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NSW DEPARTMENT OF PLANNING, INDUSTRY AND ENVIRONMENT

Water Efficiency Study for Urban Tree Management

FINAL REPORT / June 2020

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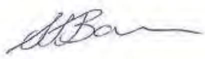
Signed	
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1. Glossary

Active irrigation – Irrigation of plants and trees using a pressurised / pumped water source available on demand and energy to supply water. Supply can be from mains drinking water or an alternative water source

Alternative water source – Water that isn't sourced from the mains drinking water supply system. This may include rainwater, stormwater, greywater or recycled water.

Aquifer – A water holding geological feature such as sediments or permeable rock. Often perched on top of or between impermeable layers of rock.

Aggregate – A mass of rock, concrete or sand fragments, loosely compacted together.

Amelioration – An improvement in soil condition through the application of soil amendments such as gypsum, lime and organic matter.

Capillary rise – The movement of water vertically up through a soil profile (against gravity) through small openings/air spaces.

Catchment – An area that drains to a given point, typically drainage is dictated by topography but may be modified by man-made structures including kerb and channel.

Deep soil storage – Water that soaks down into deep soils where it is stored and helps replenish the moisture in surface soils during dry times and may be accessed by deep tree roots in some tree species.

Disinfection – the process of destroying pathogens (in water) through processes such as ultraviolent exposure and chlorination.

Evapotranspiration – The loss of water to the atmosphere through the combined processes of evaporation (i.e. the transfer of water from the land to the atmosphere) and transpiration (i.e. the transfer of water from plants to the atmosphere).

Filter media - Soil media that retains pollutants as stormwater passes through it.

Fit for purpose water supply - The delivery of water that meets but does not unnecessarily exceed the requirements of the end user (e.g. in terms of water quality).

Hardness – A measure of the mineral content of water, specifically calcium and magnesium. Known to cause scale and problems with irrigation infrastructure.

Hydrophobic – water repellent, typically with respect to sandy soils that have high organic matter.

Impervious surface - Surfaces that do not allow natural infiltration of rainfall to the underlying soil, thereby increasing the volume and peak flow rate of surface runoff.

Infiltration - The process by which surface water enters the soil.

Inflows – The movement of water into a tree pit or other place.

Loamy Sand – A description of soil texture that is the preferred growing media for trees, containing mostly sand (min 50%) and approximately equal parts clays and silts.

Non-potable water - Water that is not fit for drinking purposes but may be fit for other end uses (e.g. irrigation, toilet flushing, dust suppression).

Passive irrigation - Irrigation that occurs without active intervention (i.e. not using an irrigation system which required energy/power to operate). Generally, refers to areas that are irrigated through the diversion of stormwater runoff to a landscape area.

Pathogens – Living biological agents capable of causing disease or illness such as bacteria contained in water. Pathogens typically of concern include *Enterococci spp.* and *Escherichia coli (E. coli).*

Pervious pavement - A type of pavement that does not contain fine particles, and which is designed to allow the infiltration of water into underlying soils, thereby producing less runoff than conventional pavements.

Plant available water capacity – The amount of total soil moisture that is available for uptake by plants, being that water not bound to soil and not infiltrating beyond the reach of tree roots.

Ponding – Water accumulating on the surface that is unable to infiltrate, or infiltrates at a very slow rate.

Potable water – Water that is treated to a standard fit for human consumption.

Raingarden / bioretention - A system of vegetation and layered filter media that captures, retains and treats stormwater before slowly releasing it to receiving waterways.

Rainwater – Water that is generated off roof areas.

Receiving environment – The natural environment into which water from surface flow enters. This includes waterways (streams, creeks, rivers, estuaries), wetlands, lakes, groundwater, bays and the ocean.

Recycled water - Water, usually wastewater, that has been treated to a level that makes it fit for use (the uses that it is suitable for will depend on the level of treatment).

Runoff - Stormwater generated from rainfall. This runoff travels over land or through drainage networks (e.g. Council pipes and pits) before discharging into local waterways.

Saturated – A volume of soil that can't hold any additional moisture.

Saturated zone - An area beneath or adjacent a tree designed to hold water.

Sediment – Small-grained material (such as sand, silt and clay) that is carried by water and is deposited on the surface.

Sewer mining – Taking, treating and using wastewater straight from the wastewater pipes (Sydney Water).

Soil compaction - The process of increasing the density of soil by packing the soil particles closer together causing a reduction in the volume of air. A compacted soil has a reduced rate of both water infiltration and drainage which can impede root growth and can cause oxygen deficiency.

Soil volume – The volume of soil that is accessible to the tree roots. In compacted soils or where root growth is restricted (e.g. lined pits), the volume of soil backfilled into the pit dug for the tree may represent the total soil volume available to the tree.

Soil water retention capacity – The amount of water that can be held by soil.

Stand-pipe – An access point where water trucks can refill from the drinking water mains or an alternative water source. The latter are most likely to be located at Sydney Water storages and treatment plants.

Storage volume – The amount of water that can be captured before bypass or overflow occurs.

Stormwater - Rain that hits the ground and runs off to drains or elsewhere. The term is often used in an urban context where rain runs off hard surfaces such as roads and car parks, often picking up contaminants (Sydney Water).

Surface condition – The exposed soil surface around the tree or the interface where water from a leaky pipe, trench or well infiltrates the soil.

Urban Heat Island Effect – Refers to the higher average temperatures in cities when compared to surrounding rural / natural areas. Urban areas have surfaces like roads and roofs that absorb and retain heat leading to higher temperatures in urban areas relative to surrounding areas with more vegetation.

Wastewater - Water that has been used, usually in human activities. This includes water from households (blackwater and greywater) as well as water from industrial and commercial uses (Sydney Water).

Waterlogging – The saturation of soils with water. Waterlogging occurs when there is too much water in a plant's root zone, which decreases the oxygen available to roots. Waterlogging can be a major constraint to tree growth and, under certain conditions, will cause tree death.

Water sensitive urban design (WSUD) - A holistic approach to water management that integrates urban design and planning with social and physical sciences in order to deliver water services and protect aquatic environments in an urban setting.

Wetting agents – soil additives that help to overcome hydrophobic properties of soil and allow soils to hold water.

Wicking – Water being drawn up and raising through a soil profile.

2. Introduction

2.1 Project background and context

The NSW Government is committed to increasing urban tree canopy and green (vegetated) cover throughout Greater Sydney. Progressively the canopy cover in Greater Sydney will increase shade, reduce the urban heat island effect, provide more habitat for flora and fauna, enhance amenity and improve the community's resilience to a changing climate. Replacing paved areas with green cover also increases the amount of water that is able to soak into our landscape, complementing the benefits of tree canopy as well as improving the health of our waterways through reducing excess stormwater runoff.

To achieve this, the NSW Government established the 5 Million Trees (5MT) program for Greater Sydney to plant five million trees by 2030 and help achieve the Greater Sydney Region Plan's target of 40% canopy cover by 2036. Figure 1 presents canopy cover in Greater Sydney in 2018.

In 2019, the Premier announced a key priority: Greening our City, which aims to have one million of these five million trees planted by 2022. To support this, the Department of Planning, Industry and Environment (the Department) has:

- launched an inaugural grant program in 2019 that has co-funded Greater Sydney councils to plant approximately 21,000 new trees in Greater Sydney.
- partnered with non-government organisations such as Landcare and Greening Australia to fund and deliver large-scale tree planting projects.
- funded demonstration projects to increase canopy in suburbs with low canopy coverage e.g. Campbelltown Council's Rosemeadow Pilot Project.

Councils who received grant funding in 2019 reported that planting trees during a time of drought and water restrictions put their commitments and funding under the 5MT grant program at risk. These risks included loss of trees due to the harsh conditions experienced in urban areas and public perception about using mains drinking (potable) water to establish and maintain trees during water restriction periods.

The harsh conditions are associated with reduced available soil volumes, less infiltration of water into soils due to impervious surfaces and reflected heat from hard surfaces. This becomes more pronounced with increasing climatic variability. This means all but the most drought tolerant native species may need some form of ongoing and/or supplementary irrigation to thrive and reach their full potential canopy cover.

It is recognised that there are growing pressures on potable water supplies including population growth, declining dam yields due to climate change and the risk of drought. While recent rains have topped up Sydney's dams and allowed restrictions to be eased, in 2019 they fell to their lowest levels since the Millennium Drought in 2004 leading to water restrictions and the concerns described above.

Potable water is highly treated, high-quality water which is needed for essential purposes such as drinking and showering as well as business and industry. There is a growing need to potable water supplies to be conserved during both wetter periods and in drought to ensure that during droughts the dams have sufficient stored water to meet these requirements. There are other available water supplies, which may not be treated to the same standards, which can be suitable and more appropriate for purposes such as irrigation of trees. These include sources such as stormwater and wastewater. There is an excess volume of these alternative water sources within urban areas that adversely impacts our waterways and oceans. Therefore, the use of these for irrigation not only increases the overall supply available but also reduces impacts on the natural environment.

The efficient use of water to support tree growth is an important element in the success of the ongoing roll-out of the program due to a combination of:

- low water availability due to drought conditions, water restrictions and climate change.
- high demand for water because of chosen tree species, the stage of development of a tree and local climate in Greater Sydney.
- the program's aim to minimise use of high-quality potable water for irrigation purposes at any time.

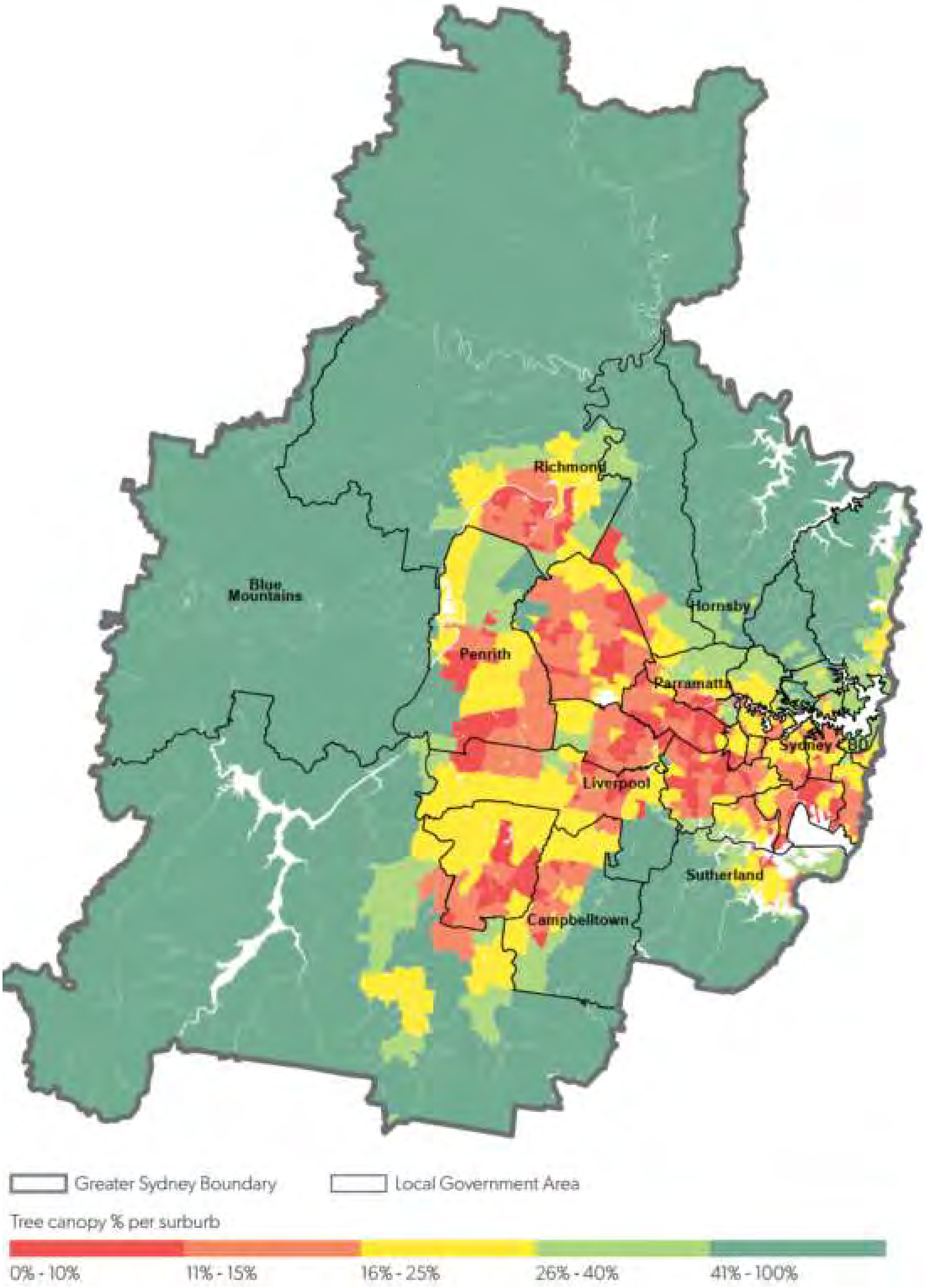


Figure 1 - Canopy cover of Greater Sydney suburbs in 2018 (from: 5M Trees for Greater Sydney Local Government Grant Program 2018-19 Guidelines, data source: Energy, Environment and Science (EES) Division within the Department of Planning, Industry and Environment.)

2.2 Project scope

This project aims to undertake a water efficiency study for urban tree management. The objective of this work is to understand what opportunities there are to build in innovations to use water more efficiently to irrigate street trees in Greater Sydney, with the aim of incorporating these as requirements into future grant programs. The outcomes of this project will be used by the Department to inform criteria to:

- assess projects for future 5MT program council grant rounds.
- assess expressions of interests for future demonstration projects.
- determine future research that could inform further innovations.

2.2.1 Water efficiency definition

Water efficiency has typically been considered in terms of reducing the demand on potable water supplies. This can be done by reducing the amount of water that is used (demand management) or in the case of trees choosing species that have lower water use requirements or greater drought tolerance. It can also be achieved using alternative sources of water (substitutes). Whilst these substitutes for potable water, such as stormwater or recycled water, may not always be suitable for drinking (although they can be with appropriate treatment), they may be suitable for uses such as irrigation of urban trees. These can potentially be used in the short term for establishment or during droughts or more effectively as an ongoing long-term supply. For long term supplies they can potentially be supplied at a lower cost relative to alternatives such as using water trucks for potable water or maintaining extensive active irrigation systems within streetscapes. Lower classes of water typically may also have lower embedded energy costs to produce and distribute than new sources of potable water, making them more sustainable sources. Figure 2 presents a hierarchy of water use which outlines the preservation of high-quality potable water for essential services such as drinking, cooking and showers. Lower quality water can preferentially be used for other purposes such as irrigation.

For the purposes of this project, water efficiency refers to *"the growth and ongoing resilience of healthy urban trees without ongoing reliance on potable water".* This includes either planting trees that do not use a lot of water, retrofitting existing planting or installing new planting with innovative water efficient designs or the provision of alternative water supplies to support healthy tree growth. The work undertaken in this project has sought to inform grant criteria and present solutions which will help to achieve these outcomes across the 5MT program and for the Greening our City Premier's priority.

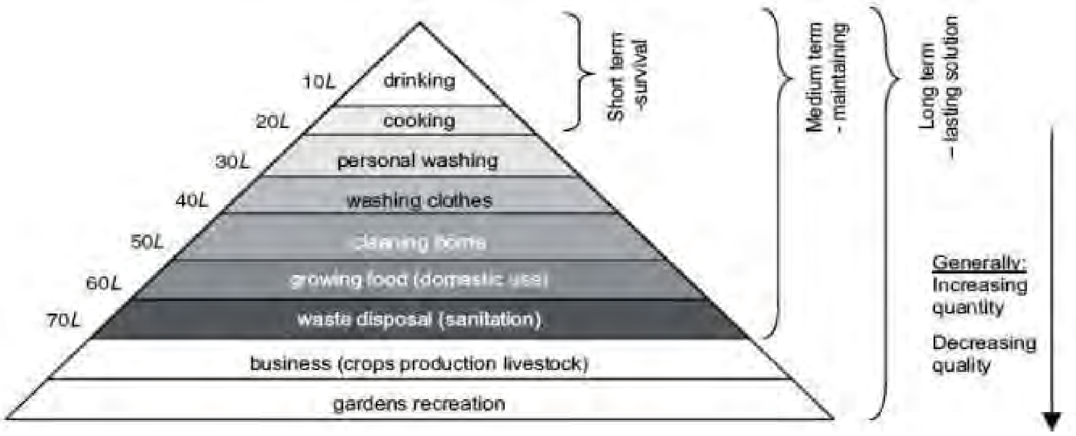


Figure 2 - Hierarchy of water requirements (WHO, undated)

2.3 Project approach and report structure

The following key tasks were undertaken in the development of this report:

- review of grant programs and criteria.
- literature review to identify requirements for healthy and resilient tree growth.
- review of case studies and guidelines to identify potential water efficiency solutions.

The outcomes of this work have been presented in the following sections:

- Healthy and resilient trees – to provide an overview of healthy tree requirements.
- Water efficiency solutions – to assist in the delivery and demonstration of resilient tree planting projects.
- Key messaged - summary of key messages.

3. Healthy and resilient trees

3.1 Benefits of healthy and resilient urban trees

The potential benefits of healthy and resilient urban trees span urban greening, water management and social outcomes and are summarised in Figure 3.

Figure 3 - Typical benefits of healthy and resilient urban trees

Some of these benefits can be quantified as shown in Figure 4.

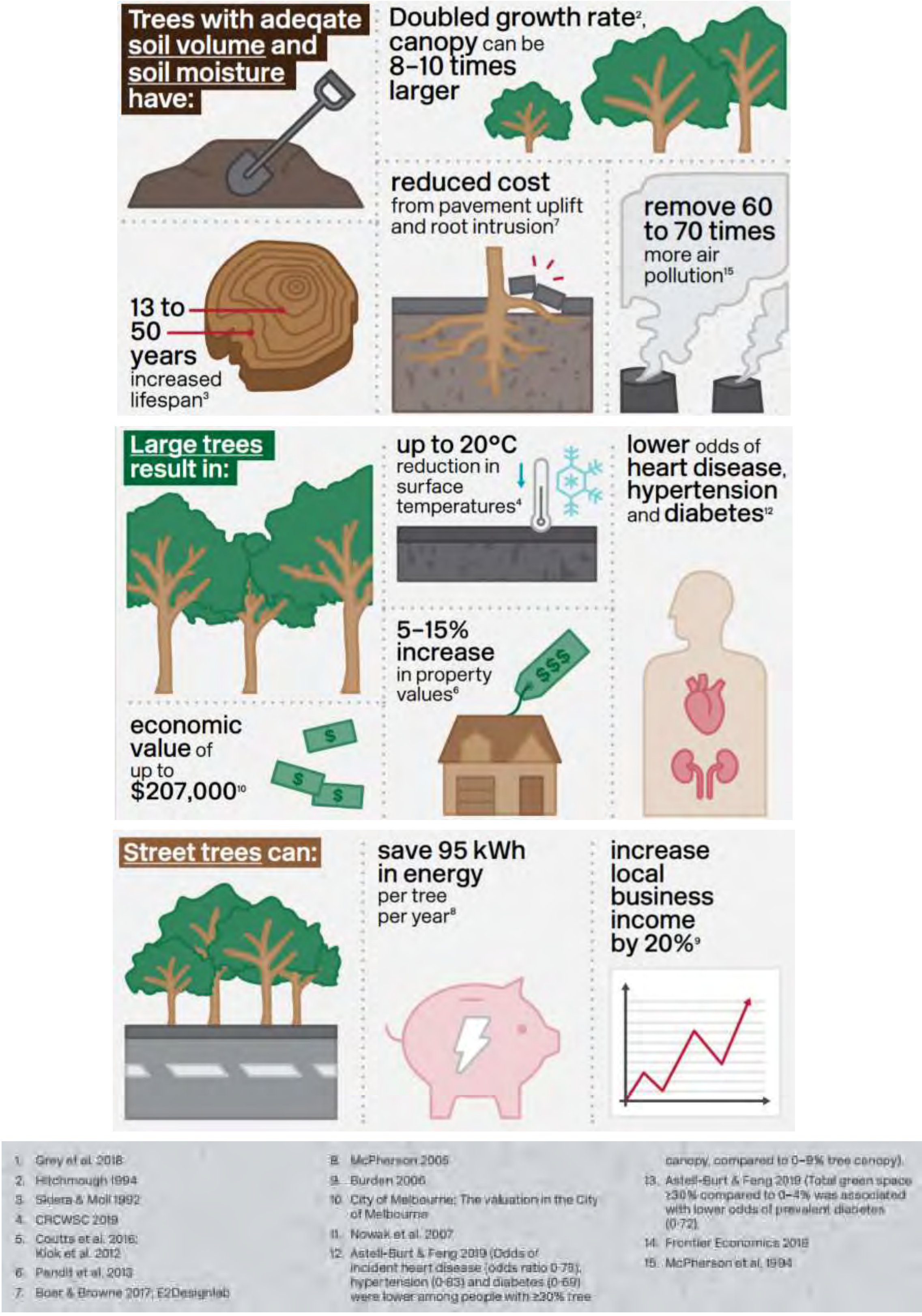
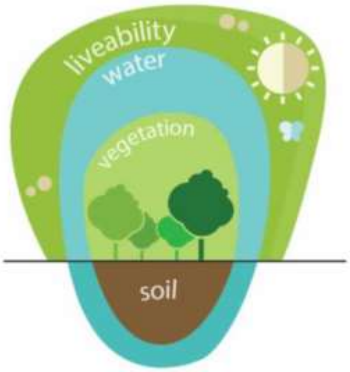


Figure 4 - Quantifying the benefits of healthy urban trees (From CRCWSC (2020) Designing for a cool city: Guidelines for passively irrigated landscapes)

3.2 Requirements for healthy and resilient trees

Healthy trees provide many benefits in our urban areas (see Figure 3 and Figure 4 for a summary of benefits). It is therefore important that these green assets are established successfully and are resilient now and into the future. To ensure this, when planning a tree canopy and urban greening projects, careful consideration needs to be given to species selection, soil volume, soil condition and water.



3.2.1 Species selection

Different tree species have varying requirements and it is important to place the right tree in the right place at the right time. Guidance on tree selection is provided by the NSW Government in the Tree Selector Tool (https://5milliontrees.nsw.gov.au/search).

Tree water demand is highly dependent on the tree species selected. It is important to understand these requirements to ensure trees have access to sufficient water to establish successfully and the ongoing soil moisture conditions to support healthy tree growth. The selected tree species should either be well adapted to the proposed site and require no supplementary irrigation after initial establishment or have an ongoing water source (preferably alternative sources such as recycled water or stormwater) designed into the project to meet the trees additional water demands (or both). An understanding of tree water demands, and the response adopted to ensure trees have sufficient water should be clearly documented in any funding application and/or concept plan.

3.2.2 Soil volume and water

It is well documented that trees that have access to greater soil volumes and reliable water establish larger and denser canopy cover than trees with limited access. The specific soil and water requirements will depend on the tree species selected. Figure 5 shows a generalised relationship between soil volume, irrigation frequency and canopy cover (adapted from Hitchmough, J. 1994) and illustrates how important water and soil volume is in supporting healthy tree canopies in Sydney.

Ideally, the soil volume should be maximised to allow the tree to grow to its mature size (i.e. reach its full growth potential). The following guides and rule of thumbs can inform this process:

- root systems of a healthy tree have the potential to grow approximately 3 times the radial area of the canopy.

- fruit and ornamental trees have an effective root zone depth of between 300 and 600 mm, which is highly dependent on soil type, compaction and any subsurface barriers (soil conditions).

Depending on the tree type and its condition, the larger the soil volume, the greater the canopy. The provision of regular water will also support the growth of larger canopies (Figure 5). The combination of larger soil volume with improved soil moisture conditions means the tree can grow to its full potential and support a much larger canopy.

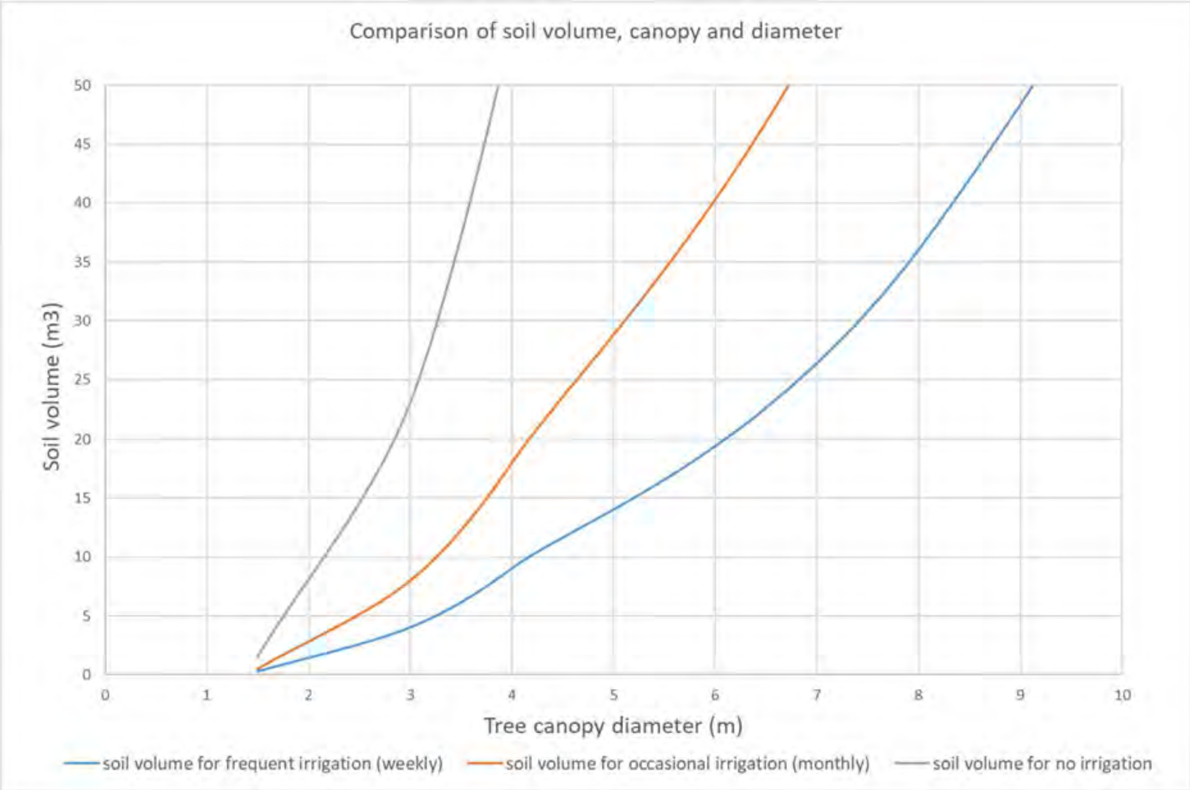


Figure 5 - Comparison of soil volume required for a given canopy diameter with and without irrigation for an urban tree in Sydney (central) (Hitchmough, J. 1994)

As demonstrated in Figure 5, an increased soil volume and availability of water for irrigation can result in an increase in canopy cover. For example, a tree pit in Sydney (central) with a soil volume of $10m^3$ and no irrigation has an expected maximum tree canopy diameter of approximately 2m, while a tree planted with access to a soil volume of $30m^3$ and occasional irrigation, has an expected maximum tree canopy diameter of approximately 5m. The impact on canopy area is further pronounced with the corresponding canopy area being $3m^2$ and $20m^2$ respectively. This is summarised in Table 1.

Table 1 – Summary of possible expected maximum canopy cover for different tree pit designs in Sydney (central) based on Hitchmough, J. 1994 (see Figure 5).

Tree pit design	Soil volume	Irrigation	Expected approximate maximum canopy diameter	Expected maximum canopy area
Design example 1	$10m^3$	No	2m	$3m^2$
Design example 2	$30m^3$	Occasional (monthly)	5m	$20m^2$
Design example 3	$35m^3$	Frequent (weekly)	8m	$50m^2$

The canopy cover provided by a tree planted with access to an appropriate soil volume and soil moisture has a canopy area over 6 times greater than a tree in constrained conditions with limited access to any water supply.

Note, Figure 5 and Table 1 provide a generalised relationship and is a guide only as there are numerous variables that will influence canopy cover. For example, canopy form (e.g. upright versus wide spreading tree species), differing transpiration rates, leaf size/surface area and density. The graph is also based on the assumption that the trees will be fully containerised (i.e. cannot access soil beyond the tree pit/soil volume they are planted in) and is based on a rainfall period when greatest water stress is most likely (in Sydney this was November to January).

Soil condition

Trees need the soil available to be of a suitable condition for optimum growth. Even with adequate soil volumes, if the soils are of poor quality (e.g. lack nutrients, are compacted or otherwise lack oxygenation) the tree may not achieve optimum growing outcomes, or may not survive in some cases, even with adequate soil volumes.

Ideally soils will have:

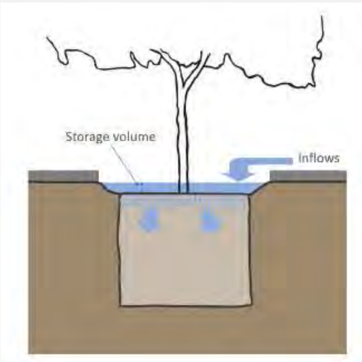
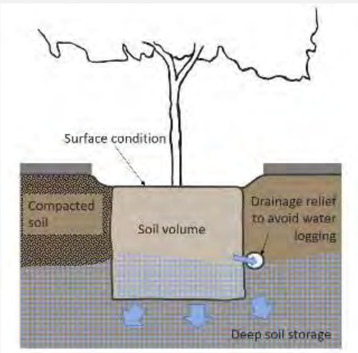
- 500 mm depth that is freely draining (i.e. not waterlogged). (Best practice tree planting details allow for a minimum 700mm total depth).
- adequate nutrients, aeration and water retention and be uncompacted.

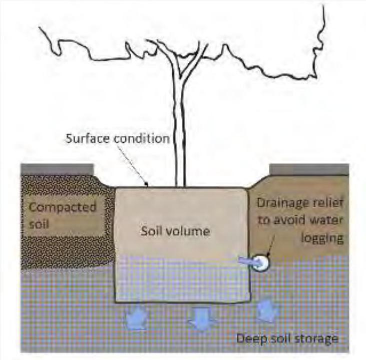
Compacted soils, such as soil under roads and pavements, confine and restrict root growth. This can result in a simple root system that adversely affects the structural integrity of the tree as it reaches mature size. Poor soil quality often results in slowed or stunted growth.

Further guidance on street tree soil specifications, soil testing and common amendment approaches can be found in a range of guidelines. One example that may be useful is the City of Sydney Street Tree Master Plan – Part D Technical Guidelines, updated 2015. The soil specification in this guideline is based on the book 'Soils for Landscape Development' by Simon Leake and Elke Haege (CSIRO Publishing; 2014) who are experienced soil scientist and arborist, respectively. City of Sydney adapted the guideline for common and typical street tree planting scenarios. This provides potentially useful initial information on soil specifications with input from soil scientists although users should always consider the specific context, soils and relevant expert advice for their site. Barriers to growth and ongoing resilience of healthy urban trees.

Trees in urban areas must compete with and complement a range of human service and infrastructure needs within our streetscapes including roadways and pavements and below and above ground services. These often limit trees' access to both adequate soil volumes as well as water and can result in poor canopy cover, failure of trees to establish or thrive and premature tree death. Table 2 presents a summary of key risks related to water and soil which should be considered in any urban tree projects to improve the resilience of these important green assets.

Table 2 - Key risks to water supply and soil condition for urban trees

Risk element		Description and risk management
Water supply  	Inflows	Water demand will depend on the tree species. If irrigation (post establishment) is required, a suitable supply must be sought. This could either be passive or active irrigation with alternative water sources (e.g. stormwater / recycled water)
	Storage volume	If additional water is required to sustain trees between rain events, a suitable volume of water will need to be provided. This can either be provided as storage within a passive irrigation solution (capture volume), or through active irrigation with an alternative water source.
Soil condition  	Soil volume	Having enough soil volume to provide the stability, nutrients and moisture trees need is critical to optimal tree growth. The accessible soil volume available to a tree is highly dependent on the quality of in situ soils and design of the tree pit. Where in situ soils are of poor quality and/or highly compacted, the size of the excavated tree pit at time of planting could represent the total volume of soil available to the tree. It is therefore important to provide a tree pit of suitable volume for the selected tree species and backfilled with quality soil or ensure the tree can access quality in situ soils without encountering barriers (e.g. compaction or pit liners).
	Surface condition	To ensure that water can infiltrate into the soils, it is important that the surface of the tree pit does not clog. Having additional planting or access to the surface for maintenance (especially if stormwater is directed to the surface) is important.

Risk element		Description and risk management
Soil condition (cont.) 	Deep soil storage	Providing a connection between the soils in the constructed tree pit and surrounding/deep in situ soils enables deep soil moisture recharge during wet periods. And when the dry weather comes, the tree uses the moisture in the top layers but then, the moisture from below can be drawn up to the tree roots through capillary rise. Lined systems and systems with a bioretention style aggregate drainage layer limit this deep soil moisture connection. Where liners are required (e.g. to protect building footings), lined water storage zones in the base of the tree pit (i.e. wicking beds) can be provided as an additional dry period water source.
	Compaction	Soils are often compacted to support roads and other urban infrastructure. Compaction compresses the soil and increases its density. Compaction is a major restriction to healthy tree root growth and can adversely impact the structural integrity of the tree. Compacted soils usually have fewer voids (depending on soil type) which limits air flow to oxygenate soil, reduces the soils capacity to hold water and affects microbial health. Tree planting projects need to carefully consider requirements for soil remediation, mechanic breakdown of the tree pit interface with site soils and/or the use of structural soil or structural soil cells to enable uncompacted soil volumes to extend under pavements.
	Water logging	Tree roots need both water and oxygen. When the soil becomes saturated through the root zone (typically upper 300-600 mm of soil) this can result in water logging and drowning of a tree. This is particularly an issue of concern for tree pits receiving additional water in slowly draining soils like clays although less of a concern in freely draining soils like sands. In slowly draining soils, relief drainage is important to ensure the upper 500mm or so of soil remains aerated/'aerobic' and not waterlogged. Some saturation below the aerobic zone and in the surrounding soils is ok. This can promote deep soil water storage which trees may access during extended dry periods through capillary rise bringing water upwards into dryer soils or via deeper roots.

3.3 Water sources for tree irrigation

Sources of water for irrigation include:

- potable water.
- rainwater or stormwater.
- recycled water.
- greywater.
- groundwater.

Table 3 provides a summary of these different options for irrigation water.

Table 3 – Summary of different options for irrigation water supply

	Potable Water	Rainwater or Stormwater	Recycled Water	Greywater	Groundwater
Description	Potable water is water that is treated to a standard suitable to drink. It typically refers to water supplied through the main water supply network to end users. Sydney's potable water supply is mostly sourced from dams and treatment plants. A portion of the bulk supply is sourced through desalination. The use of desalinated water provides a more certain supply during droughts when dam yields can decrease. The availability of desalination water reduces the risk of disruptions to supply or the requirements for water restrictions during times of drought, however it is more expensive and energy intensive than dams.	Rainwater and stormwater refer to rain that has fallen on roofs and on a mix of surfaces (such as roads and gardens) respectively, which has resulted in runoff. This runoff is then collected or harvested in tanks or storage reservoirs such as lakes or ponds. In urban areas there is an excess of rainwater and stormwater that carries pollutants to downstream waterways and it can be beneficial for it to be retained and used within the landscape or urban area.	Recycled water refers to sewage that has been treated (to varying potential standards) and re-distributed for use by a range of potential end users. The potential uses depend on the level of treatment, however in Sydney recycled water is not generally treated to standards suitable for human consumption or direct human contact.	Greywater refers to wastewater that comes from kitchens, baths, showers, wash basins and laundries. Greywater (as opposed to blackwater, which is from toilets and bidets) has a lower level of harmful bacterial contamination, however still requires treatment to be suitable for most uses. Treatment typically consists of septic tanks or filters to remove solids, oils and greases. Additional treatment (e.g. UV) is required where human contact cannot be avoided.	Groundwater has been used as a water source in many areas throughout Sydney. The quality of groundwater can be highly variable, particularly in terms of its physio-chemical properties such as salinity, pH and hardness. As such, groundwater should always be used with caution, as untreated it may be harmful to vegetation. Ideally any use of groundwater should be sustainable and recharge volumes exceeding extractions provided. For any aquifer recharge schemes, it is important to consider groundwater as a receiving environment and avoid any potential groundwater contamination.
Pros	• Widespread availability through water mains in urban areas. • Not likely to be subject to restrictions except in extended drought periods. • Ease of access. • Can be provided under pressure to support irrigation.	• Can continue to provide water during extended drought, as runoff is generated from small rainfall events in urban catchment and storage reservoirs (tanks/ponds) can be topped up. • Can be provided passively (gravity fed). • Harvesting reduces the harmful impacts of excess runoff on our waterways.	• Prevents discharge of treated sewerage (still containing nutrients and pathogens) to the receiving environment. • Consistently available regardless of drought conditions.	• Typically used at source, limiting energy costs associated with distribution. • Readily available and consistent water source.	• Consistent water source. • Generally accessed on site limiting distribution requirements. • Can potentially be used for irrigation without treatment. • Safe for human contact.
Cons	• Supply can be impacted in extended drought (usually consecutive dry years). • Following extended dry period significant volumes of rainfall are required to generated runoff in natural pervious catchments. • Additional (desalinated) sources have high cost and energy use to treat and distribute.	• Susceptible to supply issues during long periods without runoff (weeks to months). May have reduced supply availability during extended dry spells with no or very little rainfall. Overall volumes vary in proportion to rainfall but are not affected by consecutive dry years (as dams are). • Not suitable for many uses (particularly human contact) without treatment systems such as filtration and UV disinfection.	• Required to be near a recycled water pipeline for use. • Not suitable for human contact without treatment. • Ensure water quality is suitable for irrigation of trees.	• Can be supply limited for larger volume requirements. • Treatment requirements have maintenance costs and implications. • Generally, not suitable for human contact without disinfection. • Potential odour associated with water if treatment systems are not appropriately maintained.	• Limited by aquifer locations and access licences/permits. • Over-extraction of groundwater can cause many environmental problems. • Water quality and suitability for irrigation can be variable.
Recommended use for trees	Recommended in the absence of viable alternative sources, for short term use and as a back-up to alternative sources. Where it is the primary source, potable water should be used in conjunction with other water efficiency approaches such as scheduling technology or drip irrigation. It may also be used when irrigation of trees is only needed for establishment.	Ideal approach for street trees and raingardens as it limits the need for active irrigation infrastructure which may be difficult to install and maintain in streetscapes in urban areas.	Recommended for irrigation where near a recycled water pipeline. Ideal for open locations such as parks where sprinkler irrigation does not conflict with other services or have a risk of being damaged by third parties.	Best suited for privately maintained systems, such as private dwellings or substantial buildings, businesses or campuses with a body of management capable of overseeing or contracting out ongoing operation and maintenance.	Groundwater may be useful in shallow sand aquifers that have consistent recharge, or where aquifer recharge schemes enable replacement of groundwater with treated stormwater.

3.3.1 Potable water

Potable water refers to water that is fit for human consumption. Most water used in Sydney is potable water that is collected in dams and treated at water treatment plants or produced through desalination. This water is distributed throughout Sydney directly to homes and industry via Sydney's water mains. As the drinking water for the residents of Sydney, it is important that potable water is prioritised for essential purposes such as drinking, showering and use by business and industry.

Climate change is forecast to increase the risk of extreme drought, characterised by higher temperatures and corresponding evapotranspiration as well as likely lower rainfall. A combination of lower rainfall and dryer catchments threatens the reliability and water yield of dams which are the major water provider. This is particularly the case as demand increases in response to a growing population. The use of potable or drinking water for tree watering can be considered generally undesirable from a sustainability perspective, as it is energy intensive and costly to produce and distribute, particularly when produced by desalination.

To reduce the pressure on potable water supplies and in acknowledgement of its cost, energy consumption and hence position on the water use hierarchy, potable water should preferably only be used for tree irrigation in the absence of viable alternative water sources.

Despite these considerations, potable water is reliable and has the benefit of being readily available through access to existing pressurised water lines. Irrigation with potable water will often be the most practical and cost-effective approach for the establishment of trees that will not require ongoing watering, as establishing alternative supplies will commonly have higher upfront capital costs.

During times of drought when irrigation is most critical, the use of potable supplies for irrigation may be restricted. Therefore, alternative water options are typically best suited when long-term irrigation is required.

3.3.2 Rainwater or stormwater

Urban rainwater and stormwater refers to runoff generated by rainfall falling on impervious surfaces (as well as pervious surfaces with vegetation and soils in urban areas). Stormwater for reuse is often stored in small reservoirs such as tanks or ponds due to low available space in built up areas. This lower volume of water means they require regular rainfall to be filled. Consistency of supply is therefore strongly dependent on climate, and the volume of supply will reduce in a dry season or year in proportion to the rainfall. However, urban impervious surfaces readily generate runoff with only small amounts of rainfall. This means that during most rain events even within a dry season or year, runoff and irrigation will still occur. In contrast, large storages such as dams require more rainfall in a catchment to generate runoff. They therefore behave very differently and are more affected by an extended dry period or sequential years of drying which can result in greatly reduced yields.

The use of stormwater to supply the bulk of the water demand with occasional top-up from potable water if required, is an effective way to leverage the strengths and benefits of both systems.

Urbanisation creates vast expanses of impervious surfaces that result in greatly increased stormwater runoff volumes relative to pre-development conditions. This runoff can cause localised flooding issues, physical degradation of our waterways through erosion, and water quality issues by delivering pollutants such as nutrients, hydrocarbons and heavy metals to our waterways. Stormwater capture can turn this damaging nuisance into a valuable resource by capturing it prior to entering receiving waterways.

Stormwater contains pollutants such as nutrients, hydrocarbons and heavy metals. There is a strong focus on introducing stormwater treatment measures (called water sensitive urban design or WSUD) into urban areas to ensure all urban stormwater is treated prior to discharge to waterways and new developments have objectives that must be met for water quality treatment. Sydney Water and Councils are also seeking to reduce the volumes of stormwater through retention approaches that retain water within urban areas and the landscape through reuse, evapotranspiration and infiltration. This means that passively irrigating trees with stormwater not only helps keep trees healthy but also *delivers on a range of stormwater objectives that would otherwise have to be met using other infrastructure.* While other WSUD assets (such as wetlands or raingardens in parks) are more cost effective than street trees passively irrigated with stormwater there is potential for budgets for tree planting and for WSUD to be combined to construct assets that deliver both tree canopy and water management outcomes more effectively.

Passively irrigated trees can provide effective treatment of stormwater through the tree root zone and increase retention of water within the landscape. Pollutants such as nutrients can increase the risk of algal blooms for waterways but can be beneficial for plant and tree growth.

Where stormwater is to be used for irrigation, the catchment land uses and potential pollutants should be considered. Tree pits which have stormwater draining directly to them from a road or pavement (passive irrigation) require minimal pre-treatment to address litter and sediment. As water moves through the soil profile, further treatment is then provided to the stormwater (removing nutrients, metals etc) within the tree pit. If stormwater is to be captured directly off the roads or other hard surfaces and stored for an extended period before it is used for irrigation (stormwater harvesting), it will require treatment before it can be used. Ideally this treatment should occur before it is stored.

Stormwater can be applied both passively and actively. Passive irrigation can direct stormwater to the surface, the base or to soil adjacent to trees (Figure 6). Figure 6 is an example of a street tree passively irrigated with stormwater from the kerb and channel.

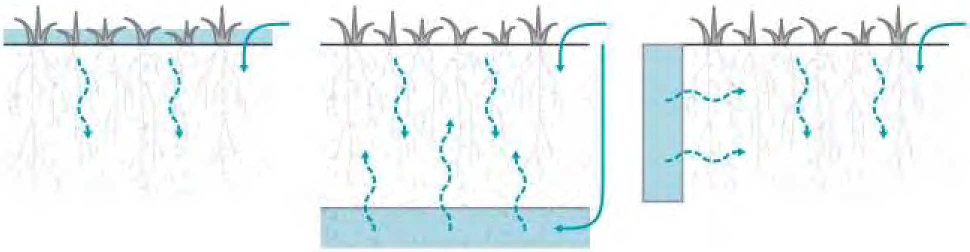


Figure 6 - Surface irrigation (left) infiltrates the soil from above, while subsurface irrigation can be designed to improve soil moisture through capillary rise (centre) or lateral movement (right) (source Designing for a cool city, CRCWSC 2020)

Figure 7 - Example of a street tree passively irrigated from the surface by road runoff (E2Designlab)

Stormwater harvesting strategies which collect, treat and store stormwater for later use are a form of active irrigation. Stormwater harvesting is most cost effective when supplying relatively large demands. It is not likely to be feasible for individual urban canopy projects but may be an option as part of a larger scheme. See the text box below for an example of a stormwater harvesting scheme with treatment for irrigation suitable for potential human contact.

Stormwater harvesting example – Blacktown City Council

Blacktown City Council's Angus Creek stormwater harvesting and re-use scheme extracts excess stormwater flows from Angus Creek and harvests stormwater runoff from hard surfaces to irrigate the Blacktown International Sports park and neighbouring reserves, supplying up to 200ML of fit-for-purpose water each year. The scheme includes a treatment train incorporating wetlands, storage ponds, filtration, chlorination and UV treatment to achieve high quality water for spray irrigation (https://watersensitivecities.org.au/solutions/angus-creek-stormwater-harvesting-and-reuse-scheme/).

3.3.3 Recycled water

Recycled water refers to sewerage that has been treated to be suitable for reuse in several applications. Whilst it can be treated to potable water standard, recycled water is generally treated to a lower standard (class) suitable for some industrial uses and irrigation. Sydney Water operates a recycled water network including 16 water recycling plants of which 14 are directly operated by Sydney Water. There are also some council and privately operated water recycling plants. Figure 8 identifies the location of existing recycled water schemes across Greater Sydney including both Sydney Water and private operations.

The use of recycled water for tree irrigation requires the trees to be located within proximity of a recycled water network, recycled water plant or access point. Besides these existing recycled water networks, in greenfield areas there may be an opportunity to construct new recycled water distribution lines for supply to residential and non-residential uses as well as for tree irrigation.

Sydney Water operates the following recycled water plants:

- Bombo
- Castle Hill
- Gerringong-Gerroa
- Glenfield
- Liverpool
- Picton
- Penrith
- Quakers Hill
- Richmond
- Rouse Hill
- St Marys
- St Marys advanced water treatment plant
- West Camden
- Wollongong

Figure 8 - General location of water recycling facilities across Sydney (Accessed online - https://www.sydneywater.com.au/web/groups/publicwebcontent/documents/webasset/zgrf/mdq1/~edisp/dd_045234.jpg)

When and where is it likely to be used?

Irrigation of trees with recycled water occurs most readily in the following circumstances:

- Parks: In practice, recycled wastewater would most likely to be used for tree irrigation in parks from the recycled water network.
- Streetscapes: In streetscapes if a recycled water network exists in the street and the relevant council was comfortable with active irrigation of assets in streetscapes.
- Water trucks: There is also potential for water trucks to deliver recycled water from stand-pipes. This is more likely for short-term and occasional watering such as establishment and drought, due to the cost of supply using water trucks. Availability of existing stand-pipes is limited. Any new ones are most likely to be constructed at existing recycled water treatment plants or reservoirs prior to distribution for use to ensure appropriate quality is achieved.

Quality of recycled water

The water recycling plants treat wastewater according to the Australian Guidelines for Water Recycling. This ensures recycled water is safe and suitable for its intended use. Recycled water may have elevated levels of pollutants such as nutrients and salts and it may contain other contaminants within acceptable levels. In some cases, recycled water may be tertiary treated to high standards (e.g. for residential use) and have few if any pollutants of concern although these supplies.

Most trees will cope with higher nutrient levels and this is likely to lead to better tree growth for many species.

Elevated salinity levels can stunt tree growth if it is retained in the soil profile. Tree planting design should seek to encourage rainfall flushing of salts through the soil profile to mitigate this risk. High salinity and sodium levels can also adversely impact on soil structure. This can be of concern for reactive clay soils. The recycled water source, its salinity levels and soil type for the site should be identified and potential impacts on soils assessed for projects where recycled water is proposed to ensure its use is a viable irrigation supply.

The main pollutant of concern for human contact is pathogens. The quality of recycled water varies between treatment plants. For most recycled water plants in Greater Sydney disinfection treatment is provided to ensure it is safe for human contact.

The standard of water quality treatment required prior to use will depend on the intended uses, the method of delivery and irrigation risk control measures in place. For surface or sprinkler irrigation of public spaces including streetscapes and parks where there is a risk of public contact, Class A recycled water considered safe for human contact is required. For lower quality water, either access controls or a subsurface irrigation method is required to prevent public exposure. This can potentially be achieved through methods such as wicking beds with water levels maintained with recycled water. Other access control measures, as listed below, are likely to be impractical for most street tree applications:

- restrict public access during and after irrigation for four hours or until dry.
- implement spray drift controls to prevent drift beyond the irrigation area.
- implement a minimum buffer distance of 50 metres from the irrigation area to the nearest point of public access.

Benefits

In addition to providing a potential source of water for trees, the use of recycled water prevents discharge of treated waters with often elevated nutrient concentrations into downstream creeks, rivers and bays.

3.3.4 Greywater

Greywater refers to wastewater from kitchens, showers, baths, wash basins and laundries. This water is treated, including removal of any physical solids, greases and oils, if used as an alternative water source. A range of physical separators are typically used to treat greywater, including sand and soil-based filters.

The use of greywater requires a separate wastewater line to blackwater (water from toilets and bidets) and hence is typically not available in urban areas with sewers except at the lot scale. To ensure a reasonable volume is generated from this source, it is best supplied from commercial or multiple-residential sources to provide irrigation for trees at a precinct scale. However, it can be used at a house/small commercial area to water smaller numbers of trees and gardens.

Like many other non-potable sources, greywater can contain pathogens, so it is best applied using sub-surface irrigation or in a way that prevents direct contact with people. If direct contact cannot be avoided then disinfection will be required. Greywater use can be an appropriate approach to irrigation of trees where a greywater disposal system may already be planned or in place as an on-site disposal mechanism to reduce wastewater discharge volumes. The capture and use of greywater at source can also improve water quality discharged from a wastewater treatment plant. Of particular note is the reduced presence of phosphates in the greywater from detergents and soaps, which enter the receiving environment.

3.3.5 Groundwater

Groundwater resources across much of Australia have historically been subject to over-exploitation and abuse. Many groundwater aquifers have a residence time of thousands of years (particularly large inland systems such as the Greater Artesian Basin) and very low recharge rates. As such, when not carefully managed the rate of water extraction can easily exceed the rate of recharge, resulting in net depletion of the aquifer. Because of the long residence time and confined nature of many aquifers, it is important that groundwater be considered as a receiving environment as well as a potential resource. When groundwater is subject to pollution, the quality of this water may never be recovered.

Groundwater supports many different ecosystem types including creeks and rivers, estuaries, swamps, wetlands, terrestrial vegetation and the life within the aquifer itself. The extraction of groundwater therefore needs to be carefully regulated and monitored, as over-extraction can have serious and unintended consequences on Sydney's natural ecosystems. Depletion of the aquifer can also lead to issues such as subsidence, which has the potential to cause major structural damage and saline water intrusion.

The three key basins in a Sydney are shown in Figure 9 below. All three basins are known to have experienced contamination in the past, some of which have undergone remediation. Parts of the Sydney Basin are known to be saline.

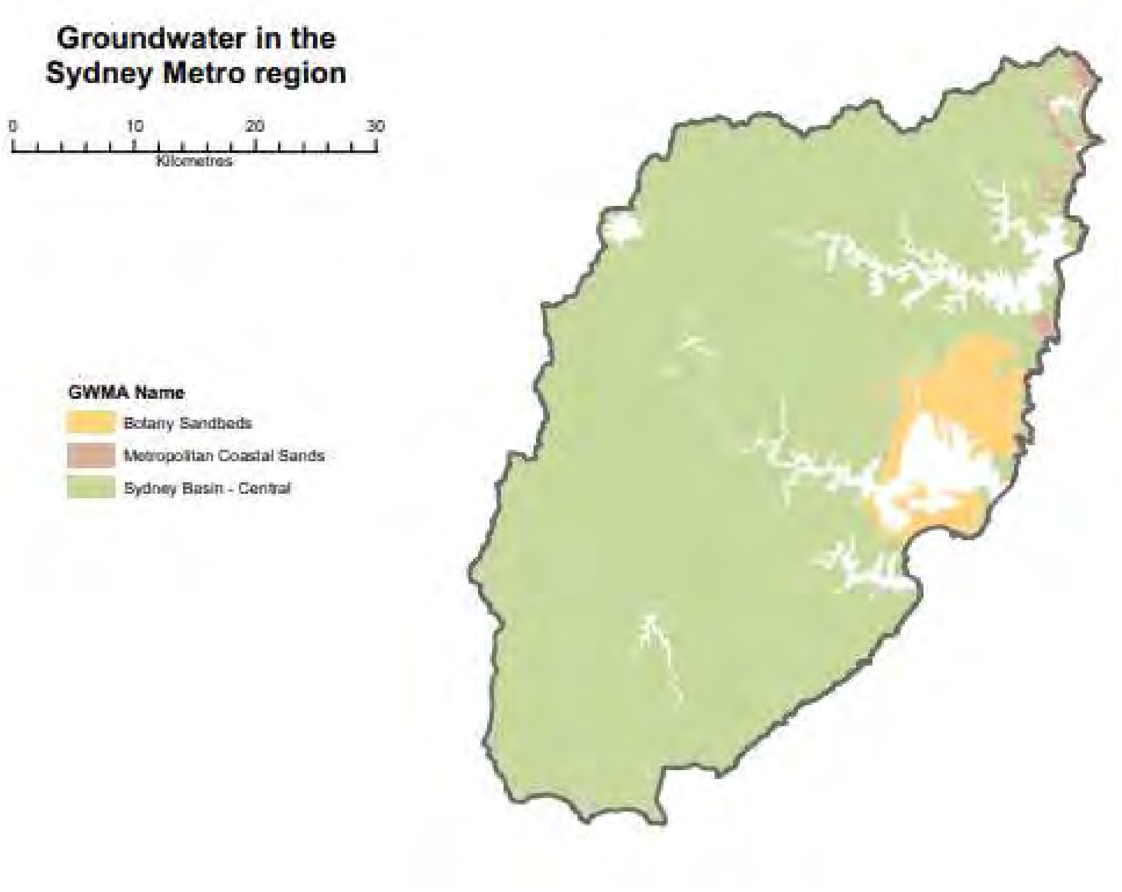


Figure 9 - Groundwater Management Areas in Greater Sydney[1] (from Department of Environment, Climate Change and Water, 2010. State of the Catchments 2010: Groundwater, Sydney Metropolitan Region. Accessed online: https://www.environment.nsw.gov.au/resources/soc/sydneymetro/10465SYDMETgwater.pdf)

Despite the care required in the management of aquifers, where it is deemed feasible, safe and appropriate to do so, groundwater use presents a reliable source of irrigation for trees. It will usually be undertaken by accessing groundwater from a bore.

Aquifer recharge schemes have emerged as a method of capturing and storing water from sources such as treated stormwater, allowing water to infiltrate rapidly into the aquifer for later re-use and to match or exceed any extractions so that these are sustainable. However great care needs to be taken to prevent contamination and is best suited to locally confined aquifers. Such approaches have been successfully adopted in dry climates with groundwater resources such as Adelaide (Kretschmer, 2017) and Israel (Pers. Comm, E2Designlab 2020).

In addition to contamination from urban and industrial sources, groundwater can be naturally hard (high mineral levels, specifically calcium and magnesium) and saline. As such, local groundwater testing should be undertaken to confirm the suitability of groundwater as an irrigation source. Salinity can negatively impact trees, particularly when salts accumulate in soils over time. Portions of the Sydney basin are known to have salinity issues. Hardness can impact irrigation systems, causing clogging.

3.4 Approaches to irrigation

In urban environments, where conditions are typically harsh for trees (e.g. reflective heat off hard surfaces and less infiltration of water into soils due to impervious surfaces), all but the most drought tolerant native species will need some form of ongoing and/or supplementary irrigation for them to thrive and reach their full potential canopy cover. Hence the water sources and how to get that water to trees should be key considerations in the planning and design of urban tree canopy projects.

The following describes key approaches to irrigating trees.

3.4.1 Irrigation and watering approaches

Irrigation can be provided using two methods - passive or active irrigation systems. Passive irrigation systems use gravity to deliver water to where it is needed and require no energy. These are typically systems that capture stormwater in the road network or elsewhere, delivered through kerb and channel or other overland flow paths. Water delivered via this passive method only occurs in response to rainfall. As such, some passive irrigation approaches can result in poor volumes of supply during extended dry spells, however storage reservoirs such as those found in wicking bed designs, infiltration trenches and pits (see Section 4 for further detail) can alleviate this stress ensuring a more consistent soil moisture supply.

Actively irrigated systems are those that use energy to pump water to where it is needed via pressurised irrigation systems. It has the benefit that it can be provided on demand, subject to availability of source water (e.g. potable water restrictions during droughts). Active irrigation systems can include surface (aerial), sub-surface (drip-line) irrigation systems and manual application methods (e.g. water trucks).

Both active and passive systems can be effective, with the choice of irrigation method being highly dependent on the site and available water supply options.

3.4.2 Water trucks

Water trucks may be used to provide top up water from drinking or alternate sources to street trees where required to support trees during establishment, times of stress, or as a back-up to other water sources (e.g. stormwater). When used in combination with other methods that promote storage of stormwater, this will allow reduced frequency of watering. Water trucks are a relatively expensive method of irrigation, so it is preferable to use them for short-term establishment or occasional watering as a back-up rather than a regular supply.

Two contributors to the cost of water trucks are the time required to irrigate each tree and the frequency of watering required. The efficiency of water trucks can be improved with simple and cheap responses.

Water wells around the tree allow a greater volume of water to be pumped within a short time and retained in the well close to the tree to slowly soak into the soil.

Water butts or leaky water storages can be placed beside trees during establishment or during drought periods when regular watering is expected to be required. These can then be less frequently filled up and allowed to slowly irrigate the tree over several days.

During the Millennium drought Councils in Melbourne adapted other infrastructure such as road barriers and wheelie bins with drippers to serve as leaky water storages. While these approaches are not preferred as permanent measures, similar approaches could readily be adopted in Sydney when required as interim measures as part of an emergency response to drought.

Wheelie bin with drippers – City of Port Phillip

The City of Port Phillip trialled wheelie bins connected to local sub surface drip irrigation during drought. The costs were $338 per device plus filling at $26 per site or around $100 per tree per month (http://www.portphillip.vic.gov.au/default/meeting_agenda_archive/o24737.pdf).

3.5 Soils and water availability

The soil characteristics of a site, including any imported soils and in-situ soils, can have a significant role in determining the amount of water available to a tree. By extension this impacts on the tree's ability to reach its full potential in both size and vigour. Designs must be cognisant of soil condition and how flows to deep soil storages may be impacted. The following details some of the key soil considerations in designing street trees.

3.5.1 Soil water retention

The amount of water that soil can hold, called the soil water retention capacity, is an important consideration for tree health. In soils, some water is tightly held to the soil, some is available for plants (the plant available water capacity) and some can drain by gravity. Sandy soils typically have the lowest retention capacity as most water drains by gravity. Clays hold more water but more of it is held tightly to the soil while some loamy soils have the highest plant available water capacity. Soil testing can be undertaken as part of the tree design process to ensure that the soils are appropriate for the proposed tree species or if soil improvements (such as the addition of gypsum) or imported soils are required.

The Greater Sydney area includes a range of soil types from sands with high infiltration, along coastal areas and the Blue Mountains, to clays with slow infiltration rates (e.g. Western Sydney). Soil types can be highly variable and often relate to geology and topography. The central resource for Sharing and Enabling Environmental Data (SEED) in NSW provides an estimation of Hydrologic Groups of soils according to the four classes of soil and their likely infiltration rates (high to very low). The data set covers all of NSW and is based on linking a hydrologic group class to a particular soil type using the Great Soil Group classification (Office of Environment and Heritage, 2017, Hydrologic Groups of Soils in NSW, NSW Office of Environment and Heritage, Sydney). This resource can be a useful tool in identifying the likely soil water retention characteristics of an area. A small snapshot of this mapping is provided in Figure 10.

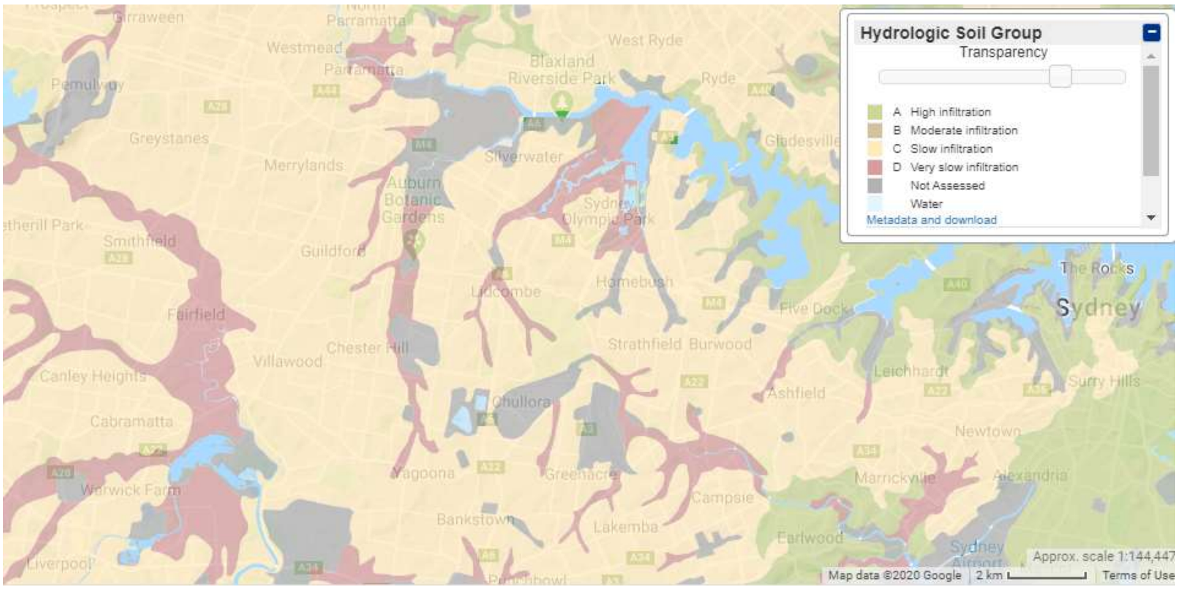


Figure 10 - Example of Hydrologic Soil mapping showing likely infiltration rates of soils (© State Government of NSW and Department of Planning, Industry and Environment 2012)

In many areas of Western Sydney, the in-situ soils will be clays and will generally have good soil water retention capacity. Some trees can grow well in clays while others prefer more freely draining and less dense soils. Where needed, clay soils can best be improved by digging a layer of organic matter such as compost into the upper soils. There are also other approaches such as adding lime or gypsum.

The filter media used in raingardens is usually a loamy sand (or preferably a sandy loam) and often has a low plant available water capacity. The nutrient levels are also usually low to avoid leaching nutrients to the stormwater drains and waterways. Organic matter such as compost that breaks down generally shouldn't be added to systems with drainage to stormwater as this can leach additional nutrients as demonstrated by the research undertaken by the Cooperative Research Centre for Water Sensitive Cities (CRCWSC), and prior to that the Facility for Advancing Water Biofiltration (FAWB).(Payne, 2015). The CRCWSC Adoption Guidelines for Stormwater Biofiltration Systems (Version 2) provides further guidance on this.

Water storing agents can potentially be used to increase the water holding capacity of sandy soils. These include vermiculite, coir fibre and water crystals. This increases the plant available water holding capacity and reduces the frequency at which irrigation is required.

Wetting agents and gels are intended to overcome hydrophobic properties of sandy soils. These should be less frequently required in Greater Sydney but may be used for coastal sandy soils or to amend sandy filter media used in raingardens with trees if required.

There are a range of approaches to improving soils including natural and man-made soil amendments that can potentially improve soil moisture retention and address other issues. It is recognised that understanding soil properties is key to plant selection, tree pit design and understanding the ideal additives. As such, soils advice should always be obtained from suitably qualified professionals with testing undertaken by an accredited laboratory prior to applying any soil ameliorants or additives.

3.5.2 Deep soil storage

When persistent or heavy rain falls, excess water that is not taken up by the soil or tree can infiltrate through the soil profile to recharge deep soil moisture reserves. This can provide a valuable water source to trees when the dry weather comes. When the tree uses all the water in the top layers of soil, the moisture from below can be drawn up through capillary rise to the tree roots. Some deep rooted trees (e.g. many Eucalyptus species such as river red gums – see Figure 11) can also access this deep soil moisture directly. To promote deep soil moisture recharge or "banking", it is important to retain a connection between the tree pit soils and the in-situ site soils. Impermeable tree pit liners or adding a layer of drainage aggregate across the entire base of the tree pit (such is common practice in bioretention systems) will prevent or limit access to this deep soil water source. Coarse aggregate, such as drainage gravel, breaks the capillary rise action and thus creates a barrier to rising moisture. The use of aggregate should be restricted to immediately around drainage pipes and not used across the base area of tree pits.

Figure 11 Stormwater harvesting and infiltration restore deep soil moisture at Napier Park where an urbanised catchment, drought and climate change have reduced natural groundwater supplies sustaining a valued River Red Gum community (E2Designlab)

4. Water efficiency solutions

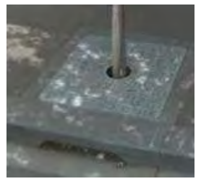
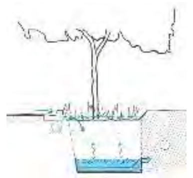
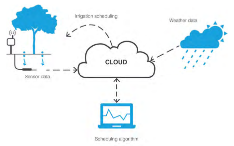
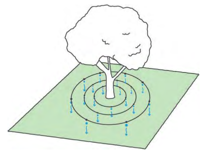
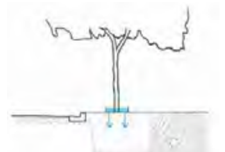
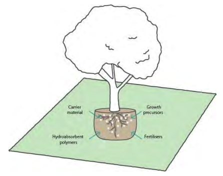
4.1 Water efficiency solutions summary

There are a number of solutions available to provide efficient water supply to urban trees to overcome the barriers outlined in Section 3. Table 4 provides a summary of these passive and active irrigation approaches. These design responses enable water efficient irrigation in a range of contexts and settings. They can also be implemented at a range of scales from individual tree passive irrigation to whole of street integration. The increasing scale of this application generally results in increasing benefit for tree health and vigour, and for broader benefits such as stormwater management, groundwater/deep soil moisture recharge and urban cooling. The costs are also likely to increase with this increasing scale of intervention, so the right solution will be very site dependent and will respond to the objectives of a project. More intensive solutions (for example linear irrigation and infiltration trenches) may be more suitable where constructed in conjunction with other significant infrastructure projects, such as pavement resurfacing or drainage works. Conversely, where limited disturbance is required, such as in instances where trees are established and disturbance to an existing road work is not desirable, less intensive interventions may be provided at a lower cost.

The following sections provide additional detail on each of these solutions with supporting case studies. Table 4 presents a summary of the potential design responses, their benefits, costs, risks and suitable locations. The images below provide a summary of the different scales and applications.

Table 4 - Summary of water efficient solutions

KEY: High (green) Moderate (yellow) Low (red)

Water efficient solution	Leaky pipe around tree	Below ground infiltration trench or well	Sunken tree pit or raingarden - open	Sunken tree pit - grated	Below ground storage	Permeable pavements	Structural soils and cells	Irrigation scheduling technology	Drip irrigation	Water wells and butts	Soil moisture retention improvements
Example image											
Description	Kerb cut-outs and sleeved slotted pipes divert road stormwater into tree pit.	Kerb cut-outs direct road stormwater to a leaky infiltration trench or well	An open sunken tree pit captures road stormwater over a vegetated surface	A grated sunken tree pit receives stormwater from an inlet to the surface of a tree pit	A storage below the root zone of a sunken tree pit that makes water available to plants during dry periods	Permeable pavements allow water to pass through them from the surface. Often used with structural soils and cells.	Structural soils and cells can support roads or pavement while storing water and allowing root growth. Often used with permeable pavement.	Soil moisture probes Programming / weather station connections	Drip irrigation delivers water directly into the tree root zone.	Water wells and butts allow rapid filling from a water truck with slow leakage to a tree	Soil additives can improve properties such as aeration, wetting, soil water retention capacity and others.
Site suitability											
Park suitability	Moderate	Moderate	High	Low	High	Moderate	Low	High	High	High	High
Plaza suitability	Moderate	Moderate	Moderate	High	High	High	High	High	Low	Low	High
Streetscape suitability	High	High	High	High	High	High	High	Moderate	Moderate	High	High
Likelihood of success due to the following considerations											
Design simplicity	High	High	High	High	Moderate	Low	Moderate	Low	High	High	High
Ease of retrofit	Moderate	Moderate	Low	Low	Low	Moderate	Moderate	Moderate	Moderate	High	Moderate
Poorly draining soils (water logging)[2]	Low	Low	High	High	High	Low	Moderate	High	Moderate	High	High
Likelihood of delivering the following benefits											
Stormwater treatment	Low	Low	High	High	High	Moderate	Moderate	N/A	N/A	N/A	N/A
Extended soil moisture retention	Low	Low	Low	Low	High	Low	Moderate *Can be designed with underground storage to improve soil moisture*	Moderate	Moderate	Moderate	Moderate
Connection to deep soils	High	High	Moderate	High	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Other considerations											
Typical water source	Stormwater from road / pavement	Stormwater from road / pavement	Stormwater from road / pavement	Stormwater from road / pavement	Stormwater from road / pavement	Stormwater from road / pavement	Stormwater from road / pavement	Mains potable, recycled, harvested stormwater	Mains potable, recycled, harvested stormwater	Recycled water	Any
Ideal soil conditions	Freely draining soils	Freely draining soils	Any soil type with drainage, freely draining without	Any soil type with drainage, freely draining without	Any	Freely draining soils or structural soils and cells	Any	Any	Freely draining soils	Any	Response depends on soils

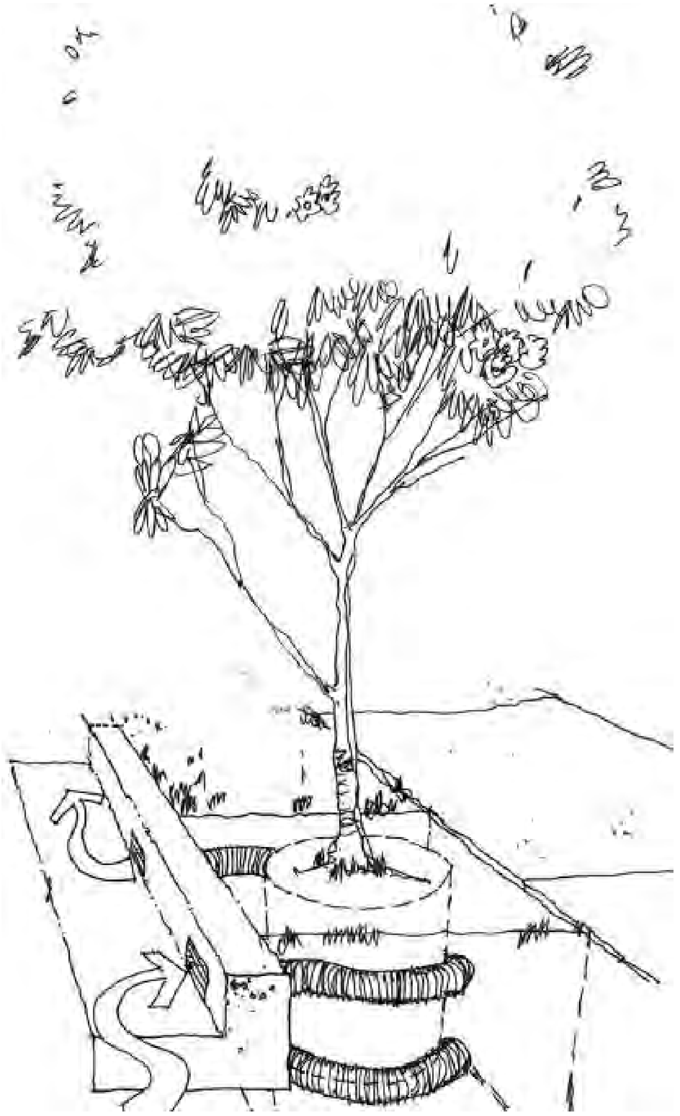
[2] Note this risk can be addressed in design (e.g. inclusion of drainage)

Water efficient solution	Leaky pipe around tree	Below ground infiltration trench or well	Sunken tree pit or raingarden - open	Sunken tree pit - grated	Below ground storage	Permeable pavements	Structural soils and cells	Irrigation scheduling technology	Drip irrigation	Water wells and butts	Soil moisture retention improvements
Typical cost range[3]	$500 - $1,200	$500 - $1,500	$2,000 - $10,000	$3,000 - $15,000	additional $1,000 - $3,000	$1,500 - $2,000	$5,000 - $8,000 (soils) $5,000 - $25,000 (cells)	$5,000 to $20,000	varies	$50 - $400	varies
Applicability to Greater Sydney[4]	Suitability is not uniform across Greater Sydney depending on soil	Suitability is not uniform across Greater Sydney depending on soil	Applicable to all three cities	Applicable to all three cities	Everywhere – preferred configuration in Western Sydney	Applicable to all three cities	Applicable to all three cities	Applicable to all three cities	Applicable to all three cities	Applicable to all three cities	Applicable to all three cities
Key benefits / drivers for use	• Low cost • Low complexity	• Low cost • Low complexity • Can be retrofitted • Scalable	• Useful for stormwater quality treatment • Underdrainage reduces risk of water logging in clay soils • Open surface allows easy access for maintenance • Scalable • Suits a variety of contexts	• Useful for stormwater quality treatment • Underdrainage reduces risk of water logging in clay soils • Grate reduces risk of soil compaction, whilst increasing trafficable area	• Good water availability • Low chance of waterlogging • Lined systems so can be adapted for use on podiums or areas with poor soils (e.g. sodic soils)	• Soil moisture recharge over a wider area • Pre-treatment to prevent sedimentation of other systems • Improved stormwater management	• Provides adequate soil volume in otherwise highly constrained sites • Adequate soil volume reduces risk of root damage to other structures (e.g. pavement damage) • Uncompacted soils can be provided under pavements	• Easily retrofit to existing irrigation system • Highly reliable supply except during water restrictions when using mains water	• Where health risk prevents aerial application • Low loss of water through runoff, aerial drift and evaporation	• Low cost intervention that may improve efficiency of manual watering • Can be set up to facilitate effective watering during drought response • Generally low risk owing to low complexity solution	• Can increase soil condition to support plants including plant available water and water retention
Key management implications / risks	• Limited water volumes in pipes • Inlets and pipes can clog • No drainage so at risk of waterlogging	• Infiltration trenches not easily cleaned of sediment • No drainage so at risk of waterlogging	• Can dry out rapidly when sandy filter media used • Filter media with high organic matter can leach nutrients into stormwater • Drainage aggregate/gravel, when laid across the full base of the pit, will create a barrier to deep soil moisture access	• Can dry out rapidly when sandy filter media is used • Filter media with high organic matter can leach nutrients into stormwater • Maintenance required to ensure surface does not clog • Grate can inhibit maintenance	• Ensure the storage zone is sized for an infrequent average dry spell	• Excessive wear from very heavy traffic and turning • Clogging of the surface in the absence of effective regular maintenance	• Higher cost solution	• Maintenance of irrigation systems can be high • Calibration of soil moisture probes required • Moderate expertise levels needed to realise benefits	• Maintenance of irrigation systems can be high in streetscapes • Prone to clogging • Linear infrastructure may be broken by other construction activities • Poor moisture distribution away from irrigation lines	• Requires manual delivery of water to fill reservoirs • Water trucks are a high cost response	• Adds cost but may be more cost effective then importing topsoil particularly if the other soil qualities are good
Cost benefit summary (see Section 4.13 for more details)	Good benefit cost ratio in areas with good drainage	Good benefit cost ratio in areas with good drainage	Good benefit cost ratio in areas with poorly draining soil and requirement for stormwater treatment	Good benefit cost ratio in areas with poorly draining soil, pavement, requirement for stormwater treatment	Good benefit cost ratio for trees which may be impacted by extended dry periods	Good benefit cost ratio in areas that require a hard surface but where infiltration is desired	Good benefit cost ratio in areas where there is a risk of compaction to roots from pavement and/or where roots could damage pavement	Good benefit cost ratio where demand management is required	Good benefit cost ratio where demand management is required	Good benefit cost ratio as a temporary measure to improve watering efficiency	Good benefit cost ratio where insitu soil condition is poor
For additional information, see Section:	4.2	0	4.4	4.5	4.6	4.7	4.8	4.9	4.10	4.11	4.12
Case studies provided in Attachment 1	Yes	Yes	Yes	Yes	Yes	Yes					

[3] Cost per tree. Assumes tree pits are 10m^2. These costs are estimated ranges only and are based on best available data and experience gathered through built projects. These costs will vary depending on site conditions and scale. For example, a single tree pit retrofitted in a high use street with multiple services would be more expensive than multiple trees being delivered in areas which require minimal traffic control.
[4] Greater Sydney can be desribed as a metropolis of three cities: the Western Parkland City, the Central River City and the Eastern Harbour City.

4.2 Leaky pipe around tree

Slotted or Ag pipes are placed around trees and connected to the kerb via kerb adaptors or openings, allowing stormwater to enter the pipe. This water is then able to infiltrate into the soils. These pipes are typically surrounded by gravel to avoid soil ingress, which also provides additional water storage volume. Inspection openings or access pits to allow maintenance such as flushing may also be included.



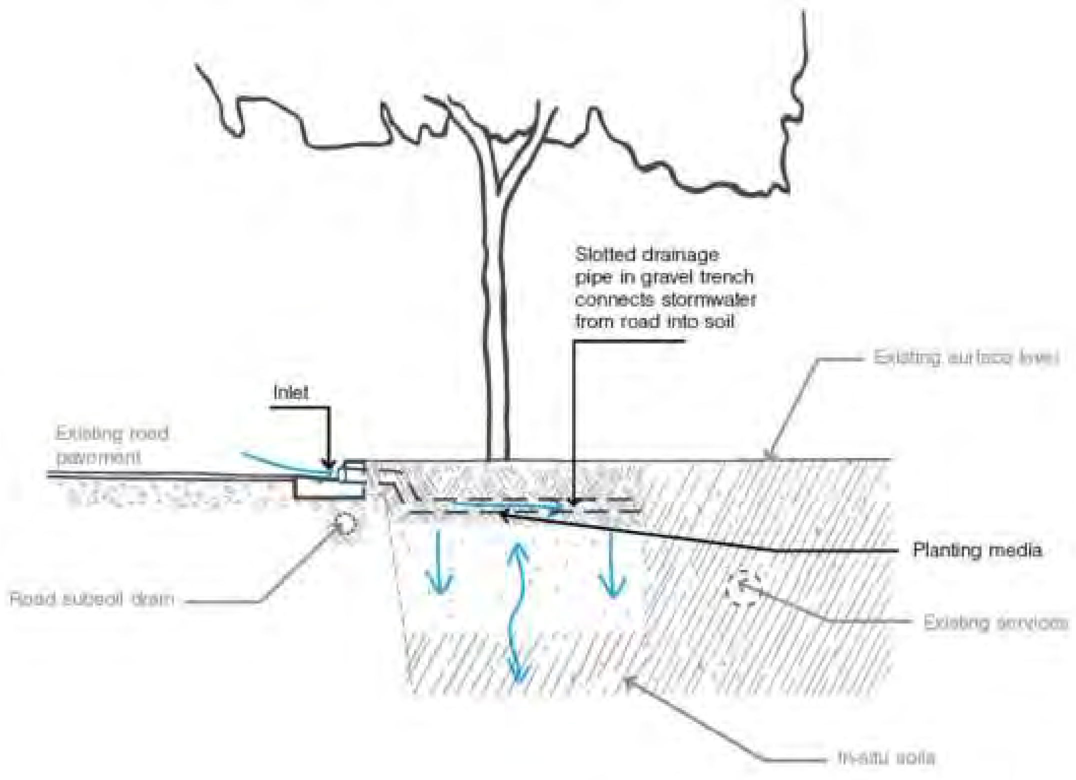
Depiction of a leaky pipe around tree. Source: Water By Design – Waterwise Street Tree Booklet

Images of example trees with leaky pipes – Source: Water By Design - Waterwise Street Tree Booklet

Key water supply and soil condition considerations	
Inflows and water storage volume	Inlet design and configuration is important to allow inflows but minimise debris and sediment intrusion. Inlets such as the Treenet inlet are designed to do this. Minimal storage provided by kerb cut-out into ag or slotted pipe around tree. Additional storage can be provided in gravel trench around pipes. Setting pipe level below the base level of the kerb ensures that water pools in the pipe to allow temporary storage and infiltration into soils. Conversely, only pipes laid flush with kerb inlet without surrounding storage can be flushed out effectively.
Soil volume	Dependent on in-situ soils and surrounds. Not typically designed for trees being planted with significant soil volume.
Surface condition / clogging	Pipes at high risk of being clogged which can reduce volume of water infiltrated into soils. Clean out pits can help reduce this risk. Using a surrounding gravel storage precludes maintenance but significantly increases time before clogging occurs.
Deep soil storage	Good connection to in-situ soils, however limited storage volume reduces the amount of exfiltration, particularly in clay soils.
Compaction	Low risk due to open system
Water logging	High risk in slowly draining soils

Key design considerations:

	Rating	Key design considerations
Site suitability		
Park suitability	Yellow	May be suitable where adjacent to a car park or similar impervious areas and kerb inlet.
Plaza suitability	Yellow	This system type has an earthen surface, less likely to be compatible with a plaza setting.
Streetscape suitability	Green	Ideally suited where there is a kerb and channel (or other clear inflow point) and soils are appropriate.
Likelihood of success due to the following considerations		
Design simplicity	Green	Low
Ease of retrofit	Yellow	This solution can be retrofitted into most streets but care needs to be taken to not damage roots. If this solution is to be retrofitted around mature trees, works need to happen away from structural roots between street trees. Infiltration trenches may be better for retrofitting around mature trees (see Section 4.3).
Poorly draining soils (water logging)	Red	This solution does not include drainage. There is a reduced risk of waterlogging where there is high permeability in-situ soils. If there is a risk of waterlogging, drainage can be included in the tree pit design to reduce this risk.
Likelihood of delivering the following benefits		
Stormwater treatment	Red	Limited, owing to limited capture and storage of stormwater.
Extended soil moisture retention	Red	Low capture and storage volume (volume of the pipe and only if set below inlet level) means that while additional water is available immediately following rainfall, there is no supply during extended dry spells.
Connection to deep soils	Green	Whilst there is good connection, the small water capture volume means there will be less excess water for deep soil moisture recharge.

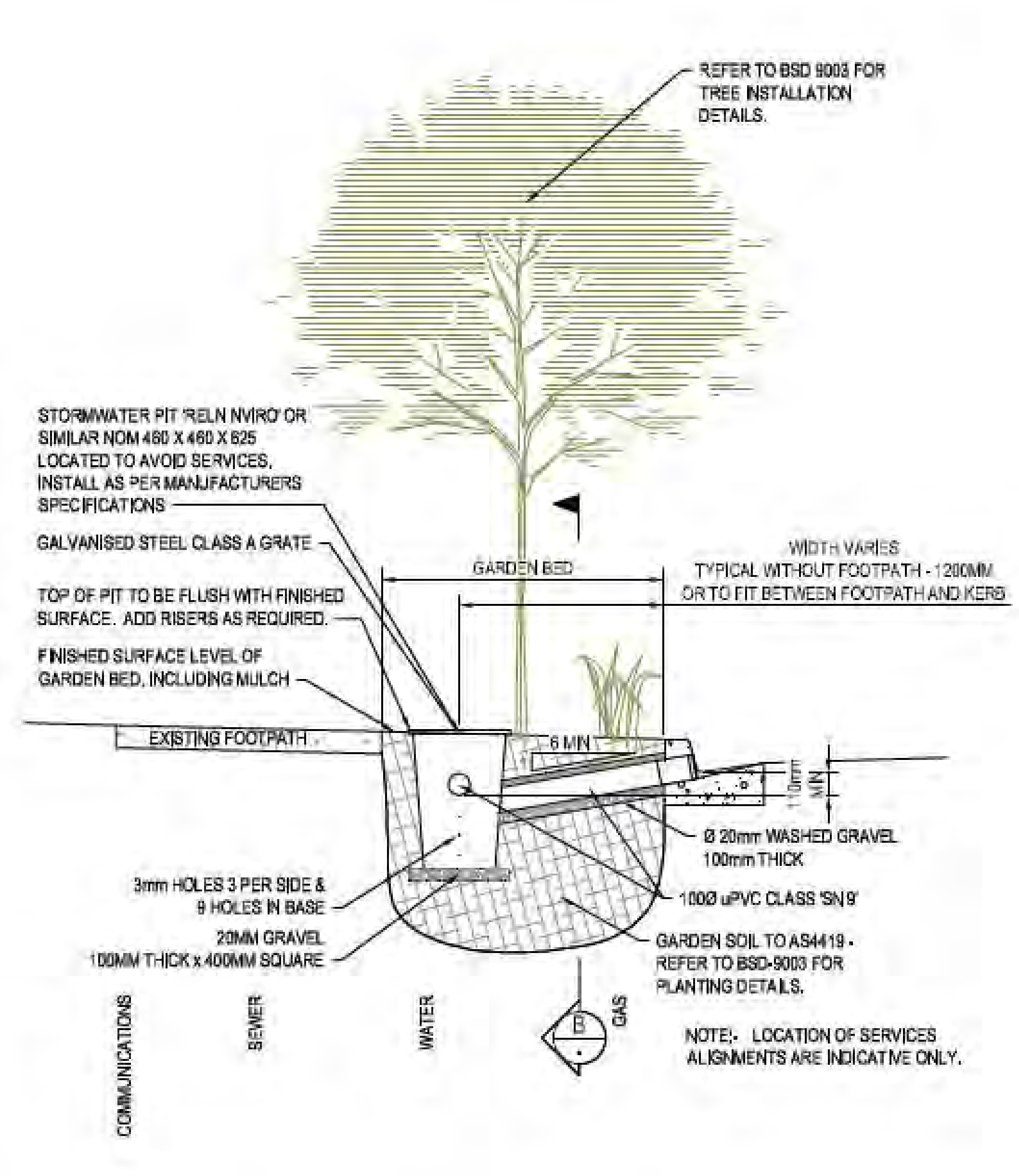


Example section showing key elements of tree pit with leaky pipes

	Brief description	Key design considerations
Other considerations		
Water source	Redirects stormwater flows from the road into the tree pit via a kerb adaptor connected to subsurface slotted pipes which are looped around the tree pit and can sit within a gravel trench.	An estimation of water demand can be determined based on the tree species. The potential volume of water available to the tree will depend on the size of the inlet, the volume of the pipe and gravel pit around it and the soil permeability.
Ideal soil conditions	Sandy / freely draining soils	While this approach can be used in any soil type, it is important to understand the conditions of the in-situ soils as this will influence the amount of water that is able to infiltrate from the tree pit.
Applicability to Greater Sydney	Suitability of this approach is not uniform across Greater Sydney	Suitability of this approach is not uniform across Greater Sydney and is a function of rainfall and soils. This approach is generally not suitable in clay soils likely to be experienced in the Western Parkland City area of Sydney.
Typical cost range	$500 - $1,200 / tree	
Key benefits / drivers for use	• Low cost • Low complexity • Can be retrofitted	This solution may be highly suitable for areas with consistent rainfall and sandy in-situ soils, such as eastern coastal areas and Blue Mountains. It may also appeal as a low cost response or retrofit, however care needs to be taken in clay soils.
Key management implications / risks	• Limited water volumes directed into system through pipes • Inlets and pipes can clog • No drainage so at risk of waterlogging	Trees in these systems in slowly draining soils are at risk of waterlogging during prolonged wet periods. The design should ensure there is a 300mm depth for the kerb inlet (or water level control) below surface level to ensure there are aerated soils provided. These systems are also at risk of the inlet and pipe clogging with sediment and litter and the design should consider this. The low infiltration rates and storage volumes likely in this design reduce the amount of water available to the tree. Best suited to climates that receive consistent rainfall to maximize effectiveness.

4.3 Below ground infiltration trench or pit

An infiltration trench, pit or well adjacent to the tree is connected to stormwater runoff via a kerb opening or adapter. An open pit or a pipe into a gravel or other aggregate filled well or trench may be used. The below ground infiltration trench or pit asset fills with stormwater during rainfall and slowly exfiltrates to surrounding soils, providing a water source long after rain stops. This is similar in principle to a leaky pipe around a tree but provides a greater stormwater storage volume and is usually placed some distance from the tree to reduce the risk of waterlogging.



Example of infiltration pit. Source: Water By Design, Waterwise Street Tree Booklet

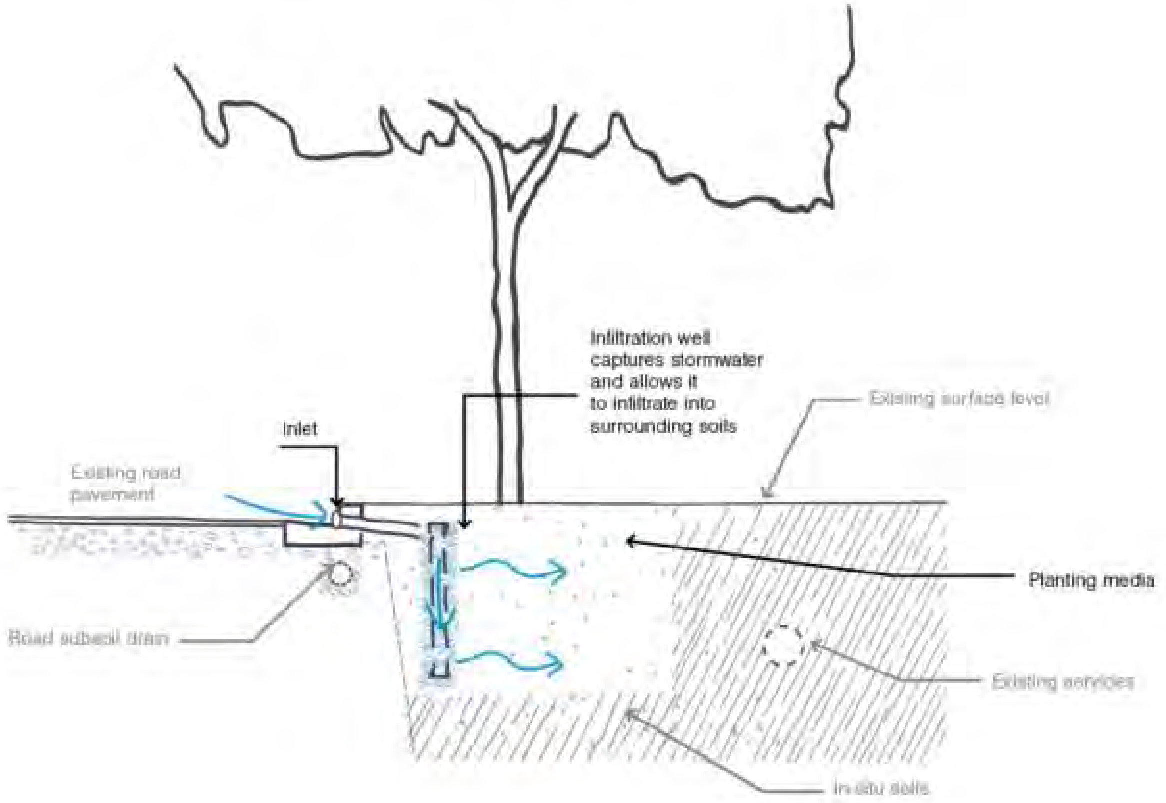
Godfrey St, Melbourne included an infiltration trench between trees. Source http://urbanwater.melbourne.vic.gov.au/wp-content/uploads/2015/02/Urban-Water_Godfrey-Street-Greening-small.pdf

Example of Treenet infiltration trench. Source: Water By Design, Waterwise Street Tree Booklet

Key water supply and soil condition considerations	
Inflows and water storage volume	Connected to stormwater via kerb adaptors. The trench or pit can provide significant storage volume, however it is dependent on design.
Soil volume	Dependent on in-situ soils and surrounds. Not typically designed for trees being planted with significant soil volume.
Surface condition / clogging	• Stormwater is provided sub-surface. • Pits may clog more quickly but are easily cleaned out. • Small wells or trenches may be difficult or impossible to maintain and prone to sediment accumulation and reduced storage over the longer term.
Deep soil storage	Good deep soil storage through large surface area contact with in-situ soils, and substantial volume of water stored for recharge of soils over a longer period of time.
Compaction	Low risk of compaction over time with good structural strength, however adjacent soils may be compacted, reducing effective soil volume.
Water logging	Water logging is a significant risk in clay soils. This may be a lower risk where retrofit adjacent to a larger tree, which has a root zone outside of the influence of the pit.

Key design considerations:

	Rating	Key design considerations
Site suitability		
Park suitability	Yellow	May be suitable where adjacent to a car park or similar impervious areas and kerb inlet.
Plaza suitability	Yellow	This system type has an earthen surface, less likely to be compatible with a plaza setting.
Streetscape suitability	Green	Ideally suited where soils are appropriate.
Likelihood of success due to the following considerations		
Design simplicity	Green	Low
Ease of retrofit	Yellow	This solution can be easily retrofitted into most streets but care needs to be taken to not damage roots.
Poorly draining soils (water logging)	Red	This solution does not include drainage. There is a reduced risk of waterlogging where there is high permeability in-situ soils. If there is a risk of waterlogging, drainage can be included in the tree pit design to reduce this risk.
Likelihood of delivering the following benefits		
Stormwater treatment	Red	Limited to the available water storage volume. May be moderate in sandy soils where water has high exfiltration capacity.
Extended soil moisture retention	Red	The capture of a moderate volume of stormwater allows it to be slowly released over time. This is closely linked to soil permeability.
Connection to deep soils	Green	Dependent on configuration. Large trenches have excellent connection, with a large surface area contact with in-situ soils and storage volume providing for extended exfiltration.



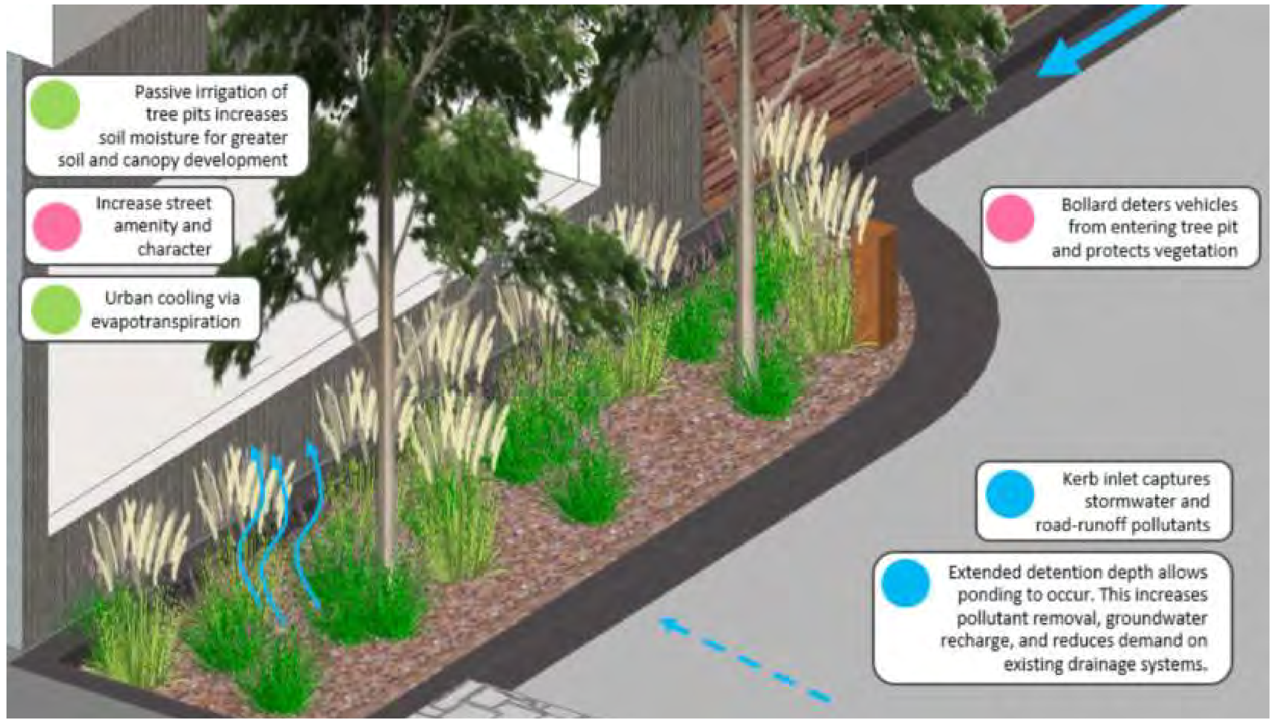
Example section showing key elements of tree pit with infiltration pit

	Brief description	Key design considerations
Other considerations		
Water source	Stormwater is connected via a kerb adaptor or opening, which enters the pit or trench. The pit or trench may also be topped up with an alternative water source from a water truck during extended dry periods.	An estimation of water demand can be determined based on the tree species. The potential volume of water available to the tree will depend on the size of the inlet, the volume of the pipe and gravel pit around it and the soil permeability.
Ideal soil conditions	Sandy/freely draining soils	While this approach can be used in any soil type, it is important to understand the conditions of the in-situ soils as this will influence the amount of water that is able to infiltrate and exfiltrate from the tree pit.
Applicability to Greater Sydney	Suitability of this approach is not uniform across Greater Sydney	Suitability of this approach is a function of rainfall and soils. This approach is generally not suitable in clay soils likely to be experienced in the Western Parkland City area of Sydney.
Typical cost range	\$500 - \$1,500 / tree	These are more expensive than the leaky pipe around tree as more excavation is required.
Key benefits / drivers for use	• Low cost • Low complexity • Can be retrofitted • Scalable	This solution may be highly suitable for areas with consistent rainfall and sandy in-situ soils, such as coastal fringe areas adjacent dune systems. They may also appeal for low cost retrofit, however care needs to be taken in clay soils. Larger trenches/reservoirs may be constructed at a further distance from established trees to prevent damage and encourage deep soil moisture recharge.
Key management implications / risks	• Infiltration trenches not easily cleaned of sediment • No drainage so at risk of waterlogging	Trees in these systems in slowly draining soils are at risk of waterlogging during prolonged wet periods. The design should ensure there is a 300mm depth between the kerb inlet (or water level control) and the surface level to ensure there are aerated soils provided.

Godfrey St Infiltration trench under construction Source: http://urbanwater.melbourne.vic.gov.au/projects/greening-projects/godfrey-street-greening-project/

4.4 Sunken tree pit / raingarden - open

The surface of these open systems is set down below the level of the surrounding road or pavement which allows water to pond on the surface, maximising the amount of water that infiltrates into the soil. Trees are typically planted into a quality sandy loam material to promote infiltration, often for the purposes of stormwater quality improvement. This intervention typically has underdrainage connected to the to the stormwater network allowing the system to freely drain, reducing risks associated with water logging. The surface is usually planted with shrubs and ground cover plants to improve water quality treatment and help maintain good infiltration capacity.



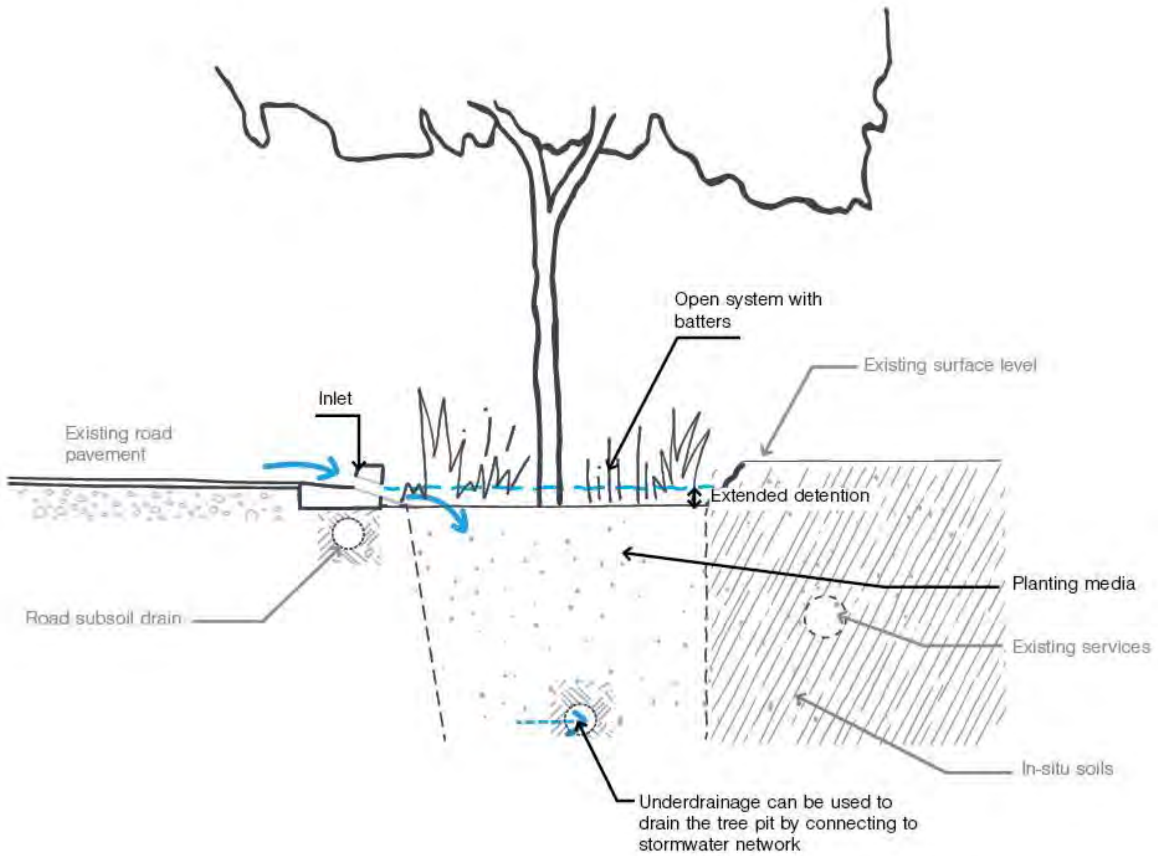
Graphic showing raingarden with trees. Source City of Yarra Embedding Green Infrastructure Guidelines

Key water supply and soil condition considerations	
Inflows and water storage volume	The system can accept flows from kerb and channel, stormwater outlets or swales. By having the surface of the system set below the inflow point, it allows temporary ponding of stormwater, allowing it to hold additional volume when inflows exceed the infiltration rate. However, the system does not have any long term storage of water for the tree to access.
Soil volume	These systems are often sized to achieve stormwater treatment objectives, so there is typically ample soil volume available. Because they are not easily retrofitted and are associated with new trees, the design should ensure ample soil volume for optimal tree size and health.
Surface condition / clogging	The systems can be prone to surface clogging from sediment and other fine material deposited on the surface. This can greatly impact the infiltration rate and ultimately amount of water available to the tree.
Deep soil storage	Deep soil storage is unlikely to be greatly improved through this intervention because of a highly efficient drainage system.
Compaction	Generally, not subject to foot or vehicle traffic so not prone to compaction. Planting groundcovers can help reduce compaction and maintain infiltration.
Water logging	Underdrainage of the systems ensures water logging is a low risk. However, the systems do need to be maintained to ensure the surface does not become clogged preventing infiltration and causing surface ponding, a cause of collar rot in trees.

Images of open raingardens with trees

Key design considerations:

	Rating	Key design considerations
Site suitability		
Park suitability		These systems are well suited to parks, where larger raingardens may provide a dual role as a garden and a stormwater treatment system.
Plaza suitability		The step down from the surrounding surface in these systems does not make them overly suitable for high traffic areas, however bollards or other barriers may be used to alleviate risk and alert pedestrians to hazards.
Streetscape suitability		A range of configurations exist to suit the streetscape, including bump outs/outstands and behind-kerb systems.
Likelihood of success due to the following considerations		
Design simplicity		Moderate
Ease of retrofit		Low
Poorly draining soils (water logging)		Underdrainage makes waterlogging a low likelihood, however maintenance is required to ensure the surface does not clog.
Likelihood of delivering the following benefits		
Stormwater treatment		This solution, when appropriately designed, can remove sediment, nutrients and other stormwater pollutants prior to entering the drainage system.
Extended soil moisture retention		The efficiency of these drainage systems can result in rapid drying and water stress, particularly where low organic sands are used (such as typical bioretention filter media).
Connection to deep soils		Efficient underdrainage doesn't allow a long residence time of water, reducing exfiltration opportunities.



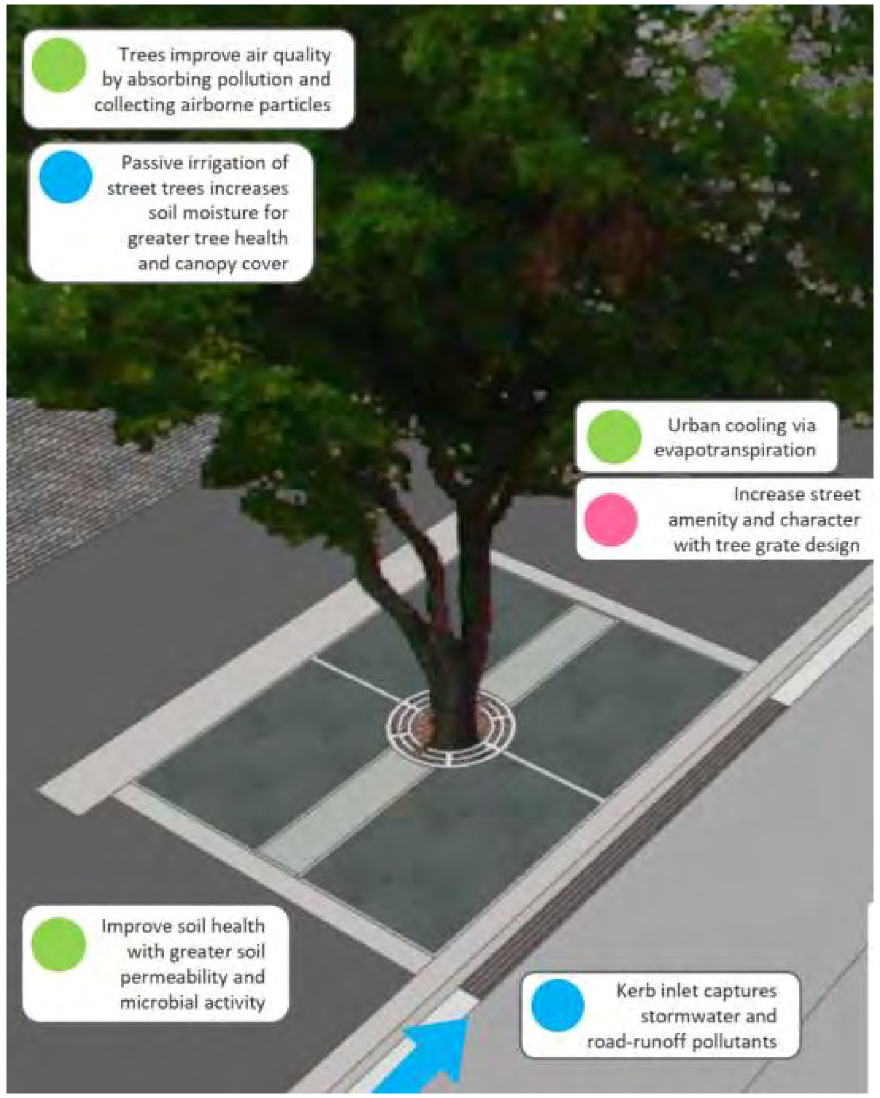
Example section showing key elements of raingarden with tree / open tree pit

	Brief description	Key design considerations
Other considerations		
Water source	Stormwater, usually from kerb openings or swales. In larger stormwater treatment systems, can be from stormwater drainage.	Consideration of pre-treatment is required for these systems to capture sediment and prevent clogging of the surface of the system.
Ideal soil conditions	Any soil type can be accommodated owing to drainage.	Sub-surface drainage ensures that these systems are not prone to water-logging, as such they can be constructed in most soil types. However, in the instance of dispersive soils, synthetic impermeable liners may be required.
Applicability to Greater Sydney	Applicable to all three cities.	This is applicable to all zones, however in drier areas such as the Western Parkland City area of Sydney, they may be prone to becoming overly dry.
Typical cost range	$2,000 - $10,000 / tree	
Key benefits / drivers for use	• Useful for stormwater quality treatment • Underdrainage reduces risk of water logging in clay soils • Open pit allows easy access for maintenance • Scalable • Suits a variety of contexts	Open tree pits and raingardens can be designed to suit a diverse range of settings. Underdrainage reduces risk of waterlogging, making them suitable for clay soils. They are often designed as bioretention basins, and as such have the benefit of providing water quality treatment.
Key management implications / risks	• When a highly sandy growth media is used, this can result in a system that dries out rapidly • Discharge of nutrients from the system • Maintenance required to ensure surface does not clog	The efficiency of drainage can cause them to dry out overly quickly, so care needs to be taken in selecting a growth media that retains sufficient moisture, and that prevents leaching of nutrients. Like most systems, these are reliant on active maintenance to ensure that the surface does not become clogged with sediment or other fines.


Image of open raingarden with trees

4.5 Sunken Tree Pit - Grated

The surface of the tree pit is set below the surrounding pavement and kerb to promote temporary storage and ponding of water when flow rates exceed infiltration rates. This maximizes the amount of water made available to the tree. The tree pit receives water from kerb openings or adaptors, swales and potentially stormwater pipes. The defining feature of this option is a grated cover of the set down surface of the tree pit, to prevent hazards in high traffic areas.



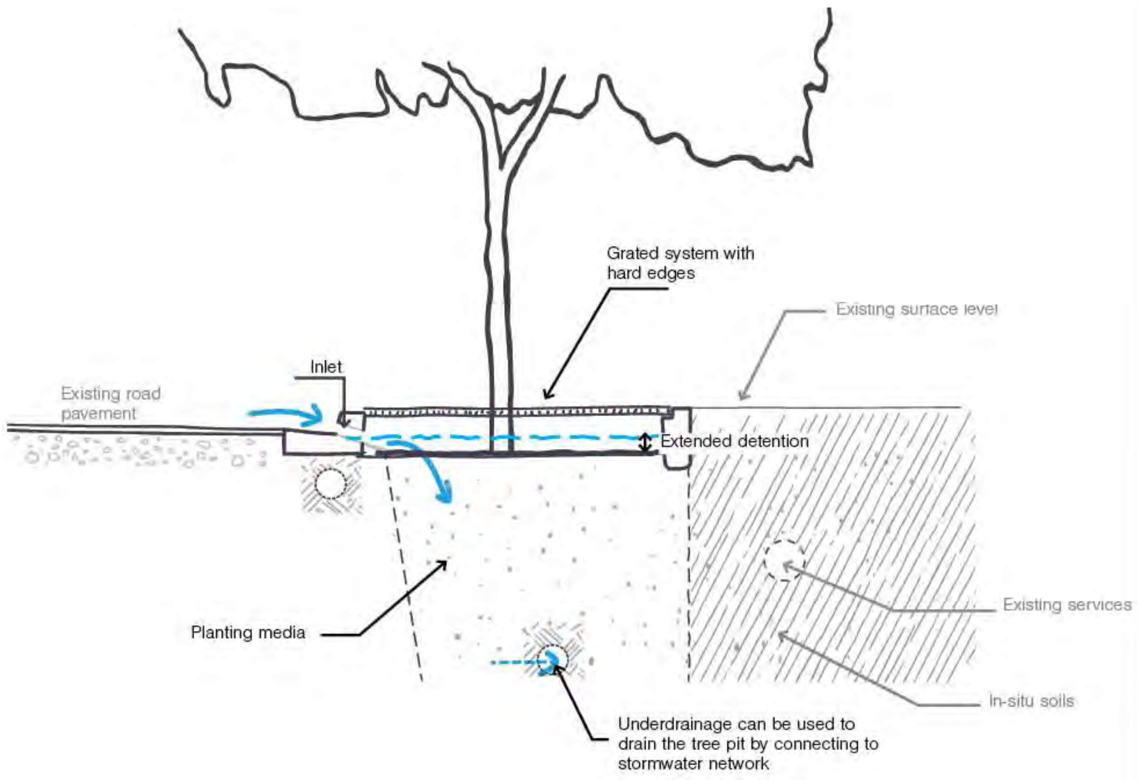
Graphic showing raingarden with trees. Source City of Yarra Embedding Green Infrastructure Guidelines

Example images of grated tree pits in Victoria (E2Designlab)

Key water supply and soil condition considerations	
Inflows and water storage volume	The systems are typically in high traffic areas, accepting water from kerb openings or adaptors. By having the surface of the system set below the inflow point, it allows temporary ponding of stormwater, allowing it to hold additional volume when inflows exceed the infiltration rate. This maximizes water availability; however the system does not have any long term storage of water for the tree to access.
Soil volume	These systems are not easily retrofitted and are associated with new trees. Design should ensure ample soil volume for optimal tree size and health. Given they are often associated with high traffic areas (roads and busy footpaths/plazas), the tree pits may need to be combined with structural systems to ensure sufficient volume.
Surface condition / clogging	The systems can be prone to surface clogging from sediment and other fine material deposited on the surface as surface shrubs and groundcovers are difficult to plant and maintain beneath grates. This can impact the infiltration rate and ultimately, the amount of water available to the tree. Ensuring the grates are removable is a key consideration to ensure the surface can be maintained.
Deep soil storage	Deep soil storage is unlikely to be greatly improved through this intervention because of a highly efficient drainage system.
Compaction	Commonly located in areas with compacted subgrades under road pavements and footpaths.
Water logging	Underdrainage of the systems ensures water logging is a low risk. However, the systems do need to be maintained to ensure the surface does not become clogged preventing infiltration and causing surface ponding, a cause of collar rot in trees.

Key design considerations:

	Rating	Key design considerations
Site suitability		
Park suitability		These systems are not well suited to areas with natural surrounds.
Plaza suitability		Well suited to plazas with the grate providing a flush surface to surrounds.
Streetscape suitability		A range of configurations exist to suit the streetscape, including bump outs/outstands and behind-kerb systems. Grated tree pits are well suited for shopping strips and other high pedestrian traffic areas.
Likelihood of success due to the following considerations		
Design simplicity		Moderate
Ease of retrofit		Low
Poorly draining soils (water logging)		Underdrainage makes waterlogging a low likelihood, however maintenance is required to ensure the surface does not clog.
Likelihood of delivering the following benefits		
Stormwater treatment		This solution, when appropriately designed, can remove sediment, nutrients and other stormwater pollutants and prevent them entering the drainage system
Extended soil moisture retention		The efficiency of these drainage systems can result in rapid drying and water stress, particularly where low organic sands are used (such as typical bioretention filter media)
Connection to deep soils		If relief drainage is elevated above base, allows exfiltration and deep soil recharge and storage of water. If drainage is placed in base, efficient underdrainage doesn't allow a long residence time of water, reducing exfiltration opportunities. In addition, drainage gravel across the base will prevent the capillary rise of moisture during dry periods (i.e. prevent access to deep soil moisture).



Example section showing key elements of grated tree pit

	Brief description	Key design considerations
Other considerations		
Water source	Stormwater, usually from kerb openings.	Consideration of pre-treatment is required for these systems to capture sediment and prevent clogging of the surface of the system.
Ideal soil conditions	Any soil type can be accommodated owing to drainage.	Sub-surface drainage ensures that these systems are not prone to water-logging, as such they can be constructed in most soil types. However, in the instance of sodic or dispersive clay soils, synthetic impermeable liners may be adopted where impacts on surrounding soils are a concern.
Applicability to Greater Sydney	Applicable to all zones.	This is applicable to all zones, however in drier areas such as the Western Parkland City area of Sydney, they may be prone to becoming overly dry.
Typical cost range	$3,000 - $15,000 / tree	
Key benefits / drivers for use	• Useful for stormwater quality treatment • Underdrainage reduces risk of waterlogging in clay soils • Grate reduces risk and soil compaction, whilst increasing trafficable area	Grated tree pits are excellent at providing an integrated finish with surrounding surface levels, reducing safety risks and maintaining functional pavement widths for adjacent roads and footpath. Underdrainage reduces risk of waterlogging, making them suitable for clay soils. They are often designed as raingardens and as such have the benefit of providing water quality treatment.
Key management implications / risks	• When a highly sandy growth media is used, this can result in a system that dries out rapidly • Careful selection of growth media to prevent nutrients 'leaking' out of the system. • Maintenance is required to ensure surface does not clog • Grate can inhibit maintenance	The efficiency of drainage can cause them to dry out overly quickly, so care needs to be taken in selecting a growing media that retains sufficient moisture but also prevents 'nutrient leaching', the mobilisation of nitrogen and phosphorus from the media entering the drainage system and ultimately our creeks, rivers and bays. Like most systems, these are reliant on active maintenance to ensure that the surface does not become clogged with sediment or other fines. The selection and design of the grate is key to ensuring that the surface of the system can be accessed to allow for maintenance.

4.6 Below ground storage

Below ground storage refers to systems that retain moisture in a saturated or wicking zone beneath the tree through use of an impermeable liner which prevents exfiltration from the tree pit. The tree is then able to access this water during dry spells, as water rises into the soil zone via capillary rise/wicking. It can be considered an 'add-on' to other possible interventions, specifically sunken tree pits (open or grated) and raingardens. Much like standard tree pits, stormwater typically enters the tree pit via a kerb opening or adaptor. The surface of the tree pit is usually set down below the inlet to maximize the volume of water that infiltrates through the system. Drainage ensures that the system does not become saturated, setting a maximum water level in the storage zone.

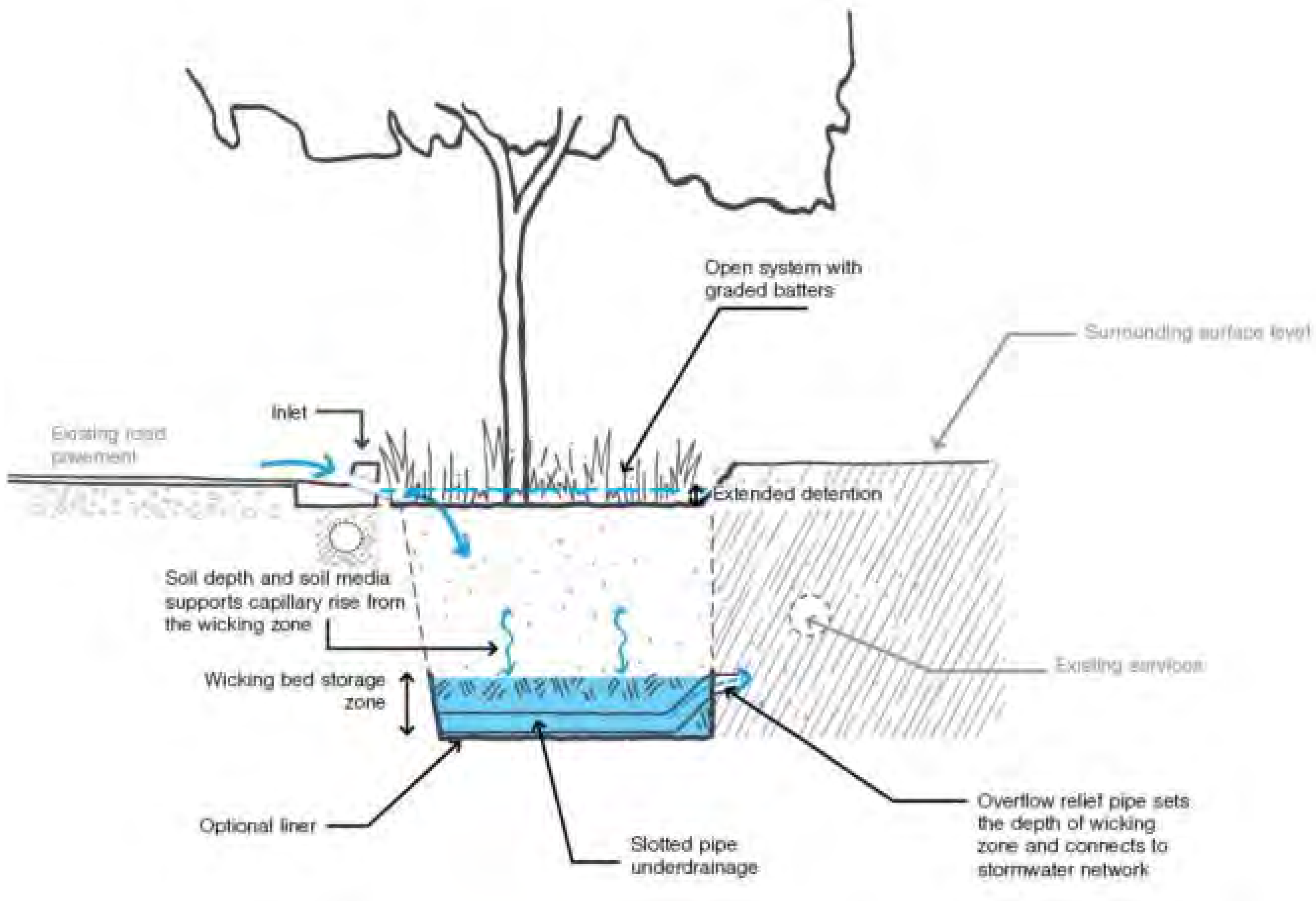
Image from: Water By Design Waterwise street tree booklet

Key water supply and soil condition considerations	
Inflows and water storage volume	These systems can be provided with any other tree pit (open or grated) or rain garden configuration. See the relevant system for inflow configuration. This configuration has a significant water storage volume, typically sized to retain water through an average dry spell.
Soil volume	These systems are not able to be retrofitted, so design should ensure soil volume is suited to the desired tree size.
Surface condition / clogging	See accompanying configuration design notes – sunken tree pit either grated or open, or raingarden.
Deep soil storage	Not effective for deep soil storage, as the use of a liner prevents exfiltration from the tree pit.
Compaction	See accompanying configuration design notes – sunken tree pit either grated or open, or raingarden.
Water logging	Drainage ensures that the system does not become waterlogged.

Installation of a waterproof liner to create below ground storage for a grassed open space area in Queensland (E2Designlab)

Key design considerations:

	Rating	Key design considerations
Site suitability		
Park suitability	Green	Suitable in any setting
Plaza suitability	Green	Suitable in any setting
Streetscape suitability	Green	Suitable in any setting
Likelihood of success due to the following considerations		
Design simplicity	Yellow	This is a moderately complex approach, requiring a large tree pit and lining.
Ease of retrofit	Red	Unable to be retrofitted, as the ideal storage location is directly beneath the tree to enable capillary rise to deliver moisture to the soil.
Poorly draining soils (water logging)	Green	Drainage ensures that there is a low risk of waterlogging.
Likelihood of delivering the following benefits		
Stormwater treatment	Green	Selection of an appropriate growth media that is conducive to growth, but limits leaching will result in a system capable of improving stormwater quality.
Extended soil moisture retention	Green	Excellent soil moisture retention.
Connection to deep soils	Red	Generally poor owing to an impermeable liner.

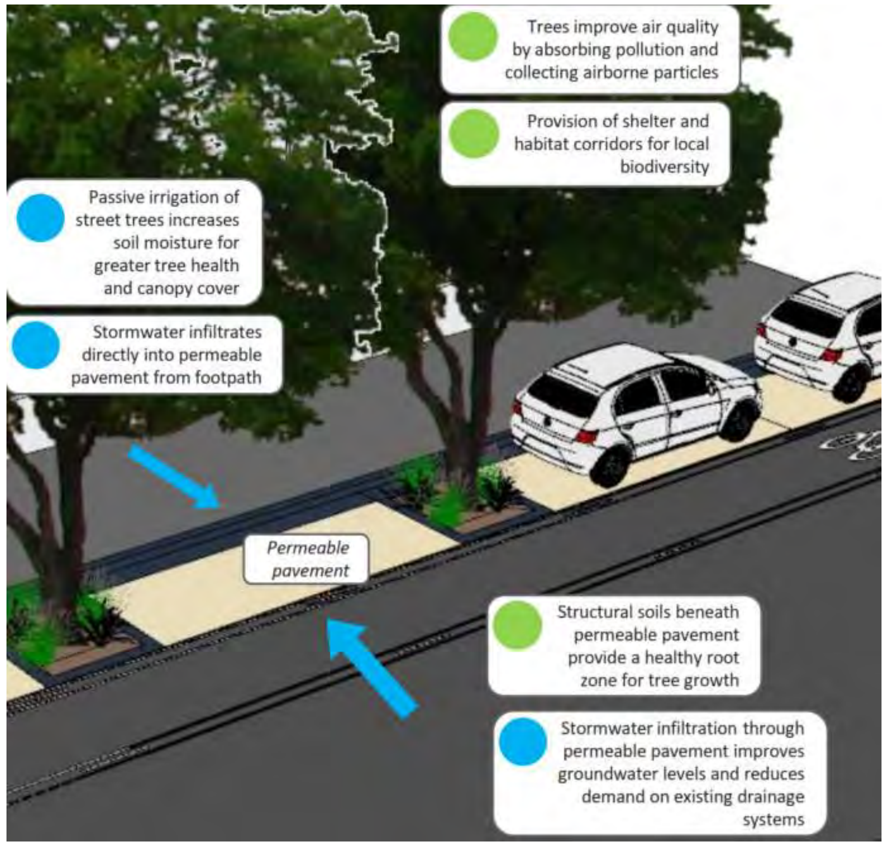


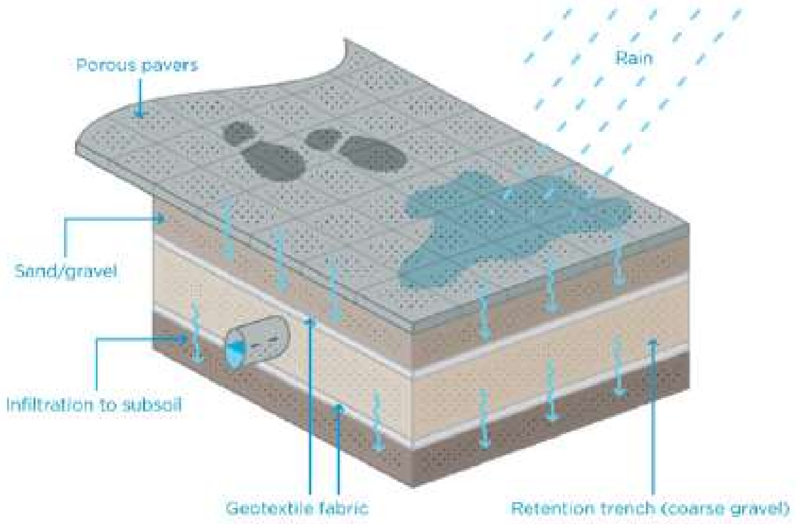
Example section showing key elements of tree pit with below ground water storage (wicking zone)

	Brief description	Key design considerations
Other considerations		
Water source	The water source is typically stormwater; however it can be topped up with other sources.	Consideration of pre-treatment is required for these to reduce the risk of the surface clogging.
Ideal soil conditions	Any	In-situ soils do not greatly impact the design, as there is limited interaction between the pit and soils due to the impermeable liner and drainage. However, in heavy clay soils a liner may not be required. Care needs to be taken in where surrounding soils have dispersive characteristics.
Applicability to Greater Sydney	Everywhere – preferred configuration in Western Parkland City area of Sydney	Low rainfall combined with higher evapotranspiration in Sydney's west results in more moisture stress of trees. This is a highly effective intervention to ensure ongoing water availability.
Typical cost range	Additional $1,000 - $3,000 / tree	
Key benefits / drivers for use	• Good water availability • Low chance of waterlogging. • Lined systems so can be adapted for use on podiums or areas with poor soils (e.g. sodic soils)	This approach optimises water availability for the tree, providing resilience to drought and maximizing growth and canopy cover.
Key management implications / risks	• Ensure that the storage zone is sized for the longest average dry spell.	Impermeable liners will be required to hold moisture in sandy soils and soils with dispersive characteristics. The volume of water should be sized based on typical dry spell lengths during a dry season or a dry spell of a target frequency to ensure year-round water availability.

4.7 Permeable pavements

Permeable pavements are hard surfaces used in trafficable areas that, unlike traditional asphalt, concrete and paved surfaces, enables water to infiltrate to subsurface soils. They can be used in this context to increase water availability to trees and surrounding soils, where under a traditional scenario it would run off. They may be used as a pre-treatment to prevent sediment and other gross pollutants entering tree pits. They are typically used in conjunction with other interventions such as tree pits and structural soils or cells.





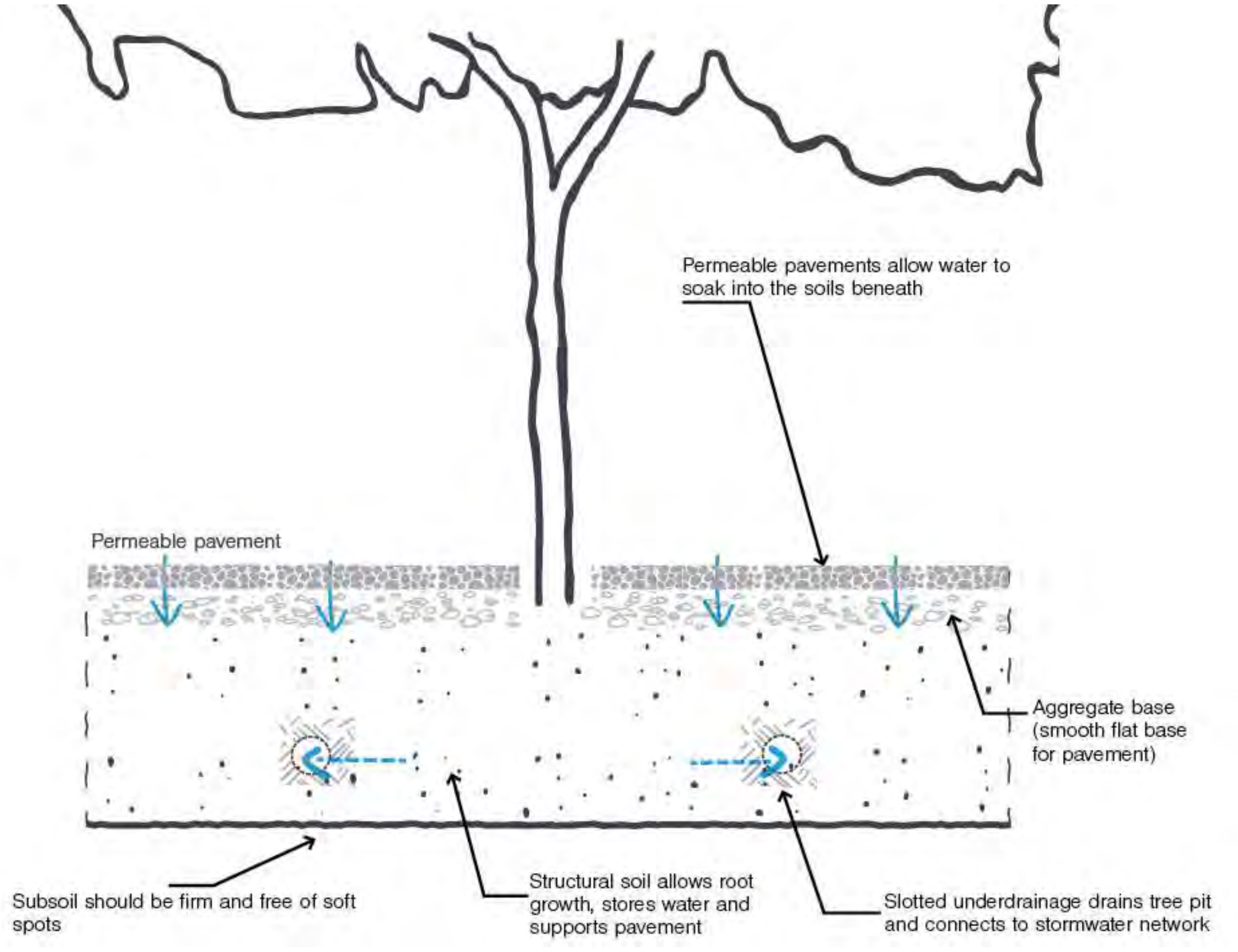
Graphics showing use of permeable pavement for street trees (left - Source City of Yarra Embedding Green Infrastructure Guidelines) and elements of porous pavement (E2Designlab 2019)

Example images of trees and permeable pavement (Tanderrum Way, Broadmeadows, VIC)

Key water supply and soil condition considerations	
Inflows and water storage volume	Permeable pavements may be designed to intercept rainfall falling directly on them (when used at a larger scale) and may also accept water from sheet flow from adjacent impermeable surfaces. In some instances, it may be used to intercept concentrated flows, such as in kerb and channel.
Soil volume	Dependent on design
Surface condition / clogging	Permeable pavements are prone to clogging in the absence of regular maintenance. It is important that they are cleaned frequently with street sweeping and are thoroughly cleaned with pressure washing every 1-2 years for optimum performance.
Deep soil storage	Excellent for promoting infiltration into soils across a large area, helping to maintain deep soil water storage.
Compaction	Permeable pavers can be designed for heavy traffic and support high structural loads, so are not susceptible to compaction.
Water logging	Water logging is not typically an issue associated with this intervention type, however if a large catchment is focused to a small area of permeable pavement, the underlying soils could become persistently wet. Generally, the total catchment draining to a permeable pavement (inclusive of the pavement) should preferably be no more than twice the area of permeable pavement and not more than five times the area.

Key design considerations:

	Rating	Key design considerations
Site suitability		
Park suitability	Yellow	Parks generally have few hard surfaces, so not typically applicable.
Plaza suitability	Green	Perfect for extensive areas of hardstand in plazas where infiltration of rainfall would otherwise be very low.
Streetscape suitability	Green	Care needs to be taken in product specification of vehicular traffic areas. Usually most effective in car park areas.
Likelihood of success due to the following considerations		
Design simplicity	Red	Cost may be high
Ease of retrofit	Yellow	Generally, requires a more significant work area, making it more difficult than some other interventions.
Poorly draining soils (water logging)	Red	Dependent on design of tree pit.
Likelihood of delivering the following benefits		
Stormwater treatment	Yellow	Can be an effective means of stormwater management, reducing runoff and capturing associated pollutants. However, only litter and sediments will be removed (maybe some phosphorus attached to sediments) but not dissolved nutrients.
Extended soil moisture retention	Red	Intervention does not promote retention of soil moisture in dry periods.
Connection to deep soils	Yellow	Can provide rainfall infiltration over a wide area (dependent on scale). Infiltration rates will depend on the base layer material.



Example section showing key elements of tree pit with permeable pavement

	Brief description	Key design considerations
Other considerations		
Water source	Stormwater enters via concentrated or sheet flow from adjacent impermeable surfaces.	Consideration to expected infiltration rate will be important in sizing the required area of permeable pavement to ensure sufficient water reaches the target area.
Ideal soil conditions	Sandy/freely draining soils	To maximize the benefit of permeable pavements, underlying soils should be sandy or freely draining. However, they may be used in conjunction with other water storage solutions such as tree pits or structural soil cells that can be used in any soil type.
Applicability to Greater Sydney	Applicable to all three cities	Most effective in areas with sandy soils when used to promote wide scale infiltration. Can be used as entry into another intervention (tree pit/structural soils) in any area.
Typical cost range	$1,500 - $2,000	Assuming a 10m^2 tree pit
Key benefits / drivers for use	• Soil moisture recharge over a wider area • Pre-treatment to prevent sedimentation of subsurface assets • Improved stormwater management	Permeable pavements are an effective means of promoting infiltration into soils over a wide area, or as a pre-treatment to another intervention such as an infiltration trench, structural soil cells or tree pits. Their reduction in runoff and subsequent stormwater quality improvement is a common driver for their use.
Key management implications / risks	• Excessive wear from very heavy traffic • Clogging of the surface in the absence of effective maintenance	In high traffic turning areas, permeable pavements such as asphalt are prone to wearing. As such care needs to be taken in terms of where they are located. Clogging is a common experience with permeable pavements to date, however it is variable depending on catchment context and this can largely be attributed to a lack of maintenance. It is recommended inspections or testing occur every 1-2 years and provision is made for cleaning every 1-5 years.

Eades Place, Melbourne.
http://urbanwater.melbourne.vic.gov.au/projects/permeability-infiltration/eades-place-permeable-parking/

4.8 Structural soils and cells

Structural soils and cells are used to extend growing media under pavements. Structural cells are proprietary products, typically made of plastic and filled with soil, while structural soils typically consist of uniformly graded and compacted rock infilled with a loamy clay soil. Such systems can extend underneath paved areas such as roads, footpaths and plazas, providing the necessary structural support for the overlying surface, while maintaining an uncompacted soil that can hold both water and oxygen suitable for tree growth. Trees extend fine roots throughout the structural soil providing significant accessible soil volume and creating a well anchored mature tree.

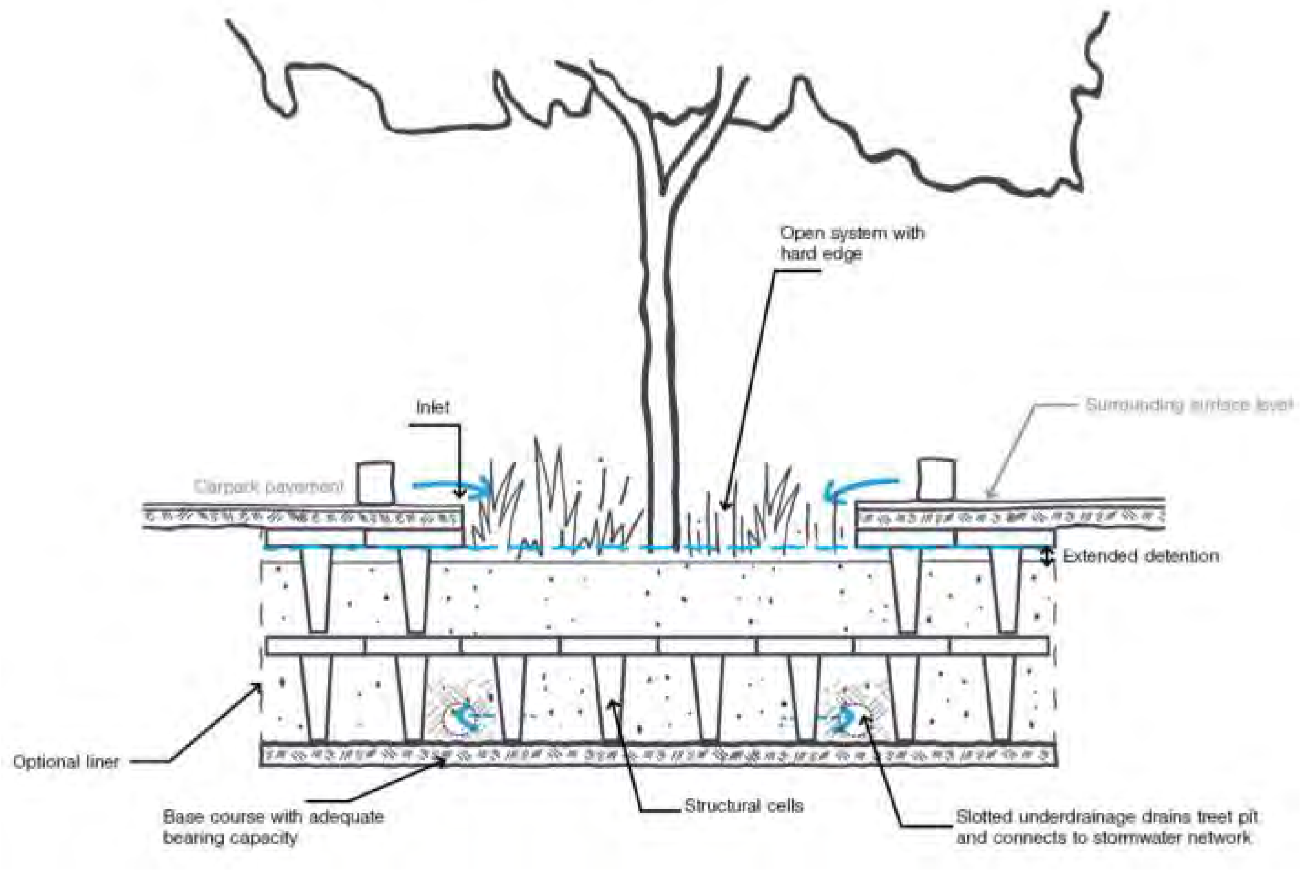
City of Melbourne - http://urbanwater.melbourne.vic.gov.au/projects/permeability-infiltration/eades-place-permeable-parking/

Key water supply and soil condition considerations	
Inflows and water storage volume	Inflow to these systems is dependent on the design configuration. They are typically used in conjunction with tree pits, where water infiltrates down into the system and out into adjacent structural soils but may also have stormwater discharging directly into them where they are not filled with soil (i.e. infiltration trenches). Another very common inflow configuration is via overlying permeable pavement.
Soil volume	These systems are designed to maximize the volume of suitable soils, from which the tree can access moisture.
Surface condition / clogging	This is a sub-surface treatment, hence clogging depends on how stormwater is delivered.
Deep soil storage	Improved volume of soil and subsequent surface area contact with in-situ soils can maximize the amount of deep soil storage possible.
Compaction	Designed specifically to prevent issues with compaction.
Water logging	Systems may become waterlogged in clay soils, where no additional drainage exists.

Before and after - Green Square Library, Sydney. Photo courtesy of CityGreen. https://citygreen.com/case-studies/award-winning-green-square-library-and-plaza-fuses-built-form-and-landscape/

Key design considerations:

	Rating	Key design considerations
Site suitability		
Park suitability	Red	Generally not required owing to ample open space and quality uncompacted soils.
Plaza suitability	Green	Ideally suited, providing soil and moisture storage in areas that are otherwise heavily compacted and unsuitable to sub-surface moisture.
Streetscape suitability	Green	Highly suited to confined streetscapes with substantial hardstand areas (e.g. CBD/industrial locations)
Likelihood of success due to the following considerations		
Design simplicity	Yellow	Typically requires greater excavation and additional products/materials to create.
Ease of retrofit	Yellow	Requires a greater area of excavation to provide improved soil volume.
Poorly draining soils (water logging)	Yellow	Risk of water logging may be high if located in clay soils without underdrainage.
Likelihood of delivering the following benefits		
Stormwater treatment	Yellow	These systems can provide good treatment if designed to hold water. Where designed as infiltration devices (typically structural soils), volumetric losses may be significant, reducing discharge of pollutant laden stormwater.
Extended soil moisture retention	Red	When designed with elevated relief drainage, structural soils may make large volumes of water available to trees over a longer period.
Connection to deep soils	Yellow	Improved volume of soil and subsequent surface area contact with in-situ soils can maximize the amount of exfiltration and deep soil storage.

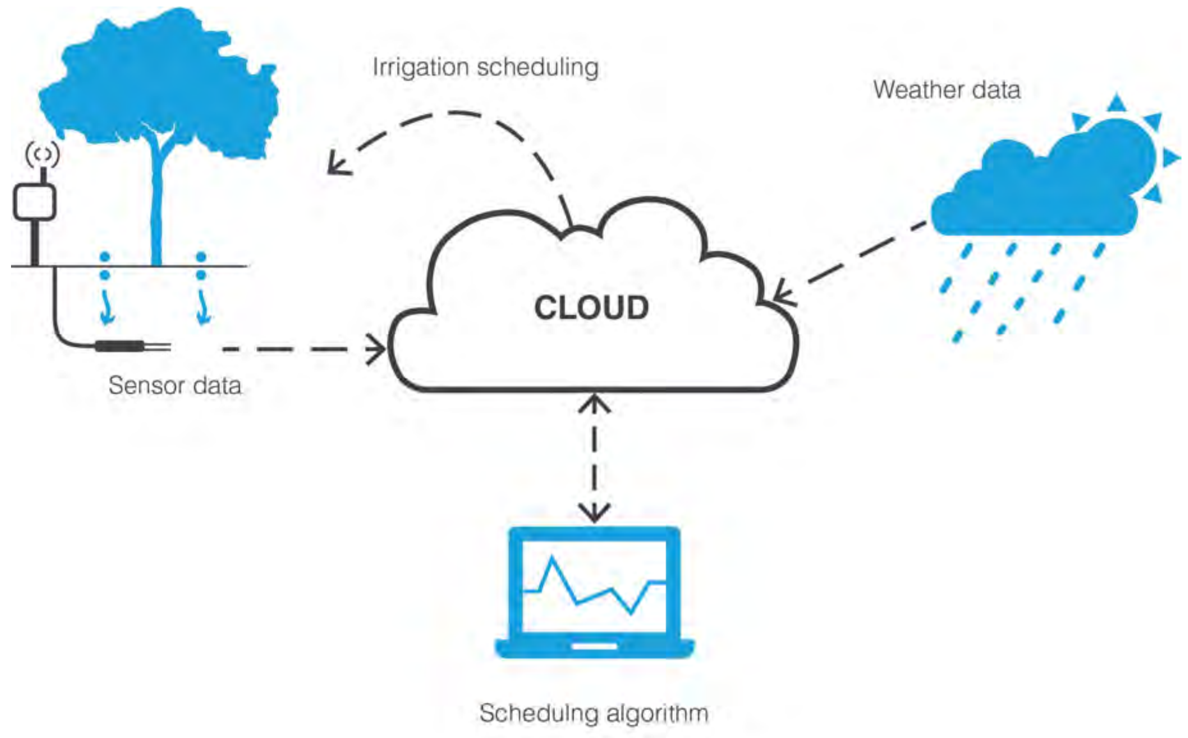


Example section showing key elements of tree pit with structural cells

	Brief description	Key design considerations
Other considerations		
Water source	Typically, stormwater	Consider catchment to storage volume ratio to ensure it does not become waterlogged.
Ideal soil conditions	Any	Systems may require relief drainage in clay soils.
Applicability to Greater Sydney	Applicable to all three cities	Not geographically limited. Structural soils are most used in areas where tree access to adequate soil volumes is constrained by surrounding infrastructure such as roads and pavements.
Typical cost range	$5,000 - $8,000 (soils) $5,000 - $25,000 (cells)	Assuming a 10m^2 tree pit
Key benefits / drivers for use	• Provides adequate soil volume in otherwise highly constrained sites • Adequate soil volume reduces risk of root damage to other structures • Used where soil volume is unavailable	This approach provides the ability to have soil storage volume underneath structures that require compaction and are hence unsuitable for tree growth. This becomes highly relevant in built up locations such as industrial areas or inner city locations with extensive hard surface areas. Adequate soil volume and moisture prevents roots seeking out more room and moisture, which can otherwise result in damage to infrastructure (root ingress in pipes/sewers and lifted pavement).
Key management implications / risks	• Higher cost solution	Once installed there are typically few ongoing issues for consideration. However, up front costs may present a barrier to this option being used in many locations.

4.9 Irrigation scheduling technology

Irrigation scheduling technology is an ever-evolving area that optimises the timing and duration of delivery of irrigation through pressurised irrigation systems that can be turned on and off. In their most basic form, this method may use timers to ensure that irrigation is applied at night to maximize plant water uptake and reduce the amount of water lost to evaporation. More advanced systems are linked to weather stations, which may trigger or suspend irrigation in response to real time weather (e.g. wind) or recent weather events (rainfall or extreme heat). These may be accompanied by soil moisture probes, that may be able to more accurately determine when irrigation may be required to prevent tree wilting.



Graphic depicting how irrigation scheduling technology can work (Based on: Dominguez-Nino et al (2020) https://www.sciencedirect.com/science/article/pii/S0378377419315641)

Key water supply and soil condition considerations	
Inflows and water storage volume	Any pressurised water delivery system, ideally from an alternative water source such as recycled water or harvested stormwater.
Soil volume	Greater soil volumes and connection to deep soil moisture stores will reduce the amount of irrigation required.
urface condition / clogging	Surface clogging is not a risk as a consequence of this intervention, however surface may be monitored to ensure that it does not become water repellent and that infiltration remains high. This improves efficiency of delivery and prevents unnecessary runoff.
Deep soil storage	Consistent irrigation prevents shallower soils drying out and preserves deep soil moisture for access by trees.
Compaction	Not a risk, however monitoring for compaction may improve infiltration and efficiency of water delivery.
Water logging	Not a risk.

Key design considerations:

	Rating	Key design considerations
Site suitability		
Park suitability		Highly suitable for irrigated open space where active irrigation systems are common and there are few other services/infrastructure preventing installation of new systems.
Plaza suitability		Generally highly manicured/visually prominent settings, so irrigation is appropriate.
Streetscape suitability		Suitable for highly prominent/high maintenance boulevards that have an irrigation system.
Likelihood of success due to the following considerations		
Design simplicity		Can have a lot of ongoing maintenance challenges in maintaining and calibrating calibrated systems. Irrigation systems are notoriously high maintenance and even more so in streetscape settings.
Ease of retrofit		Typically requires long linear infrastructure, which can make retrofit more difficult in established areas.
Poorly draining soils (water logging)		Low risk of water logging
Likelihood of delivering the following benefits		
Stormwater treatment	N/A	Generally not applicable, however volumetric loss of harvested stormwater will reduce the amount of pollutant laden runoff that reaches streams and rivers.
Extended soil moisture retention		Ensures soil moisture is maintained throughout the year, regardless of weather conditions.
Connection to deep soils		Consistent application may result in some penetration of water to deep soils.

	Brief description	Key design considerations
Other considerations		
Water source	Mains potable, recycled, harvested stormwater	Alternative sources are preferred to ease reliance on drinking water supplies and enable continued irrigation in time of restrictions. If recycled or harvested stormwater is used, risks associated with human contact must be considered.
Ideal soil conditions	Any	Optimal imported soils will aid infiltration and prevent runoff if application of irrigation exceeds infiltration capacity.
Applicability to Greater Sydney	Applicable to all three cities	Can be used anywhere.
Typical cost range	$5,000 to $20,000	
Key benefits / drivers for use	• Easily retrofit to existing irrigation system • Highly reliable supply except during water restrictions when using mains water	Irrigation scheduling technology may be applied to any existing irrigation system, making it an easy retrofit. The installation of new irrigation systems with irrigation scheduling technology ensures that trees have a reliable water source (except during restrictions, when using potable water) and water use is optimised. Wastage is prevented through avoiding watering when unnecessary (after rainfall), when evaporation is high (daytime or windy conditions) and ensures excessive amounts of water are not applied (i.e. irrigation beyond target soil moisture level).
Key management implications / risks	• Maintenance of irrigation systems can be high • Calibration of soil moisture probes required	Active irrigation systems (sprinkler systems) need a high level of maintenance to ensure sprinkler heads or drippers are working effectively. When linked to soil moisture probes, calibration of probes is necessary to ensure that the system is operating as intended.

4.10 Drip irrigation

Drip irrigation involves the application of water via sub-surface irrigation lines (whilst often surface lines, sub-surface is the focus here due to application in the public realm). This method of irrigation reduces the amount of water lost through aerial drift, whilst the slow rate of irrigation prevents waste through surface runoff that can be associated with more intensive irrigation.

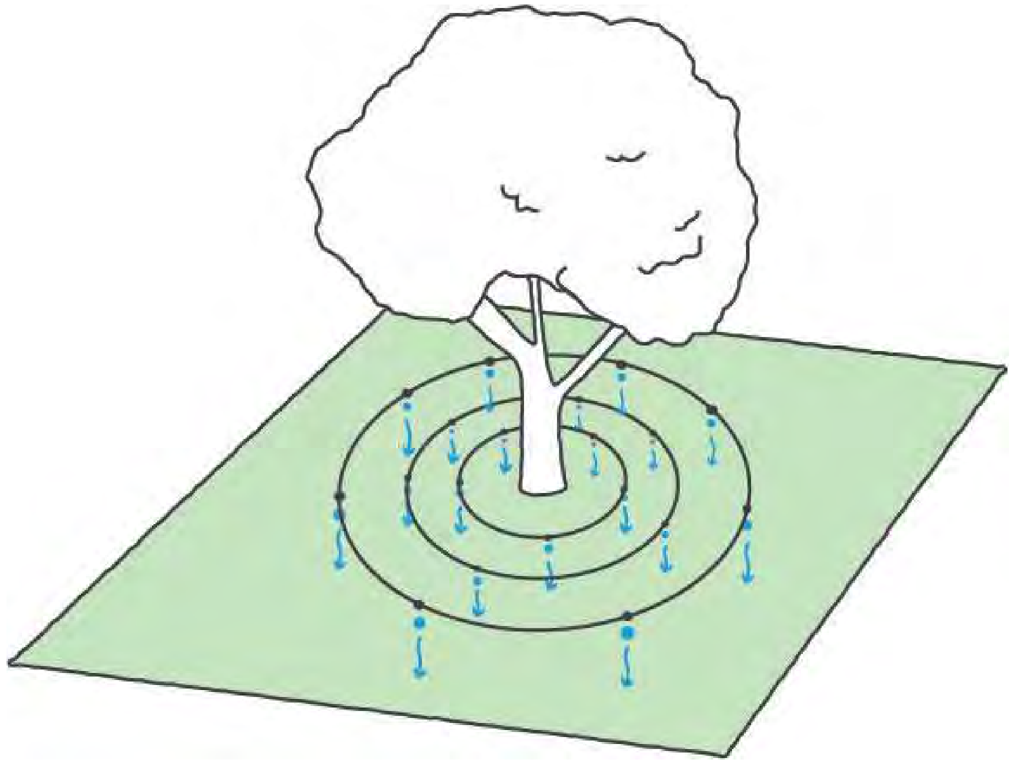


Diagram displaying potential drip irrigation configuration - (Based on Connellan 2013. *Water Use Efficiency for Irrigation Turf and Landscape*, CSIRO Publishing)

Key water supply and soil condition considerations	
Inflows and water storage volume	Any water source delivered under pressure. No storage volume associated with this approach.
Soil volume	Greater soil volumes and connection to deep soil moisture stores will reduce the amount of irrigation required.
Surface condition / clogging	Surface clogging is not a risk because of sub-surface delivery. However, clogging of drip irrigation line is a common problem.
Deep soil storage	Consistent irrigation prevents shallower soils drying out and preserves deep soil moisture for access by trees.
Compaction	Not a risk, however monitoring for compaction may improve infiltration and efficiency of water delivery.
Water logging	Not a risk.

Drip irrigation delivers water to where it is required with minimal wastage - image Netafim. https://www.netafim.com.au/drip-irrigation/

Sub-surface drip irrigation installed for agriculture - https://sswm.info/water-nutrient-cycle/water-use/hardwares/optimisation-water-use-agriculture/subsurface-drip-irrigation

Key design considerations:

	Rating	Key design considerations
Site suitability		
Park suitability		Ideal setting for drip irrigation.
Plaza suitability		Unlikely to be suitable where easy access to irrigation line is not available, owing to a requirement to clean drip line if it becomes clogged.
Streetscape suitability		Caution should be used in the streetscape owing to risk of utilities providers or construction causing damage to shallow infrastructure. May be suitable for high amenity boulevards.
Likelihood of success due to the following considerations		
Design simplicity		Simple to install, however maintenance may be a challenge to ensure it remains effective.
Ease of retrofit		Care must be taken around tree roots, to ensure that excessive root damage is not done during installation.
Poorly draining soils (water logging)		Water logging may be a risk if poorly controlled scheduling results in persistent irrigation.
Likelihood of delivering the following benefits		
Stormwater treatment	N/A	Only where water source is from harvested stormwater.
Extended soil moisture retention		Year-round water availability results in good soil moisture.
Connection to deep soils		The consistent delivery of water may result in very effective watering conducive to deep soil moisture recharge.

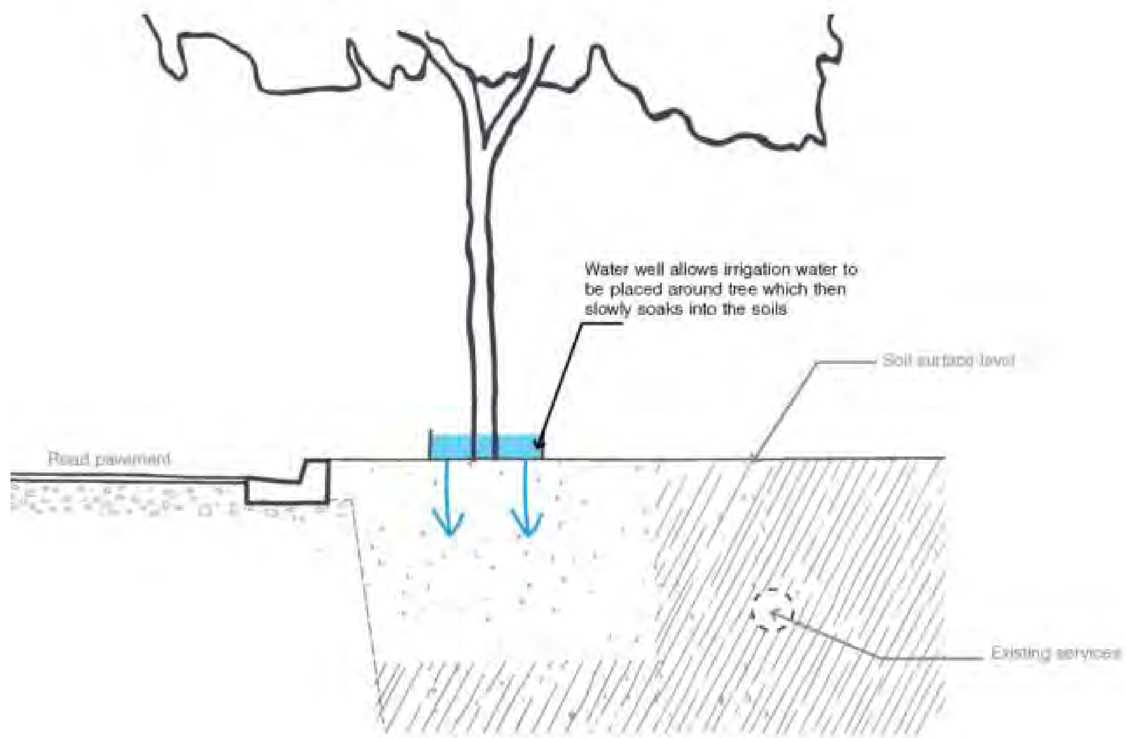
	Brief description	Key design considerations
Other considerations		
Water source	Pressurised – suitable for lower class recycled/stormwater	Any pressurised source may be suitable for this approach. Given the sub-surface delivery, it is the most appropriate irrigation method for untreated stormwater or lower class recycled water.
Ideal soil conditions	Freely draining soils	Heavy clays may prevent effective drip irrigation, only irrigating a small area directly around the irrigation line.
Applicability to Greater Sydney	Applicable to all three cities	Generally applicable across Sydney, however, be aware of clay soils.
Typical cost range	varies	
Key benefits / drivers for use	• Where health risk prevents aerial application • Low loss of water through runoff, aerial drift and evaporation	Subsurface delivery of water makes it a suitable option for use of water sources that have potential microbial contamination and is therefore unfit for human contact. This approach makes the majority of water used in irrigation available to the tree, minimizing losses through runoff, aerial drift and evaporation.
Key management implications / risks	• Maintenance of irrigation systems can be high • Prone to clogging • Linear infrastructure may be broken by other construction activities. • Poor moisture distribution away from irrigation lines.	Risk of clogging of drip irrigation lines is a common experience. Ensuring a good distribution of soil moisture can be challenging, often resulting in well irrigated areas immediately around the line only. Competition for space with other utilities may make it a poor contender for an irrigation option in the streetscape.

4.11 Water wells and water butts

Water wells and water butts are devices that are manually filled with water for irrigation, which slowly infiltrates into the root zone. Water wells are sometimes installed as a collar surrounding the tree but may also be applied in a temporary container adjacent to the tree. Water butts may be used in a similar fashion, allowing rapid filling, but slow release of water into the root zone. This provides for a more effective watering regime, that minimizes losses with runoff and reduces the amount of human resource time required to undertake effective watering of trees.

Key water supply and soil condition considerations	
Inflows and water storage volume	May use any form of available water.
Soil volume	Dependent on tree pit configuration.
Surface condition / clogging	Surface clogging is not a risk because of this intervention, however ensuring no clogging will provide adequate infiltration and effective watering.
Deep soil storage	Dependent on characteristics of tree pit design. Effective deep soil storage is likely to require very frequent watering with this approach.
Compaction	Not a risk, however monitoring for compaction may ensure infiltration and efficiency of water delivery is maintained.
Water logging	Low risk, however monitoring is required to ensure the tree zone is not becoming saturated for protracted periods.

Example tree water well. Image source: https://www.jaybro.com.au/about/water-wells-plastic-tree-surround/



Example section showing how water well encourages water to soak into soils around tree

Key design considerations:

	Rating	Key design considerations
Site suitability		
Park suitability		No restrictions to use in parks.
Plaza suitability		Collar style water wells may be suitable, however other large temporary reservoirs may not be ideal in a high amenity setting.
Streetscape suitability		May be used in streetscape.
Likelihood of success due to the following considerations		
Design simplicity		Simple to install and use.
Ease of retrofit		This approach can be easily retrofitted, however if using tree collar style water wells, ensure tree roots are not cut close to tree.
Poorly draining soils (water logging)		Unlikely to be a risk, however monitoring is required to ensure this does not occur.
Likelihood of delivering the following benefits		
Stormwater treatment	N/A	Only where water source is from harvested stormwater.
Extended soil moisture retention		Provides water to the tree zone over a longer period of time than other manual watering methods.
Connection to deep soils		Improved slow release maximizing water penetration and connection to deep soils, but dependent on tree pit design.

	Brief description	Key design considerations
Other considerations		
Water source	Any safe water source. Preference of recycled water or stormwater.	Any water source may be used, subject to ensuring human contact is minimized with lower class recycled water or untreated stormwater.
Ideal soil conditions	Any	
Applicability to Greater Sydney	Applicable to all three cities	Generally applicable across Greater Sydney.
Typical cost range	$50 - $400 / tree	
Key benefits / drivers for use	• Low cost intervention that may improve efficiency of manual watering • Can be set up to facilitate effective watering during drought response. • Generally low risk owing to low complexity solution.	These are low cost interventions that can be easily retrofitted, particularly in response to drought. They are simple systems that can be easily installed and removed.
Key management implications / risks	• Requires manual delivery of water to fill reservoirs.	Manual delivery of water to fill reservoirs (wells or butts) has higher human resource implications.

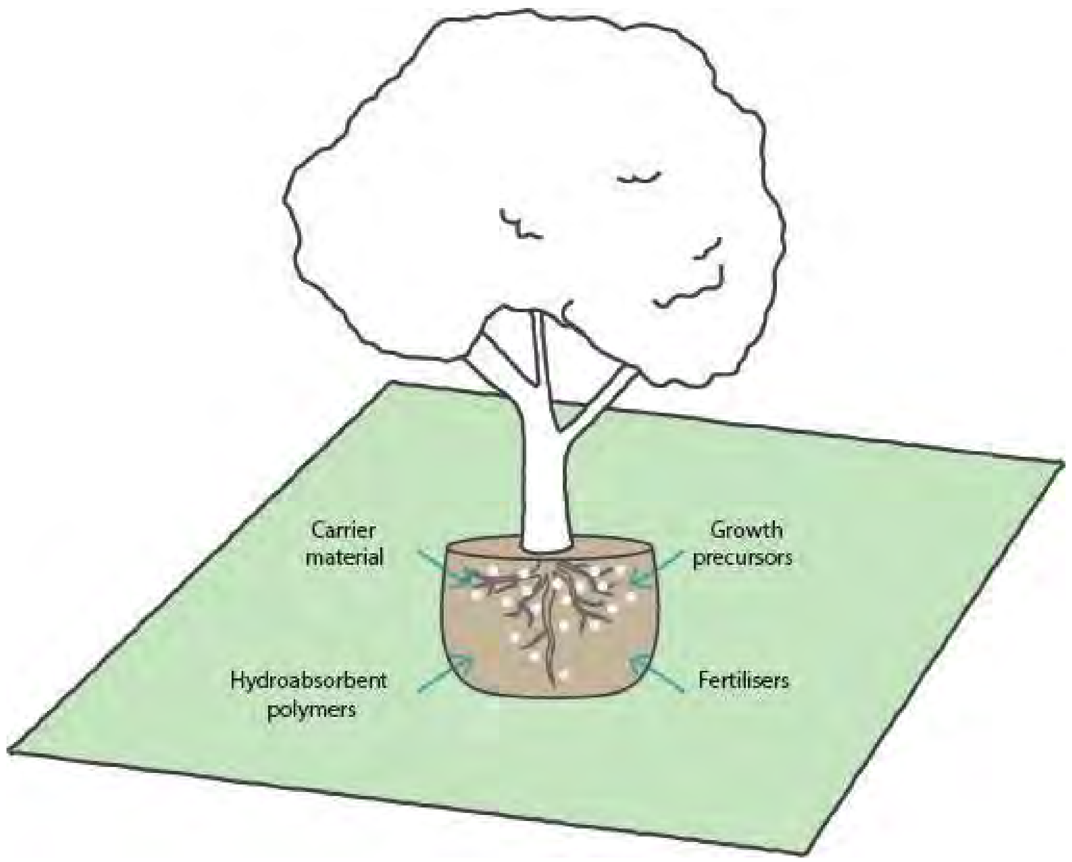
4.12 Soil additives

A range of natural and manufactured soil additives are available that can modify soil characteristics to be more conducive to optimal tree growth. They can work in several different ways, targeted at site specific deficiencies. These may include:

- improving physical structure of the soils (e.g. loosening clays).
- modifying pH.
- encouraging microbial activity.
- wetting agents to reduce water repellence in hydrophobic soils (usually sands).
- water holding additives like vermiculite, perlite, water crystals and gels to improve water holding capacity.
- water additives like perlite to improve drainage and aeration as well as water holding capacity.
- improving plant access to key minerals and nutrients.

The key consideration in choosing additives is to first understand the existing soil type and conditions and the needs of the intended tree species. The best approach and relevant corresponding additives can then be selected to match these needs. The range of soil additives commercially available continues to grow in response to the increasing recognition of good soil health to healthy environments and there is considerable potential for a response to be tailored for each site.

In Greater Sydney, it is likely that soils will be clay and the most beneficial additive at many sites will be a layer of organic matter such as compost mixed into the upper layer of existing soil. However, soil testing and the advice of qualified soil scientists should be obtained and taken into consideration wherever possible.



Example soil additives. (based on: Terracottem: https://www.terracottem.com/sites/terracottem/files/brochure_en_complete_1_by_1_20180531.pdf)

Key water supply and soil condition considerations	
Inflows and water storage volume	Any
Soil volume	Any
Surface condition / clogging	Not relevant
Deep soil storage	Not relevant.
Compaction	Not a risk
Water logging	Not a risk

Key design considerations:

	Rating	Key design considerations
Site suitability		
Park suitability		Yes
Plaza suitability		Yes
Streetscape suitability		Yes
Likelihood of success due to the following considerations		
Design simplicity		Simple
Ease of retrofit		Easily added with any new tree, and some may be added to the surface or as a liquid form for existing trees.
Poorly draining soils (water logging)		Not a risk because of soil additives.
Likelihood of delivering the following benefits		
Stormwater treatment	N/A	No stormwater treatment from this approach.
Extended soil moisture retention		Soil additives can greatly improve soil moisture retention over time.
Connection to deep soils		Dependent on tree pit configuration.

	Brief description	Key design considerations
Other considerations		
Water source	Any water source	Soil additives are not impacted by the water source.
Ideal soil conditions	Any	An understanding of soil conditions is critical in determining the best soil additives for a given site.
Applicability to Greater Sydney	Applicable to all three cities	Soil additives may be used any soils.
Typical cost range	varies	
Key benefits / drivers for use	• Improve water holding capacity • Modify site soils to be more conducive to different tree species • Improve growth rate of trees	Additives may increase rate of growth of trees and increase resilience to harsh conditions such as drought. They may ensure soil is better able to hold moisture, and that plants are better able to access that water.
Key management implications / risks	• Excessive application of some additives may have adverse impacts • Ensure supplier directions are followed	Risks are dependent on the additives being used, but care must always be taken to consider adverse side effects and health risks in using materials.

4.13 Cost benefit of irrigated trees

The upfront capital costs of providing trees with some form of irrigation (whether it is active or passive) are usually higher than the costs of simply putting a tree in the ground. There is also a range of irrigation options which differ in terms of costs and benefits. It is important therefore to consider the long-term benefits of an irrigated tree to justify the upfront cost and confirm that an appropriate design solution has been adopted for the site. The selection of an appropriate solution for a site should consider the site context and what solutions or responses are most suitable.

A cost benefit analysis (CBA) can be undertaken on urban tree projects to assess both the costs and benefits of a proposed project. Metrics that may be considered include the total costs, total benefits and the ratio of benefits to costs (the benefit cost ratio) as well as quantified and described other benefits. Overall, the project should be designed to provide the optimal value for the community, balancing potential benefits and costs. This may mean that a higher cost solution may be adopted where the additional benefits justify the additional costs relative to a lower cost solution. Often this requires consideration of not just the economics but the intangible benefits (those benefits that cannot be monetarised) likely to be realised.

In the past it has been difficult to quantify many of the intangible benefits that urban trees can provide, such as cooling, amenity, ecological benefits etc. However, there are several new industry tools which are available to assist in determining monetary values for these benefits. These include:

- i-Tree - https://arboriculture.org.au/education/i-tree
- INFFEWS (Investment Framework For Economics of Water Sensitive cities) - https://watersensitivecities.org.au/research/our-research-focus-2016-2021/integrated-research/irp2-wp3/

Before undertaking a cost benefit assessment, it is important to define the 'with' and 'without' scenarios you are going to compare, understand the difference benefits and costs between the different scenarios and to define a timeframe for the assessment. Table 5 provides an example of 'with' and 'without' scenarios which could be assessed in a CBA.

Table 5 – Example scenarios which could be compared in a business case for tree irrigation

	Site conditions	'with-out' scenario Unirrigated tree	'with' scenario Irrigated tree
Option 1	Grassed verge with clay soils	Tree with no irrigation	Tree with passive irrigation from leaky pipe
Option 2	Grassed verge with sandy soils	Tree with no irrigation	Tree with passive irrigation from leaky pipe
Option 3	Road verge with pavement	Tree with no irrigation or structural cells	Tree with no structural soils and irrigation
Option 4	Road verge with pavement	Tree with no irrigation or structural cells	Tree with structural soils and irrigation

Tools such as INFFEWS also assign the costs and benefits to different stakeholders as well so it is important to identify them early in the assessment. In a cost benefit analysis, both costs and benefits should be discounted to present value levels using a discount rate appropriate for the relevant organisation and the analysis should consider a suitable time period such as 30 or 50 years. A full business case or economic assessment of a project is quite involved, and this is not expected for grant applications, however useful guidance on this is provided in the documents and tools referred to in the 'Further information'. The CRC for Water Sensitive Cities INFFEWS tool has a Rough CBA Tool which can used to conduct a quick and rough CBA based on a project. This tool has been developed to support practitioners and others who are interested in undertaking a first step towards a full CBA, and a test of whether a CBA is feasible. This tool can be found here': https://watersensitivecities.org.au/content/inffews-rough-bca-tool/.

Further information:

City of Yarra, 2018, Embedding Green Infrastructure Economic Framework - for developing a business case for a streetscape green infrastructure project, https://www.yarracity.vic.gov.au/about-us/sustainability-initiatives/embedding-green-infrastructure-toolkit#accordion-economic-framework

CRCWSC, INFFEWS Value and CBA Tools - for identifying benefits of green infrastructure https://watersensitivecities.org.au/content/inffews-value-tool/

CRCWSC, INFFEWS BCA Tools for undertaking cost benefit assessments https://watersensitivecities.org.au/research/our-research-focus-2016-2021/integrated-research/irp2-wp3/

Arboriculture Australia and US Forest Service, i-Tree Eco - is a suite of tools to better utilise, understand and communicate the values provided by urban trees. Arboriculture Australia with the support of industry partners worked with the U.S. Forest

4.13.1 Benefits

The provision of a water efficient solution for tree watering is likely to deliver a range of benefits. Some guidance on these and potential approaches to quantify these are provided in this section.

As a minimum, the availability of regular water to trees through any of the solutions identified (excluding water butts and soil moisture improvements) can be expected to:

- Increase canopy area by at least 50% for the same given soil volume
- Improve general tree health and capacity to cope with other stresses and thereby increase life span
- Provide some passive irrigation for the tree and correspondingly increase evapotranspiration as well as stormwater treatment and volume reduction.

Table 6 provides an example of the different benefits which could be attributed to the different example options. This shows that the same design in different locations could have different cost / benefit outcomes due to the likelihood of the design improving the overall tree health. It also shows that more expensive solutions (such as the inclusion of structural cells) could have long term benefits due to the reduced risk of pavement repairs etc. Table 7 presents a summary of the different benefits which can typically be attributed to designs which include the provision of water and / or increased soil volume for street trees.

Table 6 – Summary of the different benefits which could be attributed to the example options (From Table 5)

Benefit	Without scenario	With scenario			
	All – Tree with no irrigation or structural cells	Grassed verge		Verge with pavement	
		Option 1 – tree with passive irrigation from leaky pipe in clay soils	Option 2 – tree with passive irrigation from leaky pipe in sandy soils	Option 3 – Tree with passive irrigation	Option 4 – tree with passive irrigation and structural soils
Pavement repairs	N/A	N/A	N/A	Likely to still require pavement repairs	$$ benefit • The inclusion of structural cells will reduce the need for future pavement repairs
Tree lifespan	N/A	No underdrainage in clay soils could increase the risk of waterlogging and impact tree health	$$ benefit The availability of water increases the lifespan of trees	$$ benefit The availability of water increases the lifespan of trees	$$ benefit The availability of water increases the lifespan of trees
Property value	N/A	No underdrainage in clay soils could increase the risk of waterlogging and impact tree health	$$ benefit The availability of water increases the canopy area and lifespan of trees	$$ benefit The availability of water increases the canopy area and lifespan of trees	$$ benefit The availability of water and greater soil volumes increases the canopy area and lifespan of trees
Stormwater pollution removal	N/A	$$ benefit Using stormwater for irrigation reduces the amount of pollutants entering waterways	$$ benefit Using stormwater for irrigation reduces the amount of pollutants entering waterways	$$ benefit Using stormwater for irrigation reduces the amount of pollutants entering waterways	$$ benefit Using stormwater for irrigation reduces the amount of pollutants entering waterways
Improved air quality / carbon capture and storage	N/A	$$ benefit Increased canopy cover due to water availability will improve carbon capture etc.	$$ benefit Increased canopy cover due to water availability will improve carbon capture etc.	$$ benefit Increased canopy cover due to water availability will improve carbon capture etc.	$$ benefit Increased canopy cover due to water availability will improve carbon capture etc.

Table 7 – Example benefits which can be attributed to increased water and soil volume for street trees

Benefit	Description	Monetary value
Potable water savings	Using alternative water to irrigate trees can offset the requirement for potable water used for irrigation. This is more relevant for passive irrigation with stormwater which is free rather than if the alternative water sources also incur a cost (e.g. recycled water).	Annual benefit value = (current cost of potable water ($2.08) – cost of alternative water) x annual amount of alternative water used by the tree (Can be estimated using MUSIC by Engineers)
Pavement repairs	When trees have limited access to water (especially tree pits surrounded by compacted soils) they tend to seek it immediately below pavements where oxygen and water are present. When trees have ready access to water and oxygen, they are less likely to seek out water aggressively and will tend to have less impacts on surrounding pavements. Observation of trees with surrounding permeable pavement and structural soils in Melbourne by E2Designlab as well as research into structural soils by Cornell University (Bassuk et al, 2015) indicates that trees with adequate access to water and soil in structural soils have no or minimal uplift impacts on surrounding pavements.	Benefit value = expected pavement repairs for typical street trees. This can be based on current allocations to kerb and pavement repairs and numbers. As an indication, the City of Ballarat tentatively estimated this at $1,400 per tree over its life cycle (E2Designlab, 2015).
Longer tree lifespan	Trees that regularly receive water and have access to soil areas and volumes that support their potential canopy growth have an estimated life expectancy of as much as 50 years, relative to a typical urban tree which may average just 13 years.	Benefit value = the value of replacing an average tree every 50 years rather than every 13 years (e.g. $550-$900 per tree replaced)
	Besides the financial implications, older trees grow larger, the larger canopy is retained for a longer period and the ecological and habitat values are improved significantly.	Benefit value = economic value difference between the size of a mature tree and a juvenile tree can be determined using tools such as the City of Melbourne Guidelines for Valuing a Tree.
Property value	There has been quite a bit of research undertaken which shows the economic benefit street trees provide for property value. Several researchers have evaluated the potential property uplift value that may result from increasing canopy cover in streets. These benefits have been shown to occur in both residential and commercial areas.	Benefit value = expected property value uplift (e.g. a 10% percent increase in the size of the canopy across Blacktown showed an increase in the value of property of 7.7 percent, or $55,000 for the average house (AECOM, 2017).
Stormwater pollution removal	Where stormwater is used to irrigate trees, it reduces the volume of stormwater excess discharged to waterways as well as filtering a range of pollutants including sediment, nutrients and heavy metals in stormwater. This offsets the need for such treatment to be provided elsewhere, retains water in the landscape and leads to healthier waterways.	Benefit value = the equivalent cost of a stormwater treatment system to achieve the same pollution removal achieved in the tree pits (this can be determined by a drainage engineer)
Improved air quality / carbon capture and storage	Poor air quality is a common problem in many urban areas. Increased tree canopies contribute to the direct removal of pollutants from the air. They can reduce energy consumption in buildings through shading which consequently reduces carbon dioxide emissions from fossil-fuel based power sources. Carbon storage is another way trees can influence global climate change. As a tree grows, it stores carbon within its accumulated tissue. The amount of carbon stored or 'sequestered' annually increases with the size and health of the trees.	Benefit value = i-Tree-Eco can estimate the net annual benefit in dollars of carbon storage, carbon sequestration and air pollution removal for different trees (based on height, canopy etc)
Reduced urban heat	Shade can have a dramatic impact on the cooling of our urban areas. The retention of soil moisture water in the landscape also cools surface and air temperatures (e.g. irrigated grass is much cooler than unirrigated grass). The benefits can be hard to quantify, especially those attributed to the GI asset aspects of the design contributing to potentially larger/healthier canopies compared to a standard street tree.	Benefit = this is a harder benefit to put a monetary value against. The CRCWSC Value tool identifies a CPI Ratio = 1.08 which can be attributed to the reduction in land surface temperature due to an increase in tree cover by 10% when vegetation cover is greater than 40% of total area in the Sydney Basin (NSW Office of Environment and Heritage, 2015).
Improved physical and mental health	Green spaces in our cities are important to the physical and mental health of the community. These benefits are difficult to quantify, especially in regard to the proportion of improved community physical or mental health that are attributed to the GI asset aspects of the design contributing to potentially larger/healthier canopies compared to a standard street tree.	Benefit value = this is a harder benefit to put a monetary value against. The CRCWSC Value tool identifies CPI Ratios for physical and mental health based on a study which found a person who perceives their neighbourhood to be green has 1.37 times higher odds of better physical health and 1.6 times higher odds of better mental health (Sugiyama etc al, 2008).

4.13.1 Costs

The typical costs, suitable places to use each of the potential solutions and some indicative main benefits are identified in Table 8 to assist with consideration of the relative costs and benefits of alternative solutions. This recognises that different solutions will be more relevant or applicable in different settings and that there is flexibility for different choices to be made depending on the site context as well as the level of outcomes sought by the proponent and their community. It is important to recognise that costs are also highly dependent upon the site context and complementary works. Specific site features and constraints such as underground services and working next to a busy roadway requiring traffic management can add considerably to costs while construction of assets during another road project such as kerb and channel renewal can significantly improve cost efficiency.

Table 8 - Typical costs, application and benefits

Water efficient solution	Potential capital cost range / tree[1]	Maintenance and operational cost range (Annual)	When to use	Main benefits	Canopy area increase over conventional tree with limited soil volume and no watering	Potential saving in pavement repairs	Stormwater treatment
Leaky pipe around tree	$500-$1,200[2]		Low density streets Tree surrounded by uncompacted soils (>20m^2) Low cost a priority	Regular source of water to tree Water allows moderate increase in canopy cover	50%+	-	Small benefit
Below ground infiltration trench or well	$500-$1,500[3]	Not maintainable	Low density streets Tree surrounded by uncompacted soils (>20m^2) Low cost a priority	Regular source of water to tree Water allows moderate increase in canopy cover	50%+	-	Small benefit
Sunken raingarden with trees - open	$2,000 - $10,000[4]	$150 - $300[5]	Kerb bump outs or wide nature strip Stormwater treatment and raingarden desirable for site (adjacent existing or proposed side entry pit)	Regular source of water to tree Water and large soil volume allows large increase in canopy cover Vegetation maintains infiltration and greater amenity	200%+	$1,400	Large benefit
Sunken tree pit - open	$2,000 - $10,000	$150 - $500[5]	Wide nature strip or between parking	Regular source of water to tree Water and large soil volume allows large increase in canopy cover	200%+	-	Moderate / large benefit
Sunken tree pit - grated	$3,000 - $15,000[5]	$150 - $500[5]	Shopping strips and high traffic/high value areas, narrow nature strips Covered or grated tree pit required regardless of water solution	Regular source of water to tree Water allows moderate increase in canopy cover Grate allows trafficability	50%+	-	Moderate / large benefit
Below ground storage	$1,000-$3,000 additional	Not required	Dryer climate (Western Sydney) Areas where trucking water in dry spells difficult or unlikely	Ensures water availability in longer dry spells Improved canopy cover and tree health	10-20% in dry climate (Western Sydney)[8]	-	Slightly increased benefit overall large benefit when included in sunken tree pits / raingardens
Permeable pavements	$1,000-$1,500[6]	$50-$70	Trees with limited access to uncompacted soils Higher value areas justifying increased investment in larger canopy trees, flood mitigation and stormwater management Car parking - especially where cost of losing a parking space for a tree exceeds cost of permeable paving and structural soil Generally combined with structural soils to provide water storage	Broadly and evenly distributes inflows to underlying soils	200%+	-	Moderate benefit
Structural soils Structural cells	$5,000 - $8,000 (soils)[7] $5,000-$25,000 (cells)	N/A	Trees with limited access to uncompacted soils Higher value areas justifying increased investment in larger canopy trees, flood mitigation and stormwater management Car parking Adjacent to constrained tree pits or beneath permeable pavements	Water and increased soil volume allows large increase in canopy cover	200%+	$1,400	Moderate benefit
Irrigation scheduling technology	$5,000-$20,000		Parks and some high value streetscapes Where reticulated recycled water available	Ensures water used is applied efficiently	Unknown	-	N/A

Water efficient solution	Potential capital cost range / tree[1]	Maintenance and operational cost range (Annual)	When to use	Main benefits	Canopy area increase over conventional tree with limited soil volume and no watering	Potential saving in pavement repairs	Stormwater treatment
Drip irrigation	Varies		Parks and some high value streetscapes Where reticulated recycled water available	Delivers water directly to tree roots	50%+	-	N/A
Water wells and butts	$50-$400[8]	$1,200**	Drought and dry spell response for trees with limited access to water	Allows short term response to support trees on as needed basis	Minimal	-	N/A
Soil moisture retention improvements	Varies	N/A	All new trees where soil conditions warrant amendment	Improves soil moisture retention and tree access to water for longer periods in some soils	Minimal	-	N/A

1. Assumes tree pits are 10m^2. These costs are estimated ranges only and are based on best available data and experience gathered through built projects. These costs will vary depending on site conditions and scale. For example, a single tree pit retrofitted in a high use street with multiple services would be more expensive than multiple trees being delivered in areas which require minimal traffic control.
2. Based on WbD case study indicative costs ($1,200 per tree, aim to reduce to as low as $400 per tree)
3. Based on limited data from Kingswood St, City of Mitcham, Adelaide
4. Based on rates from Melbourne Water (2013) Water Sensitive Urban design life cycle costing data as well as experience more recently in built projects
5. Based on limited data from systems built in City of Port Phillip
6. Estimated based on City of Yarra Embedding Green Infrastructure Guidelines (E2Designlab, 2018), Kingston St (E2Designlab, 2020)
7. Estimated based on City of Yarra Embedding Green Infrastructure Guidelines (E2Designlab, 2018).
8. Based on limited data from City of Port Phillip
8. Indicative based on understanding that growth rates will be sustained more effectively during dry periods
9. Estimated cost to provide tanker water to fill wells and butts

5. Key messages

In urban environments, the conditions are commonly harsh for trees with reduced available soil volumes due to compaction and underground services, less infiltration of water into soils due to impervious surfaces and reflected heat from roads, buildings and pavements.

Coupled with increasing climatic variability, means all but the most drought tolerant and hardy native species will need some form of ongoing and/or supplementary irrigation to thrive and reach their full potential canopy cover. Hence consideration of water supplies and how to get that water to trees should be a key component in the planning and design of urban tree canopy projects.

With growing pressures on potable water supplies due to population growth and climatic variability, it is recognised that relying entirely on potable water for irrigation of trees is not sustainable nor necessary. Use of recycled water and stormwater for tree irrigation conserves mains drinking water supplies.

There are a range of water efficient approaches available, as outlined in this report, and embedding these approaches into the planning and delivery of urban tree canopy projects will help deliver a greener and cooler Greater Sydney faster. These water efficient approaches also give confidence that public investments into tree canopy projects, such as 5MT, will result in successful, healthy tree outcomes.

Whilst the rainfall and climate varies across Greater Sydney, many water efficient approaches, such as irrigation with stormwater, are available everywhere. The detail around the delivery of the water efficient approaches may vary in response to specific site conditions. For example, in Western Sydney where clay soils (both dispersive and sodic) are common, a focus on ensuring drainage of tree pits to avoid water logging during the wetter months will be important. In Sydney coastal areas and the Blue Mountains where sandy soils are common, ensuring water holding capacity and access to back-up water supplies (e.g. deep soil moisture) will be a focus.

The following key outcomes would help to progress the adoption and delivery of water efficient trees across the Greater Sydney area:

- **Improved understanding of water efficient solutions** – Water and landscape have typically been designed in isolation. The integrated planning and design of these elements together will help to deliver cost effective street trees which have ongoing resilience to the harsh urban conditions with the provision of adequate soil and water. Building the capacity of both the landscape and civil engineering industry on these integrated water efficient solutions for trees will be critical.

- **Continued support of new tree projects which are resilient –** The 5M trees program is a great initiative to support the future greening of Greater Sydney. The incorporation of requirements in the grant program to ensure the trees have suitable soil and water provisions will help to ensure this investment delivers the intended canopy cover outcomes. It will be important to ensure that capacity building is undertaken as well to ensure that these requirements can be well understood and applied.
- **Integrated planning of alternative water supplies –** To allow for the cost effective use of alternative water such as recycled water and stormwater, there needs to be appropriate planning to inform where this alternative water might be needed and the quality requirements of this water. This integrated planning will enable tree projects to capitalise on broader initiatives that may be servicing new develops or buildings.
- **Best practice tree design and planting approaches** - Most Councils have streetscape and street tree guidelines. These can typically be updated more easily than planning schemes. While these don't have the same 'teeth' as planning schemes to enforce uptake of water efficient tree pit design, they can provide useful information to guide the design of these systems to ensure they have suitable soil and water provision for the tree.
- **Updates to planning documents** – Planning schemes and policies can effectively protect and promote greening across Greater Sydney by protecting existing trees and promoting the uptake of new water efficient tree projects by setting minimum requirements.

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