineers and landscape designers. These systems with inlets aim to harvest road runoff with very low maintenance. This is because there is a perception in the industry that maintenance costs are high for stormwater harvesting schemes.

The experimental site is located in the City of Mitcham, Kingswood. In total 28 inlets and distribution systems were installed between July and November 2014. The three key components of this study are: 1. water quality; 2. infiltration (water quantity); and 3. life cycle assessment of the systems with different backfill media. The inlet and distribution system design is based on a "leaky well" which has been tested at several sites in the City of Mitcham. It is a very simple design to harvest the first flush of stormwater, which has a higher nutrient content. There are four different media types located in the distribution component of the leaky well system. The different substrate types were randomly distributed at the different locations. The four types of media include 14 mm dolomite gravel (G), water treatment solids (W) from Happy Valley Reservoir, sandy loam soil (S) and control media (C) units which were backfilled with native soil.

The systems were constructed by contractors to the council. Twenty-one distribution systems, each 440 mm in diameter and 1 m deep were dug using a hydrovac system. The remaining seven control systems were backfilled with native soil backfill. The leaky well design is shown in Figure 8.

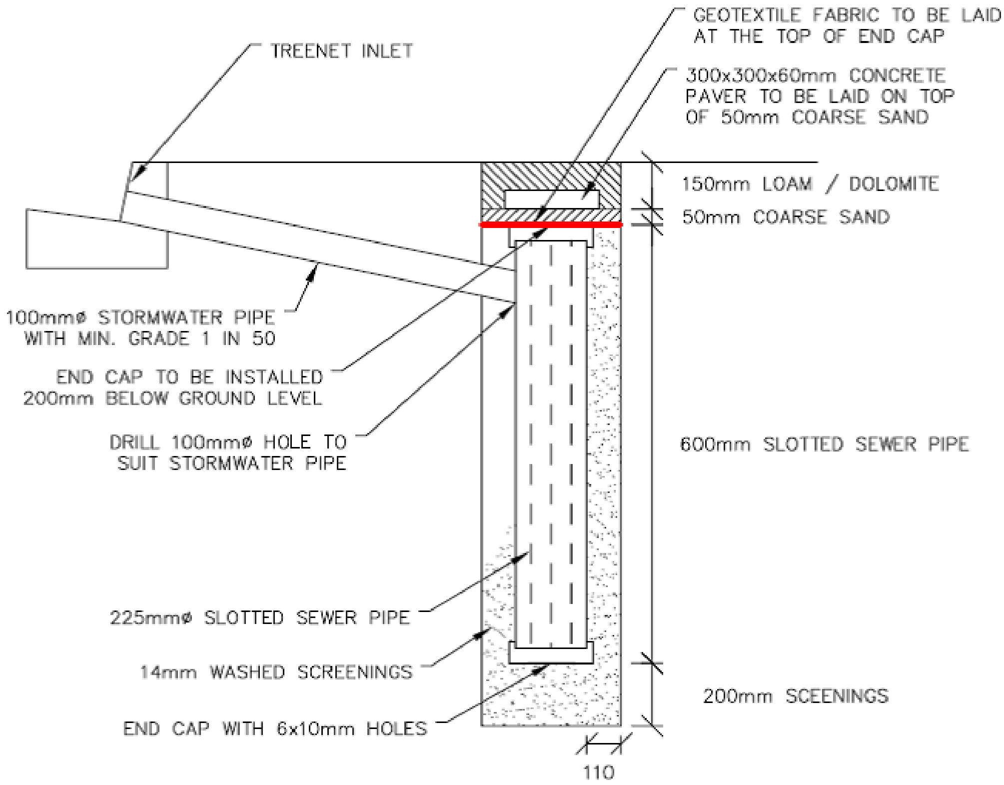

Figure 8 - Leaky Well Distribution System

The study will collect inlet and outlet water samples from one of each of the four types of leaky well unit. Runoff events will be targeted up to and including the 2 year ARI. BOM weather forecasts and rainfall radar will be monitored for the local area and on this basis the experimental site will be visited before a storm to collect the inflow and outflow samples. A total of 4 critical storms will be selected after at least 6 days' dry period. A tipping bucket pluviometer will be installed to measure the rainfall intensity. Samples will be collected at 15 minute intervals for a maximum of 2 hours (depending on event duration and presence of sample). Each inflow and out flow samples will be tested for EC, pH, total nitrogen, total phosphorous, zinc, copper, lead, cadmium and potassium.

Figure 9 - Functioning Inlet at City of Mitcham Council

This field study will also provide information on the quantitative performance of the media and leaky well distribution system. Four leaky well systems (backfilled with each of the four different media) have been selected to determine the capacity of the systems. Each of the four sites will be tested once every three months on site. The catchment area and runoff generated by the contributing impervious area will be calculated using the Model for Urban Stormwater Improvement Conceptualisation (MUSIC). Water will be poured into the systems and the infiltration rate will be measured over a given time period. The effect of sediment and organic matter will also be investigated. For this purpose, two additional kerb side inlets will be selected to test with and without sediment and organic matter settled near the kerb side inlet.

In terms of life cycle cost assessment, the construction and maintenance costs are considered over the lifetime of the project. Life cycle assessment of the TREENET inlet and leaky well distribution systems will include the performance of the various media types, the size of the leaky well distribution system, and the size and number of TREENET inlets. These will be combined to provide a full economic model that can describe the costs and benefits of street trees.

Conclusion

Street trees and other vegetation in the urban environment all help to secure and provide vibrant ecosystem services. Local councils and communities recognise the importance of street trees in the urban environment but these trees often suffer from inadequate water supplies in times of drought. The concept of WSUD, and in particular stormwater harvesting and reuse, can be used to develop sustainable solutions to the significant challenges that trees face in an urban environment. However, there are many barriers to adoption and implementation of this concept including funding for implementation, policies and regulations, political support and most importantly lack of institutional support and research. This research study will provide the baseline information on the performance of road-based stormwater harvesting systems.

Acknowledgments

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