

WATER MANAGEMENT STRATEGIES FOR URBAN TREES IN AN UNCERTAIN ENVIRONMENT

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INTRODUCTION

The vulnerability and dependence of urban landscapes on supplementary watering has become evident in recent years. Major changes have occurred both in the condition and health of urban landscapes and the approach to the management of these landscapes. A measured approach to the management of urban landscapes is required.

Many urban trees are experiencing significant stress as a result of low soil moisture. The degree of stress is dependent upon the deficiency between the water that is available in the soil and the demand imposed by the tree. Both sides of the equation are highly variable. Drought, water restrictions and climate change all influence water availability. Species, stage of development and local climate all directly influence water demand. The truly sustainable urban tree is able to grow to maturity without the need for supplementary watering. Unfortunately, due to the nature of species commonly used, the climate of the locality in which they are grown and the demanding circumstances in which they are required to perform means that many trees are stressed and do require supplementary water.

There are a number of circumstances that could have contributed to increased soil moisture stress in recent years. These include:

1. Reduced rainfall in recent years in many Australian cities. Melbourne, for example, has experienced 10 years of drought.
2. Reduced application of supplementary water through changes to irrigation management. Initiated by water restrictions.
3. Reduced availability of rainfall through low infiltration. Soil compaction and soil hydrophobicity are common problems.
4. Reduced uptake of water by trees as a result of damage to tree root systems through construction works e.g. paths, service trenches and generally stressed trees.

Many strategies including seeking alternative water sources, improved water delivery systems and various soil modification based practices have been adopted in an attempt to maintain urban landscapes.

Prior to a specific water solution being developed for a site, it is important that the performance requirements or outcomes of the landscape are identified and that the maintenance of the landscape is based on a planned approach rather than being the net result of (reaction to) a series of imposed decisions (e.g. water restrictions). The landscape outcomes of urban trees include both amenity and habitat values.

The beneficial role of urban trees are described and referenced in a recent literature review prepared by Fam et al (2008) titled, *Irrigation of Urban Green Spaces: A review of the Environmental, Social and Economic benefits*. In this CRC Irrigation Futures publication the benefits, environmental, social and economic, are outlined. Specific benefits of urban trees include reduced air temperature, through both by shading and evapotranspiration, reduced wind speed, improved air quality, reduced building energy consumption and modification of the hydrology through rainfall interception increased, infiltration and reduced surface runoff. The social benefits of improved physical and mental health resulting from access to greenspace are also described in this publication.

The limited or reduced access to urban water has highlighted the relatively low priority that urban trees have compared to other (more “productive”) users of urban water. Whilst all urban horticulture has suffered as a result of reduced water, trees are at particular risk when the water is turned off.

Sports grounds have received much attention and significant resources in the past couple of years. There has been much effort directed at promoting/highlighting the role of irrigated turf surfaces in providing facilities for active recreation. The value of irrigated sports grounds has increased both in the eyes of the community and government. Unfortunately trees have not enjoyed similar public exposure and attention.

TREES AT RISK DUE TO LOW SOIL MOISTURE

Identifying trees at risk from water stress is an important part of a water management strategy. There are a number of factors, in addition to low rainfall, that can contribute to an urban tree experiencing soil moisture stress.

(A) Limited soil volume

Trees grown in containers will generally require supplementary water due to the very limited water storage capacity. They may only have two to three days of storage during peak demand periods. In many streetscape situations, trees are effectively growing in very restricted soil volumes. These can be considered to be “containerised” trees. Tree pits are often too small and do not allow the root system to develop to a point where it can support a mature tree. While there is significant literature on soil specification and planting pit preparation for tree establishment and health (Craul, 1999), many trees are still planted into excessively restrictive spaces.

(B) Tree not suited to local climate

There is now a strong emphasis on selecting trees that are climatically well suited to the locality. This is a sensible approach at a time when sustainability of urban horticulture is paramount. The landscape design requirements of an area do not always however allow this approach. There may be heritage or specific design requirements that dictate that less water friendly species will be selected. These trees will require watering to varying degrees beyond the establishment phase. It is important that the reasons for selection of trees that require ongoing watering are well understood by the community.

(C) Ineffective rainfall

Trees, particularly large ones, use large amounts of water. The replenishment of the supply from natural sources (e.g. rainfall) needs to be effective and timely.

The maintenance of trees in street situations presents particular water challenges. Hard surfaces often result in runoff to the road or gutter. Overhanging structures along the street and sidewalk often act as rainfall interceptors. Also, the tree canopy intercepts rainfall and prevents rain entering the limited permeable area around the tree trunk.

Some strategies that should be considered include:

- Install permeable surface around trees in hard landscaped sites
- Ensuring soil around tree trunks allows infiltration
- Encourage runoff to be directed to tree water intake area

(D) Hostile soil conditions

The role of the soil is critical to a healthy tree. Both air and water, as well as nutrients, need to be readily available to the root system. Soil compaction, which can occur around many urban trees, impacts negatively in terms of water performance. Reduced infiltration rates means less water entering the soil profile and compacted soil means less space to store water. Strategies to prevent or minimize compaction include exclusion barriers and addition of mulch.

TREE WATER REQUIREMENTS

The water management of urban landscapes requires an understanding of the water use characteristics of all vegetation including trees. In order to establish and successfully manage a tree, it is important to have an appreciation of both the peak daily demand and the total amount of water required by the tree. In managing stressed trees in challenging environments it is the amount of water required to keep the tree alive that is the critical consideration.

The rate at which trees use water depends on the water use characteristics of the plant, the stage of development of the tree and the prevailing environmental conditions. When considering the water use rate for a particular species, it is the changing climatic conditions that will have greatest influence on the water use rates. Extreme climate conditions of high ambient air temperature, low relative humidity, and high wind speed and high levels of solar radiation are all associated with high water consumption by trees.

The factors influencing tree water use can be summarised as follows:

- (A) Water use characteristic of the tree species (High, Medium, Low)
- (B) Size of tree – crown area is the key dimension
- (C) Density and area of leaves – as reflected by the Leaf Area Index (LAI)
- (D) Site climate – evaporative demand
- (E) Condition or health of the tree
- (F) Stage of development of the tree
- (G) Availability of water to the tree – water stressed trees use less water than if water readily available

There are a number of techniques available to estimate the tree water use rate. The approach outlined here is based on the use of climate data and crop factor values. Evaporation data from the Bureau of Meteorology is used. A Crop Factor value for the tree is used in conjunction with an evaporation value to determine the water use rate. For established trees, values of Crop Factor are generally in the range of 0.3 to 0.8. A healthy tree will use and require a lot more water than a stressed tree. The amount required to keep the tree alive is difficult to determine. One approach is to assume a low Crop Factor value, for example in the range on 0.2 or even less, and then monitor the tree condition to assess response.

The total foliage area influences the total potential transpiration of the tree. The Leaf Area Index (LAI) can be used to estimate the total leaf area. LAI values are typically in the range of 2.0 to 5.0 for trees. There are various techniques employed to take LAI into account. The estimation of tree water use approach described here uses an all encompassing Crop Factor (CF) value that takes into account the leaf density and other influencing factors such as the grass around the tree.

The tree water use estimation relationship is as follows:

$$\text{Daily Water Use} = (C_A) \times *CF \times E_A \quad \text{litres per day}$$

C_A - Crown area of the tree (Calculated assuming crown is a circle)

*CF - Crop Factor (includes species, LAI issues, grass)

E_A - Evaporation rate (Class A evaporation pan, Bureau of Meteorology)

Example

Tree	Eucalyptus globulus
Overall height	12.0m
Crown diameter	8.0 m
Crown plan area (C_A)	50 m ²
Crop Factor (*CF)	0.8

Evaporation (E_A)	8 mm per day
Daily Water Use	320 litres per day

The evaporation rate selected in this example is a typical daily value in South Eastern Australia and on many occasions in summer this would be exceeded. This estimated water use rate represents 2,240 litres for a week. These numbers are based on a healthy tree with water readily available. The amount of water required to sustain the tree will be considerably lower than this value.

TREE WATER BALANCE

Understanding the water balance of trees provides a sound foundation to appreciate the various water transfer processes involved in the water management of the tree. A water balance is a simple technique used to account for the movement and storage of water in a system. In this case the system being considered is a single tree.

Water Balance Expression:

$$\text{Water In (WI)} = \text{Water Out (WO)} + \text{Water Stored (WS)}$$

The Water In is the Precipitation, either rainfall (Pr) or irrigation (Ir).

The Water Out includes Intercepted precipitation (Pi), Runoff (RO), Evaporation of water from soil and surface water (Es), Transpiration (T) and Deep drainage or Leakage (below the root zone) (Dd).

The Water Stored is the water added to (rainfall or irrigation) or subtracted from (plant extraction or drainage) the soil.

So, the water balance expression for rainfall situations is:

$$Pr = (Pi + RO + Es + T + Dd) + \Delta WS$$

This expression is similar to that described by Stirzaker et al (2002) in which the water balance of whole catchments is described.

In terms of urban tree water management there are some elements that cannot be changed. These include rainfall (Pr), interception (Pi) and transpiration (T). Ideally the amount of water stored in the soil should be maximised so that the greatest amount of water is available to the street. Encouraging infiltration to reduce runoff (RO), improving soil hydraulic properties so that more water is stored (E.g. addition of organic matter) reduce deep drainage (Dd) and increase the water available for transpiration (T).

The water balance analysis of a specific tree situation requires consideration of numerous aspects including the time frame over which to conduct the analysis (days, months, season), the extent of the root system (tree rainfall catchment area) and the soil properties (water holding, infiltration and percolation).

The importance of optimizing water stored in the soil is illustrated in the analysis of a 10 m high tree, with a crown of 5 m diameter, and a root extension of 10 m (the height of the tree). In an example outlined in Connellan (2005) the soil has a storage capacity in excess of 100 days. Extensive root systems, deep active root systems and soils with good water holding properties greatly increase the survival capability of trees.

OVERVIEW OF TREE WATER DELIVERY TECHNIQUES

The decision to provide supplementary watering either on a temporary or permanent basis is a significant one. In many circumstances it is made in response to evidence that the tree is seriously stressed. The following outline some of the challenges that may be preset when considering the watering of street trees, which tend to represent the more difficult cases.

- a) Tree roots contained within median and street structures – limited water storage volume and limited catchment opportunity
- b) Tree root distribution highly variable in density and position (including depth)
- c) Access to root systems often limited by impermeable or very low permeability surfaces
- d) Tree roots often in competition with turf roots for irrigation water
- e) Significant roots located deep within the soil profile – water needs to be delivered at depth
- f) Compacted soils (low infiltration rates) - particularly on nature strips
- g) Street trees are often in high traffic and high maintenance areas (risk to equipment functioning)

TREE WATERING OPTIONS

The choice of irrigation delivery method and the operation or control of the system is very important in the watering of urban trees. There are potentially numerous irrigation delivery options including:

- a. Sprinklers
- b. Sprays (short throw, high precipitation rate)
- c. Microsprays
- d. Mini bubblers
- e. Surface drip (sub mulch)
- f. Subsurface drip- Shallow and Deep
- g. Water wells (e.g. 50 mm diam. x 300 mm deep) supplied by bubblers
- h. Watering rings (perforated pipe and drainage material) supplied by bubblers or similar
- i. Watering trench (various designs)
- j. Water injection
- k. Surface water storage devices (e.g. traffic barriers) with controlled release of water

Drip is well suited to the watering of mature trees. Water should be applied slowly, so that runoff does not occur and deep, so that the soil volume, where the bulk of the roots are located, is watered rather than just the top layer of soil. Shallow ineffective watering is commonly experienced with sprinkler and spray systems irrigating trees.

Delivery of water to the middle root zone, rather than just to the surface soil layers is preferred. A subsurface drip system is one technique that allows direct application of water to the root zone. However, installing these systems into existing mature trees risks damage to tree root systems.

IRRIGATION TECHNIQUE SELECTION CRITERIA

In making the selection of an irrigation method for urban trees consideration should include the following aspects of the method.

- a) Water distribution in soil – lateral and vertical
- b) Application/precipitation rate of system
- c) System delivery flow rate (total amount that can be delivered)
- d) Installation risk to trees (potential root damage)
- e) Watering program required (irrigation program to fit time window)
- f) Ongoing maintenance requirements e.g. blockages, vandalism, risk issues

SOME TREE IRRIGATION EXAMPLES

The following permanent type irrigation methods are examples of methods used in the irrigation of urban trees. With each of these methods the effective delivery of water into the root zone, without surface runoff, is an underlying characteristic.

(A) Surface drip under mulch

This method of watering is well suited to mature trees. The mulch is a natural water conservation material, it protects the irrigation pipe and also provides benefits in terms of tree soil health. The presence of mulch, to the exclusion of turf, removes competition of water. However it is often not practicable in high traffic areas where it can be readily dislodged. In these situations other options such as granitic sand or some form of permeable pavement material can be used.

The design of drip systems needs to take into account the ground area to be watered and the total amount of water to be applied. Design considerations include:

- a) Type of drip emitter and supply line
- b) Emitter flow rate
- c) Emitter spacing along supply line
- d) Spacing between drip emitter supply pipes
- e) Installation requirements
- f) Operational requirements e.g. run time and frequency

The actual spacing of drip emitters will depend on the extent of the mulch if it is used. The number of emitters would be determined based on the amount of water to be delivered in a watering cycle and the time available for delivery.

(B) Subsurface drip

Drip pipe can be buried shallow (less than 150 mm) or deep (e.g. 200 to 400 mm). Deep installations allow water to be delivered to the mid range of the tree root zone. In both cases consideration of the risk of damage to tree root systems during installation must be taken into account. Hand digging may be required in some circumstances.

Drip systems are relatively complex compared to sprinkler systems and have special needs in terms of design, materials and installation.

The following aspects and characteristics of subsurface drip system should be considered when planning a system.

- (1) The drip emitter needs to operate reliably and precisely in a soil environment
- (2) The emitter is to be resistant to intrusion of roots and ingress of soil particles and debris
- (3) Hydraulic control devices and emitter design to prevent back siphonage
- (4) Provision for flushing of drip lines is required
- (5) Filtration required to prevent blockage of emitters
- (6) Robust drip supply lines to resist crushing by growing roots
- (7) Rigorous maintenance program to facilitate longevity of the system

(C) Tree watering wells and trenches

The delivery of water, using some form of watering well, to a limited number of ground positions within the tree root zone, is a solution in some circumstances. Street trees with confined root systems or limited accessible ground area in which to apply water are situations suited to point delivery.

The water is delivered into the watering wells (vertical installation) or trenches (horizontal installation). This method of watering has the advantage of limiting tree root disturbance to the watering points. These systems are designed to facilitate deep watering.

An example of a tree watering trench, developed by the City of Melbourne (Connellan and Shears, 2008) comprises a trench approximately 1.2 metre long, 300 mm wide and 300 mm deep. The trench is filled with a free draining gravel material (quarter minus). Water is delivered to the trench via an irrigation bubbler. It is anticipated that there would be between 4 to 8 trenches for each mature tree.

Installation of the trench will cause some damage to the tree root systems. This can be minimized using water jets to dig the trench or in some cases hand digging will be required. Water jet excavation is a relatively expensive method, however, in some circumstances, it can be justified as the value of the tree is very high and the potential risk to the tree is significant.

ROLE OF SMART IRRIGATION TECHNOLOGY

It has become popular recently to refer to technological developments in urban irrigation that have the potential to improve irrigation efficiency, as Smart Irrigation Technology. These developments can be grouped according to:

- (1) Improvements in hydraulic performance and irrigation application efficiency
- (2) Improvements in irrigation scheduling (timing and irrigation amount)

The increased precision and reliability of delivery in drip irrigation products are important technological advances. The incorporation of pressure compensation into a range of microirrigation products, including drip emitters, together with anti suck-back mechanisms are important examples. Also, the ability of drip emitters to handle lower quality water, without blockage, is another example. This latter advance has application for lower quality water (in terms of suspended solids) such as stormwater and waterway sources and some treated effluent water.

IRRIGATION SCHEDULING TECHNOLOGY

The main thrust of improved efficiency has been directed at improving the timing of irrigation. In many sectors it is considered that the greatest saving in urban irrigation can be achieved through more precise and weather sensitive timing of irrigation. Overwatering (excessive run times) is considered a major source of inefficiency. The SWAT program (Smart Water Application Technology) in the USA is strongly focused on improvement through technology such as the use of weather station data and calculation of the daily evapotranspiration rate (ET)).

Potentially the greatest opportunity for technology in the water management of mature trees is in the area of soil moisture sensing. Obtaining feedback on the actual soil moisture conditions in the tree root zones is potentially very valuable.

The feedback from the soil moisture sensor can be used to:

- a) Provide feedback on actual soil moisture levels
- b) Assist in scheduling of irrigation
- c) Inform about effectiveness of rainfall and irrigation
- d) Characterise the water behaviour of the soil root zone including drainage
- e) Monitor soil water stress conditions including water logging
- f) Identify active root zones within tree soil profiles

Various studies have been carried out in the City of Melbourne on the soil moisture conditions in both streetscape and parkland situations. Key findings in street tree situations highlighted the limited penetration that was achieved over summer months with spray irrigation (Connellan, May and James, 2002). It is very difficult to achieve deep watering with spray systems. An innovative watering system was installed in Cemetery Road, Parkville, by the City of Melbourne, to water Elm trees using a dual watering approach. Surface sprays in combination with deep (300 mm) subsurface drip system were installed in the nature strip. This approach allowed grass to be maintained on the surface and water to be independently delivered to the mid depth zone of the tree root system.

Currently a project is underway at the Royal Botanic Gardens Melbourne investigating the water management of complex or mixed planting landscapes (Symes et al, 2008). A number of garden sites have been fitted with multiple sensor soil moisture units that transmit reading in real time to a host website. The project involves Sentek Pty Ltd and The Department of Resource Management and Geography, The University of Melbourne, in conjunction with the RBG Melbourne. One of the findings from this trial has been the observed extraction of soil moisture at various root zone depths over time by the trees. The extraction of moisture occurs progressively in time at increased depths to approximately 500 mm. In some cases moisture extraction is occurring at greater than 500 mm however the main the data show the main extraction occurs in the top 200 to 300 mm of the soil

profile. An aim of this trial is to link the soil moisture readings to landscape condition so that decisions regarding appropriate amount of water to be applied and timing of watering can be optimized.

REFERENCES

Connellan, G. J., James K., and May, P. B. (2000), *Developing water management strategies for urban trees using soil moisture sensor technology*, Proceedings of ASAE 4 th Decennial Irrigation Conference, 14-16 November, 2000, Phoenix, Arizona.

Connellan, G. J. (2005) *Water efficiency strategies in our cities – Their impact on urban trees*, International Society of Arboriculture Australian Chapter National Conference, Launceston (October 2005).

Connellan, G. J. and Shears, I. (2008) *Watering of Street Trees: Theory and Practice*, Proceedings of Irrigation Australia 2008 Expo and Conference, Melbourne, May 2008

Fam, D., Mosley, E., Lopes, A., Mathieson, L. Morrison, J. and Connellan, G. J. (2008) *Irrigation of Urban Green Spaces: A review of the Environmental, Social and Economic benefits*, Technical Report No. 04/08, Cooperative Research Centre for Irrigation Futures, Darling Heights, Qld. 35pp.

Stirzaker, R., Vetessy, R. and Sarre, A. (2002) *Trees, water and salt: an Australian guide to using trees for healthy catchments and productive farms*, Joint Venture Agroforestry Program 2002, RIRDC Publication Number: 01/086

Symes, P., Connellan, G. J., Buss, P. and Dalton, M (2008) *Developing Water Management Strategies for Complex Landscapes*, Proceedings of Irrigation Australia 2008 Expo and Conference, Irrigation Australia Ltd, Sydney, 20-23 May, 2008.