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Short communication

Rainfall interception and stem flow by eucalypt street trees – The impacts of canopy density and bark type

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ABSTRACT

Understanding how trees influence water movement in an urban landscape is important because in an 'engineered xeriscape' small changes in rainfall frequency or magnitude have significant implications to plant water availability and mortality at one extreme, and stormwater runoff and flooding at the other. This study relates direct measures of tree canopy interception and discusses their implication for catchment hydrology in different urban landscape contexts. We measured canopy throughfall and stemflow under two eucalypt tree species in an urban street setting over a continuous five month period. *Eucalyptus nicholii* has a dense canopy and rough bark, whereas *Eucalyptus saligna* has a less-dense canopy and smooth bark. *E. nicholii*, with the greater plant area index, intercepted more of the smaller rainfall events, such that 44% of annual rainfall was intercepted as compared to 29% for the less dense *E. saligna* canopy (2010). Stemflow was less in amount and frequency for the rough barked *E. nicholii* as compared to the smooth barked *E. saligna*. However, annual estimates of stemflow to the ground surface for even the smooth barked *E. saligna* would only offset approximately 10 mm of the 200 mm intercepted by its canopy (2010).

Tree canopy and bark characteristics should be considered when planting in pervious green space, or impervious streetscapes, because of their profound impact upon tree and surrounding water availability, soil water recharge or runoff. This study provides an evidence base for tree canopy impacts upon urban catchment hydrology, and suggests that rainfall and runoff reductions of up to 20% are quite possible in impervious streetscapes. Street tree canopies can function as a cost-effective compliment to water sensitive urban design for stormwater reduction benefits.

Introduction

Trees provide many ecosystem service benefits in the urban landscape, such as habitat provision, carbon sequestration, reduced particulate pollution, a 'sense of place', contact to nature, microclimate cooling and mediated hydrological processes (Chiesura, 2004; McPherson et al., 2005). The mental health, cultural and economic service benefits that trees provide within an urban landscape are now well recognised and can be experienced at an individual, an organisation, or an entire community/city level (Westphal, 2003; Nowak and Dwyer, 2007). Urban trees also play an important role in urban catchment hydrology through canopy interception of rainfall, which reduces beneath canopy throughfall and therefore catchment peak flows. When trees are widely distributed throughout the urban landscape and these trees have dense, broad canopies the amount of storm water that reaches sewerage and river systems can be reduced and the peak flows delayed (Xiao et al., 2000, 2007; Wang et al., 2008). In addition, tree architecture and bark properties greatly influence the proportion of intercepted rainfall that becomes stemflow and is directed to the base of the stem and root bowl (Johnson and Lehmann, 2006). Stemflow can be extremely important for precipitation and nutrient re-distribution in arid environments (Li et al., 2008), in agricultural and forest ecosystems (Levia and Frost, 2003). Likewise, in an engineered impervious urban landscape, stemflow can be important for the hydrology and nutrient availability and cycling of individual street trees.

Canopy interception is the difference between gross rainfall and the amount of rain that passes through the canopy (Xiao et al., 2000; Barbier et al., 2009). The process of canopy interception is influenced by three main factors: (i) the type of rainfall event (magnitude, intensity and duration), (ii) the tree species and canopy structure, and (iii) the antecedent weather (Crockford and Richardson, 2000). Most studies of canopy interception have been made in natural or managed forest systems, where up to 50% interception has been measured (Schellekens et al., 1999). In urban systems, canopy cover is discontinuous, tree canopies are often isolated and there is high species and canopy/leaf trait variation which

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means that interception is difficult to measure and even more difficult to predict. Wind direction during rainfall events is important but total rainfall interception can be expected to be less than in natural forest, continuous canopy situations (Guevara-Escobar et al., 2007). Xiao et al. (2000) developed a complete under-canopy collector to determine interception rates of 15% and 27% for *Pyrus calleryana* and *Quercus suber*, respectively. This approach enabled the collection of high quality data but can only be applied in controlled research situations for tree canopies without interference from adjacent vegetation or built structures. A simpler method is required so that canopy interception (CI) and stemflow (SF) can be measured in real urban settings and for mature tree canopies.

Understanding how different tree canopy characteristics (dense/clumped/sparse), leaf traits (pendulous, compound, large blade, needle) or stem properties (smooth/fibrous/fissured bark) influence net rainfall input, distribution and runoff will greatly help in attempts to model urban catchment hydrology. Mechanistic models that are semi- or fully distributed (i-Tree HYDRO; (Yang et al., 2011), MUSIC; (Fletcher et al., 2001), SWMM; (Barco et al., 2008), TOPLATS; (Bormann, 2006)) require a process based understanding of tree impacts upon hydrology across the range of rainfall events (Elliott and Trowsdale, 2007; Cuo et al., 2008; Wang et al., 2008). Modelling and planning of urban systems should consider both the beneficial (stormwater reduction) and negative (reduced rainfall recharge) impact of tree canopy cover upon rainfall inputs and urban catchment hydrology. The benefits are optimised when canopies cover impervious surfaces and the negatives are greatest when canopies cover pervious green spaces. Modelling how tree canopies impact urban hydrology requires models with at least hourly and not daily time steps, because recognising short, discrete rainfall events and differences in rainfall intensity may be critical for accurately predicting rainfall redistribution and runoff (Xiao et al., 2000; Wang et al., 2008).

Under-canopy troughs and stem helix troughs with tipping buckets were used to test three simple hypotheses:

1. an isolated tree with greater plant area index would lead to greater canopy interception of rainfall,
2. percentage rainfall intercepted would decrease with increasing magnitude of rainfall event, and
3. an isolated tree with smooth bark would have greater stemflow than a rough bark species, given similar branching architecture and form.

In the process, the study tested the applicability of these simple field methods. The canopy interception and stemflow of a mature, smooth-barked *E. saligna* and mature, rough-barked *E. Nicholii* tree with contrasting bark characteristics were made near continuously for five months in Melbourne, Victoria. The impact of tree canopy interception is discussed with regards to two scenarios of street stormwater runoff and green space soil water recharge.

Materials and methods

The study was at the Burnley campus of The University of Melbourne, Victoria, Australia (37.82° S, 145.01° E). The average annual rainfall is 687 mm (since 1972) and mean monthly temperature minimum 15 °C and maximum 30 °C. Inter-annual rainfall is highly variable in south-eastern Australia, but in Melbourne the variation amongst monthly mean rainfall (since 1972) is small, ranging between 46.3 mm (March) and 66.2 mm (October). The minimum rainfall recorded within one month may be as low as <2 mm and maximum up to 199 mm. In 2009, the five months of measurement included a monthly minimum of 17 mm (October) and monthly maximum of 82 mm (September), so reasonably represented variation in temporal rainfall distribution.

Two trees, a 30 m tall *E. saligna*, (Sydney blue gum) and a 35 m *E. nicholii* (narrow-leaved black peppermint) were selected because of their contrasting bark but similar foliage characteristics and canopy size. *E. saligna* has smooth, grey bark and leaves that are 10–15 cm long and 1–2 cm wide (Costermans, 2009). *E. nicholii* has thick, deeply fissured bark along the entire trunk and narrow (<1 cm wide) leaves between 6 and 12 cm long. These two trees were instrumented with a stemflow helix attached to a covered Davis tipping bucket. Aluminium flashing folded in half was wrapped around each stem into an overlapping helix and tacked in place. Silicon resin was used to seal the flashing to the bark. Under both canopies, a single zinc–aluminium throughfall trough, 0.3 m wide and 2.4 m long (0.72 m^2), was installed 1.5 m above the soil surface and approximately 1–2 m north of the stem. Each trough delivered throughfall into a Davis^{TM} tipping bucket placed on the soil surface under a rainfall cover. Gross rainfall was measured using an identical trough placed 1.0 m above the flat roof of a two storey building, and a standard Davis rainfall tipping bucket. Throughfall in mm depth equivalents was calculated according to the aperture size of the tipping bucket (0.0214 m^2) and throughfall trough (0.72 m^2):

$$\mathrm{TF} = \frac{\mathrm{mm}}{33.65} \tag{1}$$

where 33.65 represents the fold difference in aperture size.

Stemflow was calculated by first converting tipping bucket mm into litres of water using the volume of the tipping bucket (4.2765 cm^3), and then back into depth equivalents (mm) but this time based on the cross-sectional area (m^2) of the tree canopy not the tipping bucket aperture:

$$\mathrm{SF} = \frac{\left(\frac{\mathrm{mm}}{0.2}\right) \times \frac{4.2765}{1000}}{A_c} \tag{2}$$

where A_c is the canopy cross-sectional area (m^2).

Air temperature, wind speed, wind direction and relative humidity were recorded from a climate station on the same roof. Gross rainfall (GR), throughfall (TF) and stemflow (SF) were measured at 15 min intervals from 25 May to 31 October 2009. This five month period spans late autumn, winter and early spring and contained rainfall events between 0.2 and 16 mm. Throughout 2009 there was 461 mm precipitation in total, of which 217 mm was captured through valid measurement during this five month period.

When tips in the gross rainfall gauge were ≥1 h apart these were categorised as separate rainfall events. Canopy interception (CI) for a discrete rainfall event was calculated as:

$$\mathrm{CI} = \mathrm{GR} - \mathrm{TF} + \mathrm{SF} \tag{3}$$

In forest systems, the volume of stemflow (SF) water is transformed into a percentage of GR using either (i) stem density, or (ii) mean crown area multiplied by stem density. For isolated trees, as in this study, %SF can be calculated as:

$$\%\mathrm{SF} = \frac{S_{\mathrm{FVOL}}}{(G_R \times C_A/100)} \tag{4}$$

where S_{FVOL} is the volume (L) of water that passed through the stemflow tipping bucket, and C_A is the horizontal cross-sectional area (m^2) of the tree canopy.

Funnelling rations (F) were also calculated according to the gross rainfall (mm), event based SF volumes (L) and the stem basal area (B_A = m2) according to Herwitz (1986):

$$F = \frac{S_{\mathrm{FVOL}}}{(G_R \times B_A)} \tag{5}$$

Plant area index (PAI), which is the index of woody biomass are and leaf area combined, was measured using a standard 3.5 mm