WATER SENSITIVE URBAN DESIGN: RESEARCH TO APPLICATION, TREENET'S FIRST 20 YEARS

David Lawry OAM, TREENET Inc.

Harsha Sapdhare, PhD Candidate, University of South Australia

Tim Johnson, City of Mitcham; University of South Australia

Abstract

TREENET's focus from its inception to the present has been to improve conditions for urban trees. In arid and semi-arid climates this has meant working to ensure trees have access to adequate water. Past proceedings record many papers on the application of water sensitive urban design (WSUD) measures with the view to increasing stormwater infiltration into tree root zones. TREENET's base at Adelaide University's Waite Campus and its association with the Waite Arboretum helped to establish a mutually beneficial relationship with Mitcham Council in 1997. Early research projects resulted in the development of the TREENET Inlet. This workshop recounts some of TREENET's work in the area of research, presents information on selected initiatives that are currently underway in association with Mitcham Council, and suggests direction for research areas into the future.

Introduction

A survey of local government practitioners in 2000 set TREENET's initial research foci. Responses indicated a review of engineering and design of urban spaces was needed to better accommodate trees, as well as noting the importance of all steps and processes in the tree life-cycle from species selection, production, planting and establishment practices to the provision of ongoing maintenance (Hodges 2000). The survey's results identified that over 60% of practitioners were '…actively disappointed with the trees they became responsible for, with the most common complaints being infrastructure damage, high maintenance, incorrect cultivation and liability risk.'

Endeavours to improve the integration of street trees into urban design and engineering have been reported in proceedings of annual symposia since TREENET's inception. Of five project areas noted at TREENET's inaugural symposium (Lawry 2000), research relating to two, began in Mitcham soon after:

- revising ways to harvest storm water in gutters for the benefit of street trees
- modelling different footpaths and assessing the effect on tree establishment

Much has changed in the 20 years since TREENET was established and TREENET can claim some credit for this progress through its effort to improve the urban forest through research, education and networking. Proceedings of symposia held during TREENET's first decade reflect its engagement with industry and academia nationally, across several disciplines, to progress research in these areas. Papers detail tree establishment practices (Fakes 2001; Leers 2007; Plant 2002), the use of stormwater for street tree irrigation (Argue 2006; Denman 2006; Lawry 2008; Wettenhall 2006) and the construction of stormwater harvesting trials (Wark 2003, Porch et al. 2003). More recently, research has involved the combined goals of harvesting stormwater and minimising tree root-related infrastructure damage, based on infiltration through TREENET Inlets and the functioning of permeable paving's gravel base layer as an air-gap root-deterrent (Johnson 2009, 2015; King 2015).

The emergence of WSUD, primarily in the civil engineering discipline to address flooding due to the increasing inadequacy of stormwater infrastructure under pressure from urbanisation, promised the dual additional goals of reducing the pollution of receiving waters and improving the health of the urban forest. At that time the focus was on constructed wetlands, aquifer storage and recovery and, on a smaller scale, the inclusion of rain gardens in boutique locations. These would provide little benefit to the widely dispersed and dominant community assets of towns and cities everywhere: our street trees.

In the grip of the Millennium Drought a common approach to address the water stress facing our urban forest was to seek solutions through the use of so called 'water wise' species, soil amendments and restriction of municipal water supplies. However, it was apparent that some of the promoted tree species, particularly some drought tolerant native species that had been widely planted since the 70s, were causing damage to civil infrastructure by initiating fine roots to absorb the condensation produced adjacent to these impermeable surfaces. As these grew, kerbs, footpaths and road pavements were lifted and some council engineers declared a war on street trees. The installation of root barriers became a common practice, with very little knowledge of and regard for the trees and their needs or of their soil environment.

The TREENET inlet system was first demonstrated in 2010. It has since been patented around the world has been refined to become a reliable and relatively low cost device. The TREENET Inlet and leaky well system was designed not only to provide water to urban trees, but also to encourage tree root growth toward the well and away from pavements and kerbs, thus preventing footpath and kerb damage that is common and widely reported (D'Amato *et al.* 2002; Day 1991). Councils and developers can now either retrofit the device or include it in new kerb and gutter installations. Future research relating to the inlet will include remote flow monitoring allowing correlation with the timing, intensity and duration of rain events.

Permeable paving has proved its effectiveness at reducing stormwater runoff and recent and as yet unpublished research has shown that it can discourage shallow root development which might otherwise cause infrastructure damage. On the strength of this research, Mitcham Council now uses permeable paving in its annual capital works programs for building new and renewing old footpaths and for construction of residential streets where localised flooding is problematic.

Soakage trenches in reserves and street verges have proved their serviceability with minimal maintenance over a period of ten years. They have greatly increased the growth of saplings planted near them, improved stormwater quality and reduced the quantity of runoff reaching creeks and rivers. In researching these types of WSUD devices, TREENET continues its work with its network of academic institutions, practitioners in the public and private sectors, and with its volunteers.

This workshop continues the two-way exchange between researchers and practitioners from interrelated disciplines. It examines tree-focussed aspects of WSUD research and its application in the field, which have advanced the knowledge which underpins the management of urban infrastructure where the tree is a principal asset. The research described below, with analysis of data at various stages of completion and publication of results anticipated in the near future, has already begun to inform local projects and to guide further research. Such progress has informed TREENET's recent call for expressions of interest in a national trial to determine best practice in design and construction that will support urban forests into the future.

WSUD and Green Infrastructure

WSUD techniques have received significant attention over the last two decades, due to their potential contribution to developing resilient cities with cost effective green infrastructure. Beatty and Heckman (1981) reported that restricted watering, nutrient deficiency, poor soil, vandalism and physical injury are the common reasons for destruction and deterioration of urban trees growth. Harvested through WSUD devices, urban stormwater can provide a fit-for-purpose water source to enhance tree growth (Denman 2006).

Leaky wells are an infiltration device that is designed to restore soil moisture and provide passive irrigation to trees. Trees and other vegetation can play a significant role in the urban hydrological cycle (Stovin *et al.* 2008); it can improve the infiltration rate of urban soil and increase groundwater recharge (Bartens *et al.* 2008), as well as reducing runoff (Ely and Pitman 2014). Some councils irrigate street trees for the first few years after planting, but they then become dependent on rainfall and infiltration of stormwater to provide the required water and nutrients for growth and survival (Dong *et al.* 2016).

Case study – Eynesbury Avenue Kingswood, South Australia

Traditionally, stormwater drainage infrastructure has been constructed to manage stormwater in urban environments by transporting it quickly to creeks, rivers or the sea. This rapid transfer of urban stormwater to natural waterways leads to negative impacts on the environment and the community. WSUD has the potential to control and treat polluted runoff from residential streets, to reduce downstream flood peaks, and to deliver water to the local environment.

Environmental, social and economic factors are all important in the assessment of WSUD tools. The TREENET Inlet system is an emerging WSUD tool which harvests road runoff from residential streets and arterial roads to irrigate street trees. By intercepting the 'first flush' of stormwater, TREENET Inlets remove pollutants near their source. TREENET inlets are installed in the kerb; they connect to an infiltration pit or 'leaky well' which detains the water until it soaks into the soil in the road verge.

In this study, 28 TREENET Inlets coupled to leaky wells were installed in suburban Kingswood in South Australia. The leaky wells were comprised of four different backfill media (quartz gravel, sandy loam, water treatment solids, and the site's natural silty clay) to investigate their performance with respect to water quality improvement. A series of experiments was performed in the field and in the laboratory, to investigate the potential of the TREENET Inlet and leaky well combinations to assist with managing water quality and water quantity. Life cycle cost and cost-benefits analyses were also conducted. Shown in Figure 1, the research components aimed to:

- quantify the treatment capability of the four media. The batch study (ASTM 2008), column study (Hatt *et al.* 2007) and full-scale model (Davis *et al.* 2001) study was conducted in the laboratory.
- test *in-situ* hydraulic performance by the constant head method (Asleson *et al.* 2009; Hatt and Le Coustumer 2008; Michigan 2000) to compare the infiltration capacity of the four different backfill media in the leaky wells and to investigate whether the infiltration rate change with time.
- test the rate of inflow into the TREENET Inlet at different kerb gradients, using grades of 0 to 5 % and flow rates of 0.5 to 5 L/s
- support a life cycle assessment (LCA, ISO 14040), (Flynn and Traver 2013; Taylor 2003; Wang *et al.* 2013).
- support a cost-benefit analysis based on physical quantifications, discounting, net present value (NPV) test and sensitivity analysis (Hanley and Spash 1993).

The installation of TREENET Inlets in Eynesbury Avenue was undertaken as part of a 'kerbing renewal' capital works project by the City of Mitcham. Installation cost approximately $1000 per installation, which was higher than the usual cost because:

- the contractor was at the time unfamiliar with the TREENET Inlet installation procedure
- excavation proceeded slowly to ensure that dimensions accurately represented the specification and were consistent across all sites (four leaky wells were installed per day)
- four different backfill materials were required, needing collections were from multiple sites
- a hydrovac system was used to ensure utilities and underground assets were not damaged

More recently construction costs of approximately $500 per unit have resulted from modification of the inlet design and the construction process, although the major cost remains dependent on the scale of the leaky well and the method of excavation. Approximately 40% of the cost is for the TREENET Inlet components, pipework and leaky well fittings; the balance is labour.

TREENET Inlet maintenance is minimal, with street sweeping carried out each six weeks as per the council's schedule. Sediments were removed from the bottom of the leaky wells after 3.5 years, but this was for research purposes only as investigations by the City of Mitcham have determined that sediment removal has not been necessary to maintain performance during the five years that some other installations have been operational. The sediments were sealed in plastic bags and later analysed to determine the level of residual contaminants.

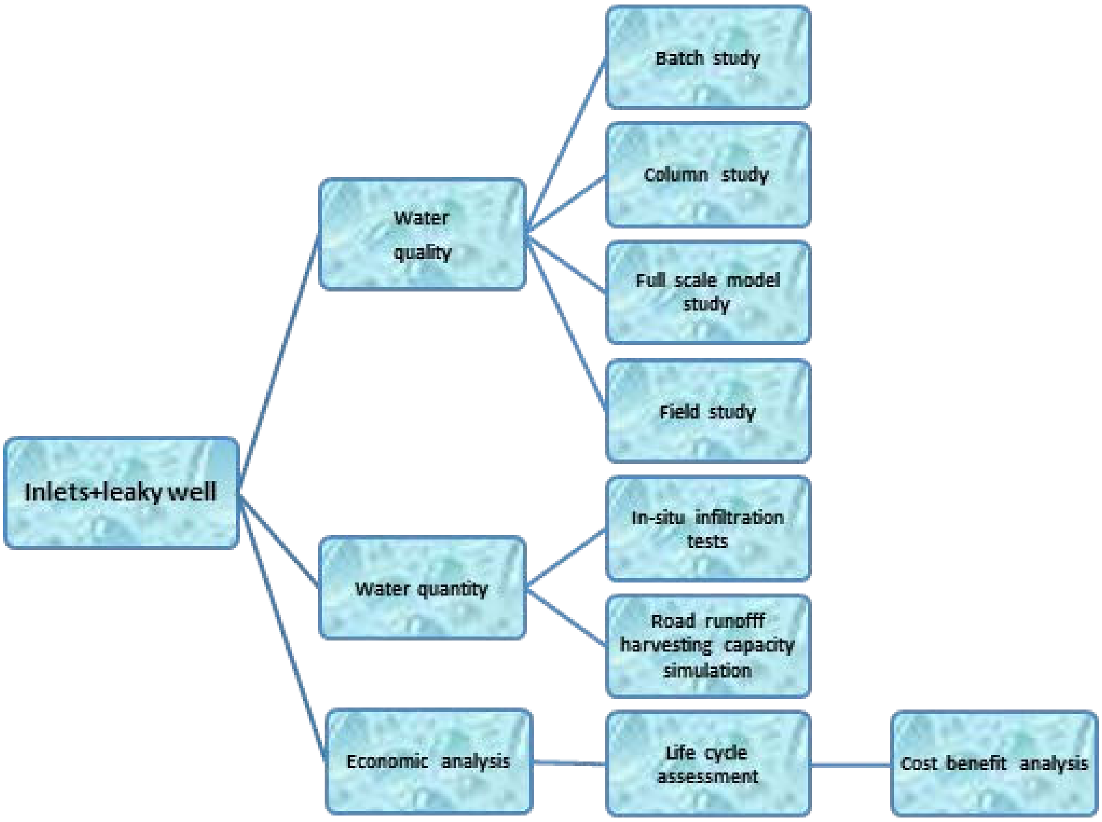

Diagram 1, Research study flowchart chart

This research is focussed on the cost and benefits of the TREENET Inlets to the local council where they are installed, however there may be positive and negative externalities which affect down-stream councils which should also be investigated. It is also suggested that tree root growth should be investigated in urban streets in different soil types and in relation to different tree species. The current research will provide information regarding water quality and quantity benefits of TREENET Inlets and the first full life-cycle assessment of the device. It is anticipated that this information will further inform leaky-well design to optimise performance and cost effectiveness.

Mitcham council's increasing use of WSUD devices

The application of WSUD devices and their use in combination with urban tree planting is still the exception in South Australia rather than standard practice. The roll-out of TREENET Inlets and permeable paving remain slow in many areas, with their use in Mitcham Council increasing progressively over the last few years. Local experience suggests the low level of adoption might be based on the misinformation that:

- water infiltration through permeable paving will increase problematic ground movement in reactive soil, increasing the potential for infrastructure damage and failure
- saturated subgrades following rainfall won't be strong enough to support traffic loads

Several publications state that infiltration through permeable paving should be avoided on reactive soil, with authors suggesting an impermeable membrane should be used to prevent water entering the soil (Eisenberg, Lindow & Smith 2015; Shackel 2006; Shackel & Pezzaniti 2009).

A review of literature, however, did not find any papers that related ground movement to infiltration through permeable paving.

Data is available in literature to inform regarding the adequacy of open-graded gravel base layers beneath permeable paving over clay subgrades where saturation is possible (Beecham et al. 2009; Heydinger et al. 1996; Raad, Minassian & Gartin 1992; Yaron, Bensabat & Ishai 1996. Using conservative values for the strength of open-graded base materials founded on saturated, low strength clay subgrades, permeable pavements have been shown to require a gravel base of as little as 200 mm in depth to support vehicular traffic (Eisenberg, Lindow & Smith 2015; Tennis, Leming & Akers 2004). With more robust base designs, permeable paving can support highway traffic (Knapton & McBride 2009) and industrial applications including storage of shipping containers at handling terminals (Knapton & Cook 2000).

This literature encouraged the trial of various WSUD devices in Mitcham's moderately reactive silty clay soils. TREENET inlets coupled to leaky wells, infiltration trenches beneath road verges fed by traditional drainage side entry pits, permeable paving and rain gardens have been constructed and reported previously (Johnson et al. 2016; Johnson 2015; King 2015). Mitcham's WSUD devices are still in the early years of their asset life cycles but to date they have demonstrated acceptable performance and reliability. In time these installations will provide data on life-cycle costs and maintenance requirements on which future decisions can be based. However, their success to date is reflected by the support of the community and their elected council to continue with construction of WSUD devices and the conduct of related research.

Following council's initial permeable pavement trial construction in 2009, in which 80 m^2 of permeable paving was laid for research purposes, during the 2016/17 financial year over 10,000 m^2 of footpaths were laid with permeable paving - an increase of one hundred and twenty five times over a period of eight years. When footpath renewal became due along an avenue of River red gums with immense heritage value, permeable paving was used. Several road sections have also been constructed with permeable paving over the last two years, to improve stormwater management and cost effectiveness. Serving as demonstration sites, these successes underpin the continued roll-out of WSUD devices and associated research. Promotion of these outcomes in print, online and through public meetings keeps the local community informed and helps to gather and maintain community and council support.

The intersection of Wheaton and Kegworth Roads in Melrose Park, South Australia, flooded in most winter and spring periods up to 2016, with water ponding to 300 mm deep or more. A traditional pit and pipe drainage upgrade to increase capacity was priced at approximately $1.2M, the expense due largely to the length of pipe required. A more cost effective option was selected which involved paving the intersection with 500 m^2 of permeable paving (Figure 1), building soakage trenches to drain into a reserve nearby and laying additional permeable paving in the road where it passed some River red gums (*Eucalyptus camaldulensis*) on the edge of the reserve (Figure 2). This project cost less than $200,000. On two occasions during 2016 the suburb was subjected to extremely heavy rainfall, equivalent to greater than 1 in 50 year average recurrence interval events, with no ponding occurring at the intersection. Promotion of the success of this project this has helped to sustain support for WSUD works.

Figure 1. Permeable paving infiltrates stormwater into the road subgrade at the intersection of Kegworth and Wheaton Roads in Melrose Park, South Australia. As part of a broader treatment, this solution cost $1M less than the alternative option of upgrading the pit and pipe network.

Figure 2. The absence of roots in road base material allowed its excavation without harm to nearby trees. Underdrains soak storm water from beneath the permeable pavement into the adjacent reserve as well as into the road subgrade; this has eliminated runoff from the paved surfaces.

The link between WSUD and vegetation, particularly trees, is acknowledged by Mitcham's community; this enables further works in high profile locations. To sustain the health of a stand of River red gums with substantial heritage value, TREENET Inlets were installed in the street to help to recharge soil water content each winter.

Working with TREENET and the local community, these devices are currently providing data on the capacity and rate of stormwater infiltration through TREENET Inlets.

Success with construction of WSUD devices and green infrastructure has helped council to win grant funding from several sources. Funds have been used to construct further devices as demonstration sites as well as to address localised flooding and environmental issues and to progress applied research. In an ongoing project with UniSA and the Goyder Institute for Water Research, the quality and quantity of stormwater discharge from a drainage catchment of 12 hectares is being monitored. The study site is characterized by large homes on properties of approximately 1000 m^2, with well-maintained gardens and traditional, impervious pavements.

Data collected throughout 2016 inform regarding baseline outflows from the catchment in its established state. A baseline survey of young trees was also conducted within and surrounding the catchment, recording their height and trunk diameter. In December 2016, a total of 90 TREENET Inlets were installed in 3 of the catchment's 8 streets. It is anticipated that data collected during 2017 will reveal impacts of the TREENET Inlets on catchment hydrology. A further 90 inlets will be installed in December 2017 and monitoring will continue. Footpaths in several of the streets are due for renewal in the next few years; these will be replaced with permeable paving and monitoring will be ongoing. It is anticipated that this long term study will inform regarding the capacity of WSUD devices to mitigate flooding and pollution at the catchment scale.

Some future applied research projects are in the early planning stages. TREENET has recently called for expressions of interest in a national project to investigate best engineering practices to establish trees in paved urban areas, and to identify barriers to the adoption of best practice and how these might be addressed. At the more local level, projects might investigate the suitability of WSUD devices for use in extremely reactive soils.

Conclusion

TREENET has been actively involved in research and communication regarding establishing and sustaining urban trees for 20 years. The City of Mitcham has been an active partner over this time. This close working relationship, well supported by academia, has facilitated applied research and delivered practical results. These results have been achieved through teamwork – the importance of TREENET's networking focus, and membership of the network, cannot be overstated.

TREENET's independence and its focus on 'doing urban trees better' has added value to the individual members and the collective. The local Mitcham community knows TREENET and values its work. Through close association, TREENET and Mitcham Council have been able to progress applied research and application better than either organisation could have individually. Ongoing work in this area is now more secure than ever before, because it is supported by the community.

To keep the applied research going, and to continue to progress and improve urban forest management practices, the community must be kept informed. Identifying high-profile opportunities for best practice like Mitcham's use of TREENET Inlets to improve conditions for heritage listed trees, leads to increased opportunities for promotion and improved community ownership of their trees and tree management practices. Best practice successes at high profile sites will change standards! Opportunities must be actively sought, and successes must be promoted widely to achieve their real value.

Achieving change can be difficult, but success can be a great inspiration. Negativity can be diminished more by practical demonstration than by explanation. Seeing a working, cost effective example of a method or practice in action in a real world application can do much to sway the opinions of those who delay change. Proceedings of TREENET's past symposia contain many examples of real world, practical solutions that have been delivered through applied research. Sharing these papers is one way of encouraging best practice. Visiting working examples is another.

No doubt TREENET will keep listening to its membership. The recent call for expressions of interest in the national research project will result in new partners, new members, new ideas and new problems (or, perhaps, better defined problems) requiring new research. The first twenty years have been fruitful; the next twenty years are likely to be more so.

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