Designing for a cool city

Guidelines for passively irrigated landscapes

CRC for
Water Sensitive Cities

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Designing for a cool city
Guidelines for passively irrigated landscapes

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Introduction

An introduction to passively irrigated landscapes

Designing for a cool city is focused on increasing soil moisture and healthy vegetation to help reduce urban heat through evapotranspiration and shade. The diversion of stormwater into vegetated systems can improve the health of plants and trees, while turning stormwater from a nuisance into a valuable resource. This is called passive irrigation as the approach uses gravity to get water to where it is needed to irrigate vegetation and rehydrate our landscapes. This helps to sustain plants during dry weather, by providing access to soil moisture stores, and provides for lusher and cooler urban forms. The use of stormwater for irrigation of landscapes can also reduce stormwater pollution and discharge volumes and thus help protect downstream environments, such as our waterways and bays, from the impacts of urbanisation.

Purpose

This guideline has been developed to introduce passively irrigated landscapes and their role and function in Australian urban landscapes. Design approaches are presented for utilising stormwater to achieve healthier trees, turf and gardens for multiple benefits including cooler cities. The intent is to increase industry awareness of these approaches, help identify opportunities for incorporating passively irrigated landscapes and to increase the capacity of the industry to successfully deliver these systems nationally.

The guideline provides high level advice on how these systems can be designed to integrate within different streetscapes and settings and key considerations for design, construction and maintenance. The guideline is not intended to provide detailed design information or standard engineering drawings; rather it is intended to introduce the concepts and key considerations for successful delivery.

Scope and audience

This guideline can be used to inform the design of passively irrigated landscapes on private and public lands for both new (greenfield) and existing (retrofit) development types. It should be noted however that the retrofit of passively irrigated systems in existing development areas is typically more complicated and costly due to the presence of existing services etc.

The focus of this guideline is providing advice on the design of passively irrigated:

- street trees
- garden beds, and
- turfed areas.

It is intended that this guideline can be used by:

- Landscape architects
- Urban designers and planners
- WSUD specialists
- Civil engineers
- Road designers
- Local government authorities.

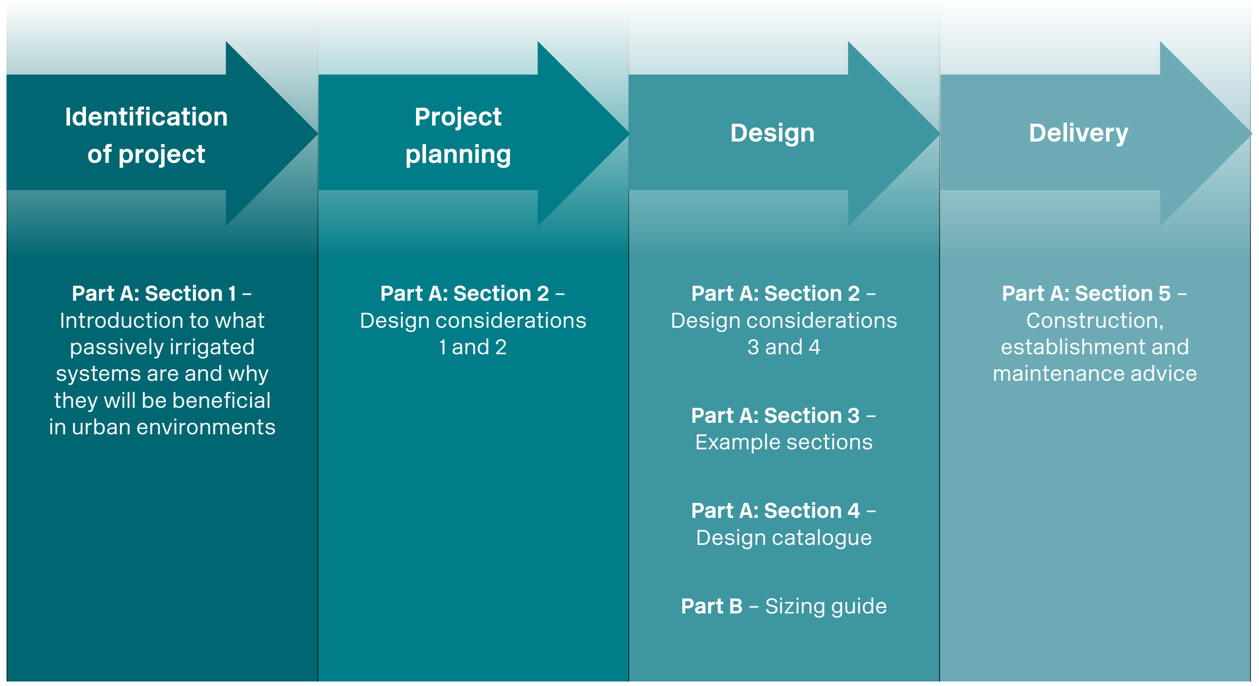
Document structure and how to use it

This guideline has been developed as two parts:

- Part A: Designing for a Cool City – Guidelines for passively irrigated landscapes
- Part B: Designing for a Cool City – Climatic zone sizing guides for passively irrigated trees.

Part A aims to assist users to include passively irrigated landscape features (i.e. street trees and wicking lawns) in the urban design process. It can help guide the early identification of projects through to concept design.

Part B provides additional information on the soil moisture modelling of tree pits and provides tree pit sizing guides for areas across Australia where this modelling has been undertaken.



Key terms

Infiltration pit / trench – a reservoir that is designed to capture stormwater which can then infiltrate into the surrounding soils. This is typically located at the side of the planting media and can contain gravel or other materials that provides suitable storage volume.

Passive irrigation – irrigation of landscapes without the use of energy (e.g. no pumps). This typically involves using gravity to direct rainfall runoff from adjacent surfaces onto vegetation or into reservoirs below or beside the planting media.

Planting media – soil that is of suitable quality to support the intended landscape (i.e. tree, playing fields etc)

Saturated hydraulic conductivity – ease with which pores of a saturated soil permit water movement

Storage zone – an area designed to capture water using gravity so that it can soak into the planting media via infiltration or capillary rise to support a vegetated landscape

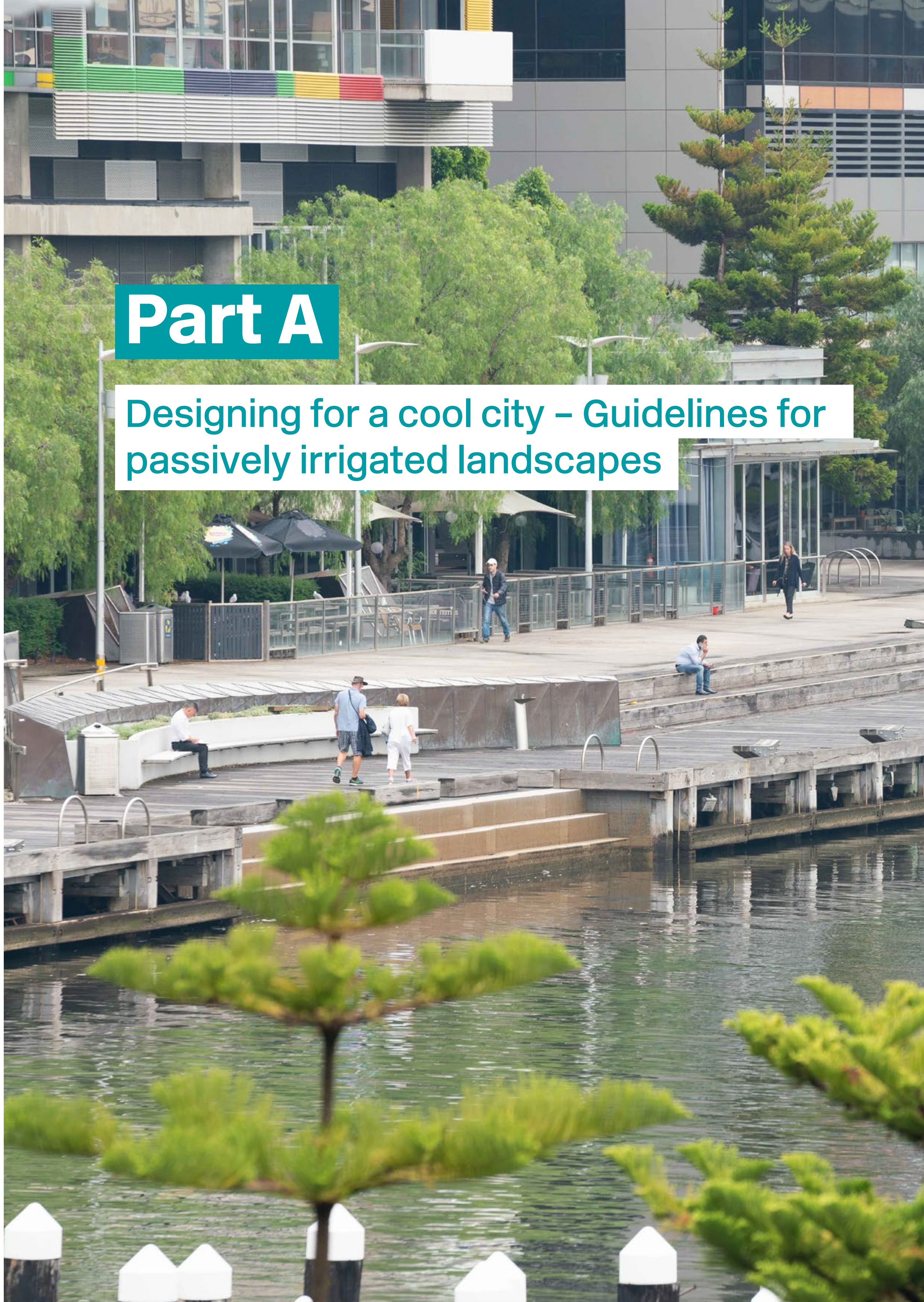
Stormwater – rainwater that runs off surfaces such as roofs and roads

Stormwater network – this includes stormwater pits and pipes which help to convey stormwater in an underground trunk drainage system through a development area

Surface area to catchment area ratio – the area of catchment from which runoff is generated compared with the surface area of the tree pit or wicking system

Tree pit - usually refers to the area of unsealed surface designed into or left open in a pavement for tree planting (typically the default minimum is just larger than the pot the tree arrives in). 'Designed' tree pits typically restrict growth in one or more directions. In the urban context the pit may represent the whole of the volume available for root growth.

Wicking zone – a reservoir of water below the planting media from which water is drawn upwards like a wick to the soil layer above to support a landscaped area (turfed open space or garden bed)



Part A

Designing for a cool city – Guidelines for passively irrigated landscapes

Section 1

Passively irrigated systems in a cool city

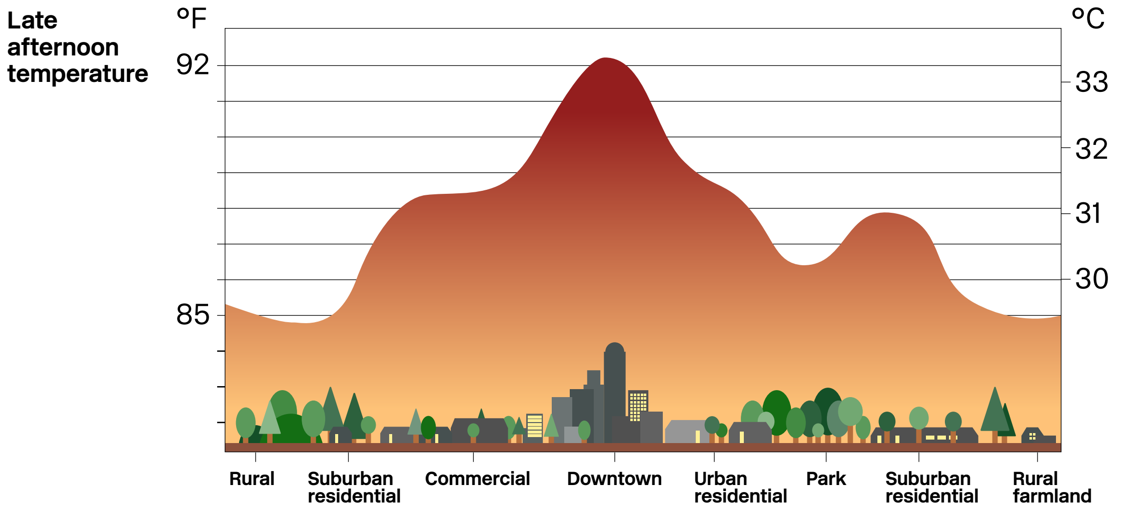
Why is cooling important?

Hard, impervious surfaces that commonly make up a city absorb more solar radiation than vegetated areas. This solar radiation is then released into the atmosphere and environment slowly overnight creating an urban heat island (UHI) effect, where the city environment is hotter than the surrounding vegetated areas (see Figure 1).

↓

Figure 1 – Urban Heat Island effect shown as higher temperature over impervious areas when compared with surrounding vegetated areas

(source: http://article.sciencepublishinggroup.com/html/10.11648.j.ijepp.20160403.16.html)



Research has shown that these high urban temperatures can increase the risk of heat related illnesses and mortality in cities (Nicholls et al., 2008). Recent research by the CRC for Water Sensitive Cities (CRCWSC) has also shown that the urban heat island impacts are enhanced during heat waves (Rogers, Gallant and Tapper, 2017). Given that heatwaves kill many more people in Australian cities than any other natural hazard (Australian Government, 2013), and this risk is likely to increase with our warming climate (Figure 2), it is important that we design our cities to be cooler.

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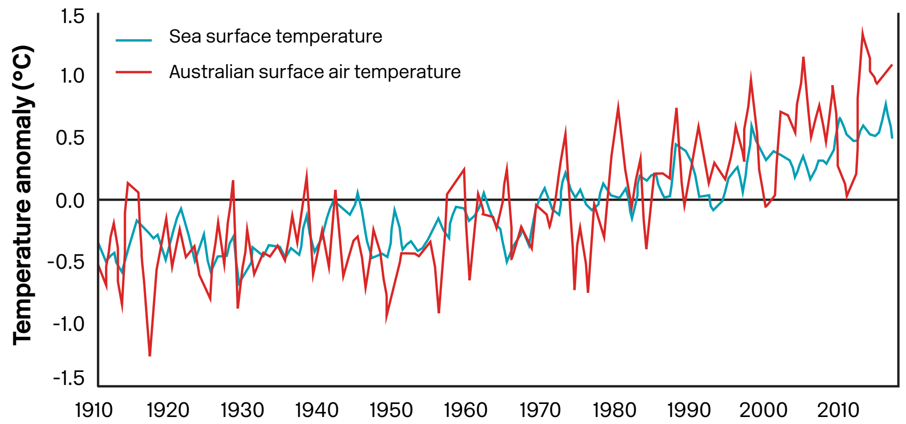
Figure 2 – Rising surface air temperatures in Australia (source: *CSIRO and Bureau of Meteorology*)



How can landscapes help cool cities?

Hard, paved ground surfaces and buildings in the city absorb and store heat during the day which is re-emitted at night. Increasing the vegetation cover and permeable soil surfaces in cities provides shade and thermal insulation which reduces the amount of heat absorbed and released by the hard surfaces, thereby cooling the cities during the day and overnight.

Trees and other green landscapes (commonly referred to as green infrastructure) can help to cool city environments and improve thermal comfort throughout the day by providing shade, evapotranspiration and cooling of the local surface. These processes can also reduce the air temperatures in the local area (Figure 3).

Irrigating these landscapes will help to improve the effect these areas have on cooling the local environment throughout the day as the addition of water will improve the health of the vegetation (more shade and evapotranspiration) and increase the soil moisture levels.

Shade:

- Shading helps to keep cities cooler and maintain human comfort on sunny days.
- Trees can intercept the majority of the sun's energy, reflecting some, and absorbing some for photosynthesis.
- Trees need to have healthy canopies which are actively transpiring to provide the best cooling outcomes.
- Adequate soil volume and soil moisture can result in double the growth rate of trees, increase the canopy cover by 8-10 times the original coverage and increase the lifespan of the tree from 13 to 50 years. [1]
- Tree canopies can reduce the temperature of surfaces they shade (e.g. buildings, roads) by 10 -25°C.

Evapotranspiration:

- The conversion of liquid to gas uses heat and reduces the temperature of the air and the tree/soil that stored that heat.
- Plants and soil must have access to water to enable cooling by evapotranspiration, otherwise heat is released slowly as sensible heat through conduction and convection.
- Evapotranspirational cooling benefits will be greatest in temperate climates.

Soil moisture:

- Increased soil moisture levels can reduce land surface radiative temperatures during the day (see Figure 4). These reduced surface temperatures will also lead to lower air temperatures (Coutts et al., 2014).
- 10% increase in vegetation cover can result in up to a 1.3°C reduction in land surface temperature (Coutts et al., 2016 and Klok et al., 2012).

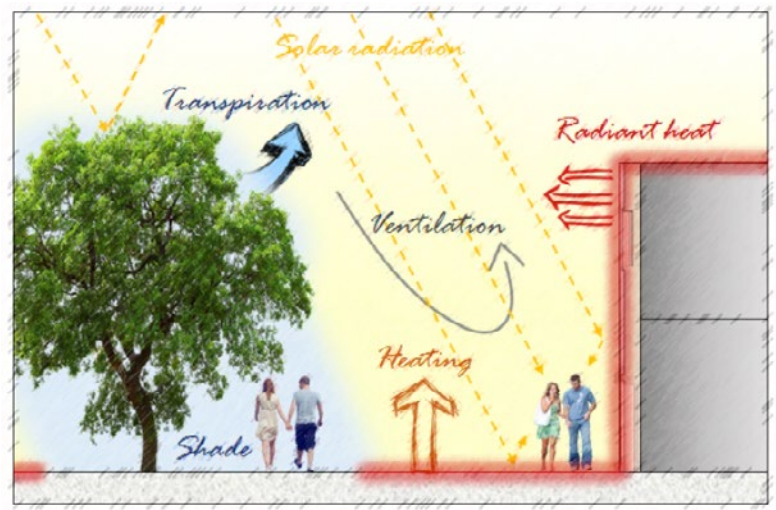


Figure 3: Trees block (e.g. absorb and reflect) solar radiation and shade urban surfaces. Cool surfaces, such as ground surfaces below trees, emit less radiant heat than hot surfaces. Trees also transpire meaning less energy is used in heating the air.

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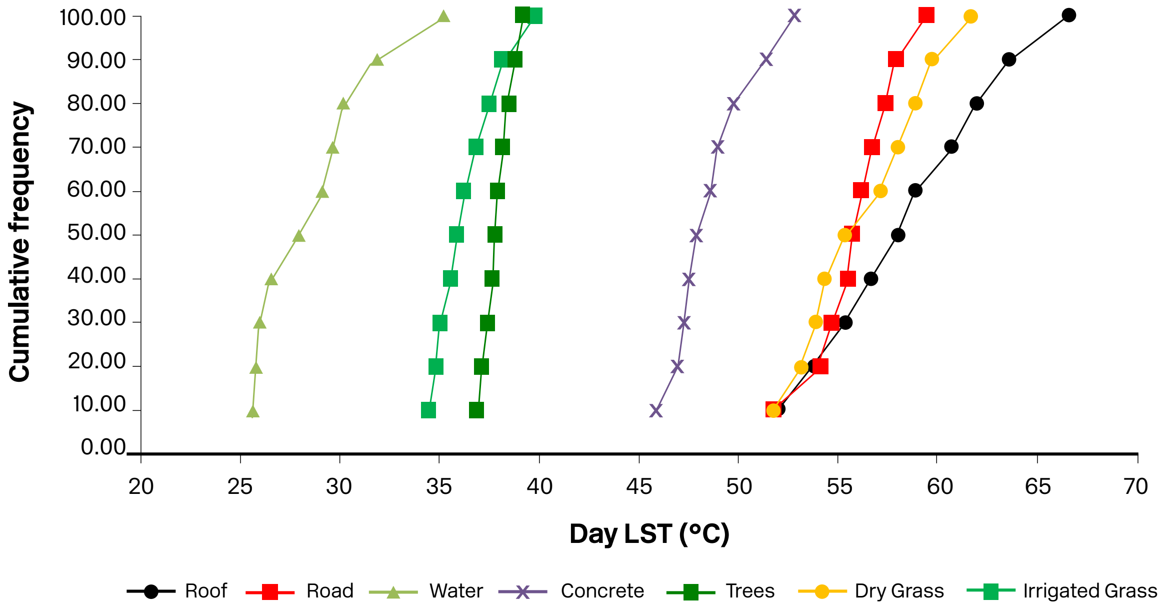
[1] Double the growth rate (Grey, V. et.al 2018), Canopy 8-10x larger (Hitchmough, J. 1994), Increased lifespan from 13 to 50 years (Skiera, B. and G. Moll. 1992).

Figure 4 – Temperature of dry grass can be as hot as road surfaces on extreme heat days while irrigated grass can be as cool as trees (CRCWSC)



Available water sources

There are a number of water sources which could be used to help cool the urban environment including potable (drinking) water, stormwater, roofwater and recycled wastewater. The water quality, reliability and cost of these water sources differs, and this may influence the use of them for irrigation for different urban landscapes.

This guideline focuses on runoff associated with rain events (roofwater / stormwater) as the preferred water source because it can be easily directly to landscapes for passive irrigation in our city environments and provides multiple benefits:

- It is a locally available low-cost and no-energy water source.
- Using it for irrigation can support cooler, healthier and more liveable city landscapes.
- It helps to protect receiving environments from the impacts of stormwater runoff by improving water quality and reducing the volume and speed of the flows.

This guideline will refer to rainfall runoff as stormwater because it is assumed that these passively irrigated landscapes may capture runoff from both roofs and ground level surfaces.

Air-conditioning condensate may offer another potential water source for sustaining urban landscapes and for 'topping up' subsurface wicking zones. Constant inflows to the surface of tree pits is not advised because moss and algae might grow, clogging the surface. Where recycled water is available, this may provide a suitable back up water source to supplement the stormwater supply to tree pits and wicking beds. The energy requirements of treating and delivering recycled water for irrigation purposes needs to be fully considered as part of feasibility assessments.

How does passive irrigation work?

Passive irrigation systems use gravity to direct stormwater from adjacent surfaces into the vegetated system. Water can be directed to these landscapes either at the surface (where water infiltrates vertically down through the soil) or through subsurface systems which can recharge soil moisture at depth where it can be accessed by plant roots (see Figure 5).

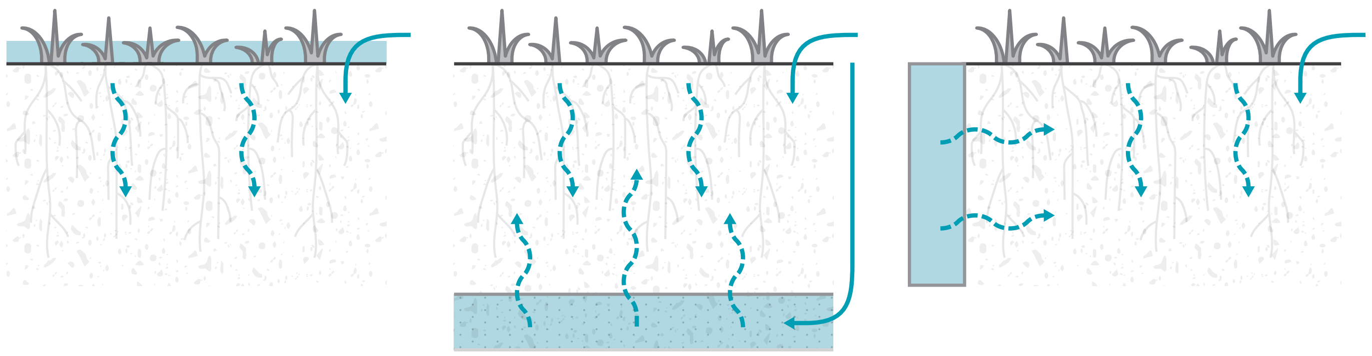


Figure 5 – Passively irrigated landscapes are irrigated using gravity fed stormwater which can be delivered at the surface, the base or adjacent to the soil. Surface irrigation (left) infiltrates the soil from above, while subsurface irrigation can be designed to improve soil moisture through capillary rise (centre) or lateral movement (right).

Types of passively irrigated systems

There are many types of passively irrigated systems, including commonly used water sensitive urban design (WSUD) assets such as bioretention, swales and wetlands which are vegetated systems designed to capture and treat stormwater. There are many technical guidelines which focus on these assets and they are therefore not included in this document. There are also many ways in which passive watering can be encouraged across the landscape by enhancing the amount of vegetated areas which have water directed to them (e.g. parks as detention areas or leaky tanks next to gardens). The focus of this guideline is providing advice on the design of passively irrigated street trees and wicking lawns.

Self-watered street trees / garden beds:

Street trees and garden beds are typically planted into the verge or in street bump outs / kerb blisters, into soils which have often become compacted due to the land uses and hard surfaces around them. Having a limited volume of good quality soil negatively impacts the growth and canopy cover of the tree in adulthood (Figure 6). Similarly, in urban environments where there are surrounding impervious surfaces such as roads and pavement, there is limited opportunity for rainfall to penetrate soils and replenish soil moisture. Street trees are also typically disconnected from local water sources by the kerb and channel. Many street trees in urban areas therefore have stunted growth and never reach their full canopy potential. Passively irrigated trees can overcome this challenge by redirecting urban stormwater runoff to infiltrate into a volume of soil that is appropriately sized to nurture a healthy tree.

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Figure 6 – Comparison of tree growth and canopy cover of trees planted in conventional tree pits (right - with limited soil volume) and stratacell tree pits (left - with adequate soil volume) in a car park in Belment, Western Australia

(http://citygreen.com/case-studies/belmont-city-forster-car-park/)

Trees planted using Citygreen soil vault after 4 years.

Trees planted conventionally after 15 years.

Wicking lawns:

Wicking lawns are vegetated systems (turf open space, sportsfield or vegetated garden bed) with a subsurface reservoir, or storage zone, that allows for water to wick up into the soil profile (Figure 7). This function is provided by the natural process of capillary rise, driven by evapotranspiration, to draw water reserves from the reservoir to the active root zone. The design depth and composition of the wicking layer is governed by capillary rise distance and storage volume. This enhanced moisture storage capacity extends the period of time that water is available to sustain healthy plants. Excess flows, greater than the storage capacity of the wicking layer, overflow at the top of the wicking layer to avoid saturation of the topsoil.

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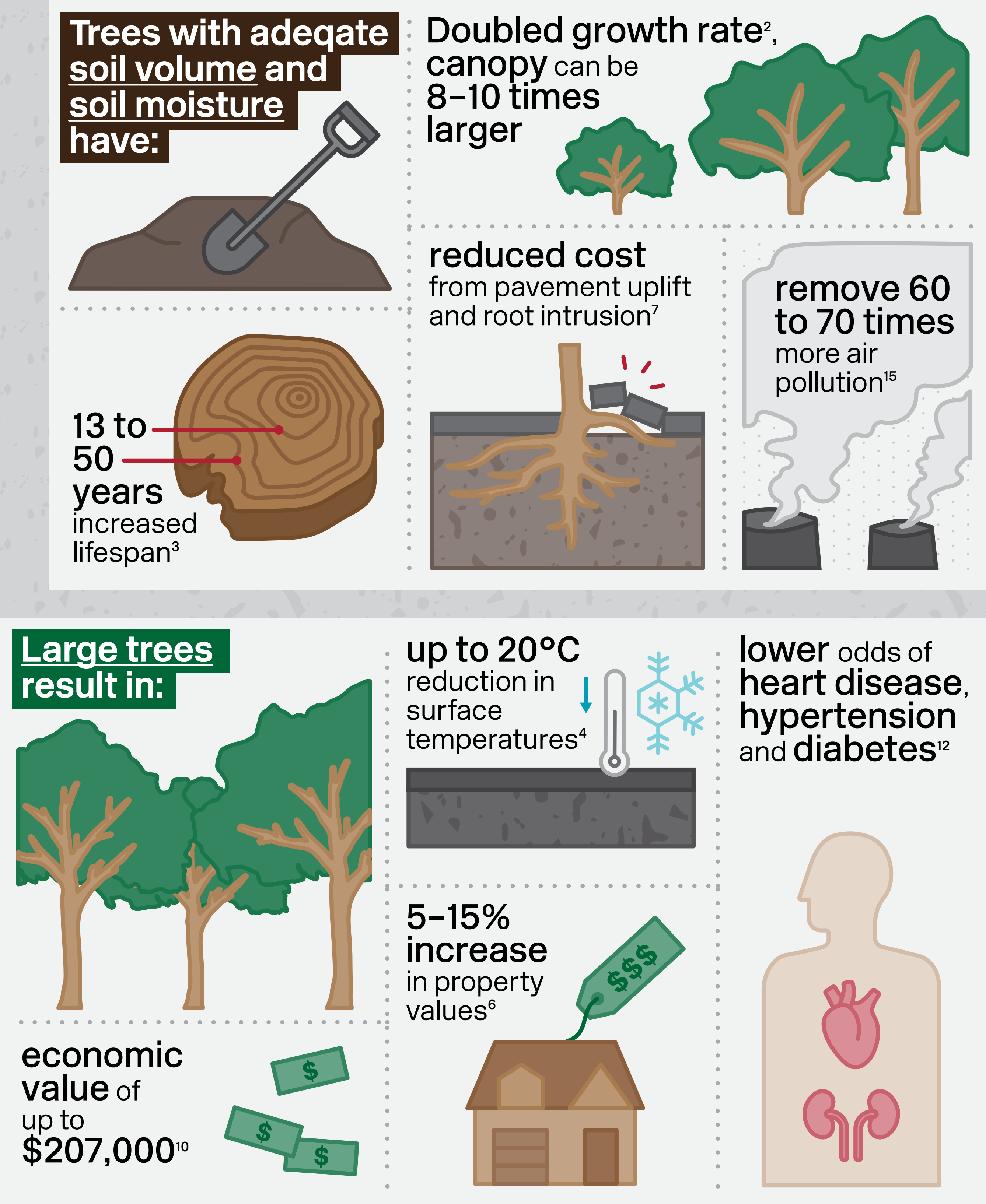
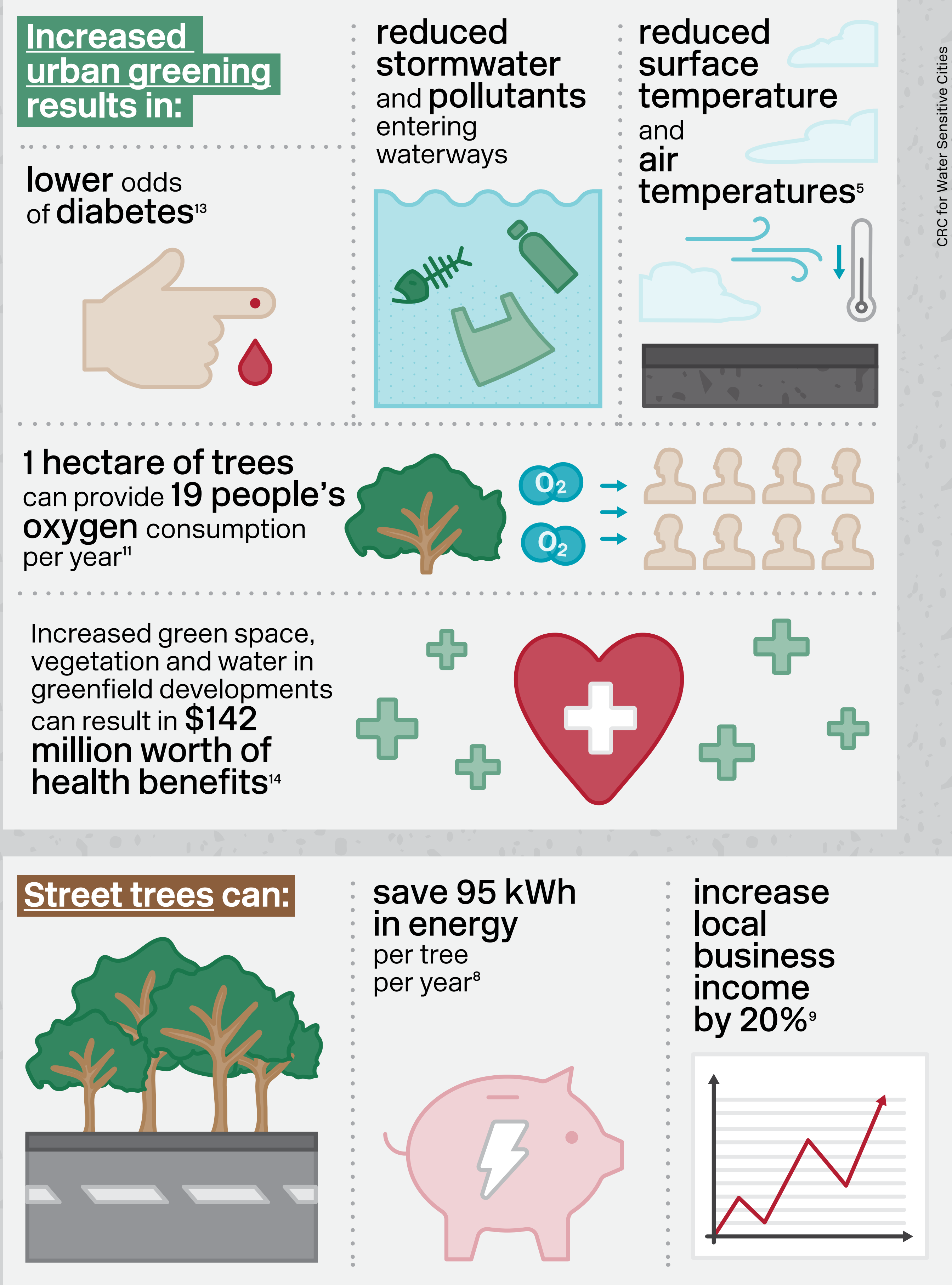
Figure 7 – Installation of drainage system for wicking lawn (top) and finished wicking lawn profile (bottom) at Gladstone East Shores Parkland. (photo credits: E2Designlab)

Benefits of passively irrigated systems

The combination of vegetation and water in the city landscape using passive irrigation provides many benefits. These benefits are shown in Figure 8.

↓ Figure 8 — Benefits of passively irrigated systems in the city landscape





1. Grey et al. 2018
2. Hitchmough 1994
3. Skiera & Moll 1992
4. CRCWSC 2019
5. Coutts et al. 2016; Klok et al. 2012
6. Pandit et al. 2013
7. Boer & Browne 2017; E2Designlab
8. McPherson 2005
9. Burden 2006
10. City of Melbourne; The valuation in the City of Melbourne
11. Nowak et al. 2007
12. Astell-Burt & Feng 2019 (Odds of incident heart disease (odds ratio 0·78), hypertension (0·83) and diabetes (0·69) were lower among people with ≥30% tree canopy, compared to 0–9% tree canopy).
13. Astell-Burt & Feng 2019 (Total green space ≥30% compared to 0–4% was associated with lower odds of prevalent diabetes (0·72).
14. Frontier Economics 2019
15. McPherson et al, 1994

Section 2

Design

Design characteristics of self-watered landscapes for a cool city

Well designed self-watered landscapes successfully achieve the following key principles:

1. **Harvesting water** = Water must be able to get into the landscape passively (without the use of energy).
2. **Improved soil moisture** = There must be an ability for the landscape to soak water into the soil media (either from a surface or subsurface storage volume). This should ensure that an aerobic zone is always provided for the tree (e.g. ensure the top 400-500 mm of soil is free draining in all circumstances).
3. **Creating room to grow** = There should be adequate soil volume and soil quality to support the intended landscape.

These design principles need to be considered early in the design process as the location, size and spacing of systems will have an influence on the amount of water they receive and thus soil moisture.

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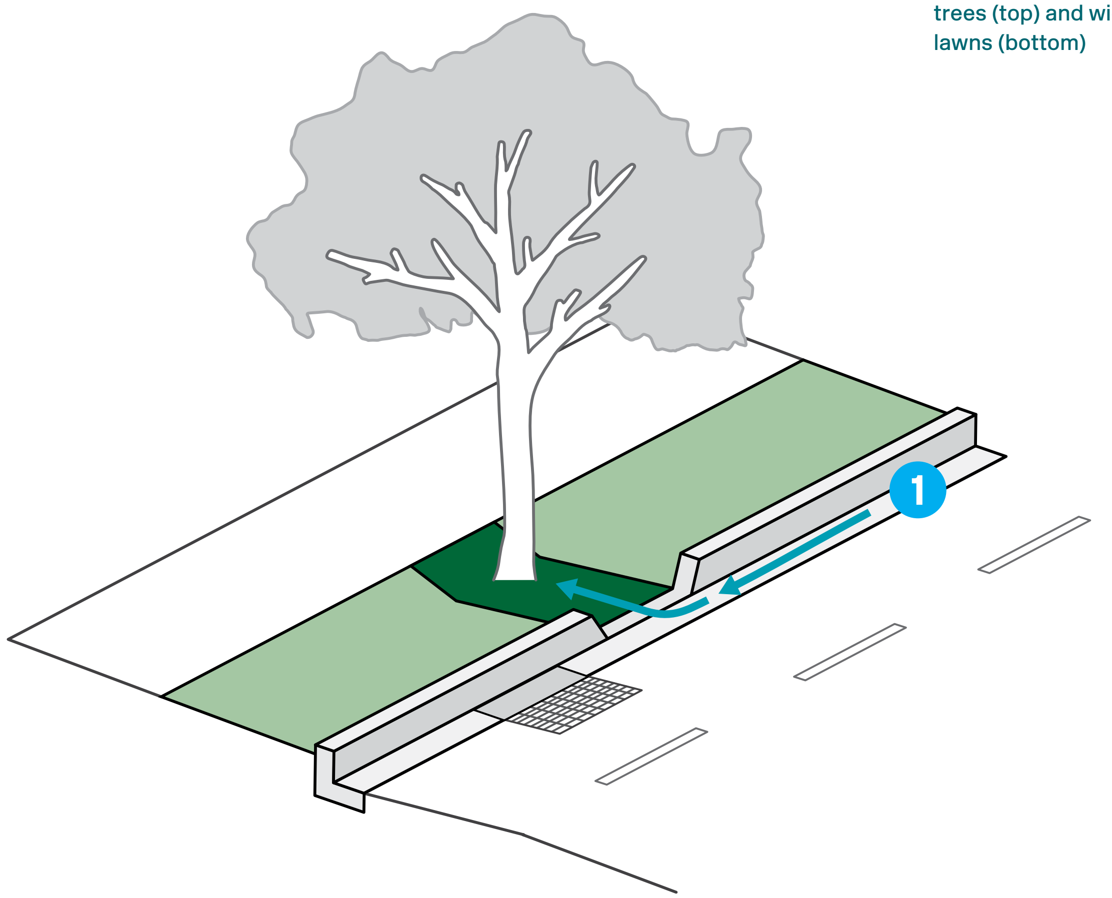
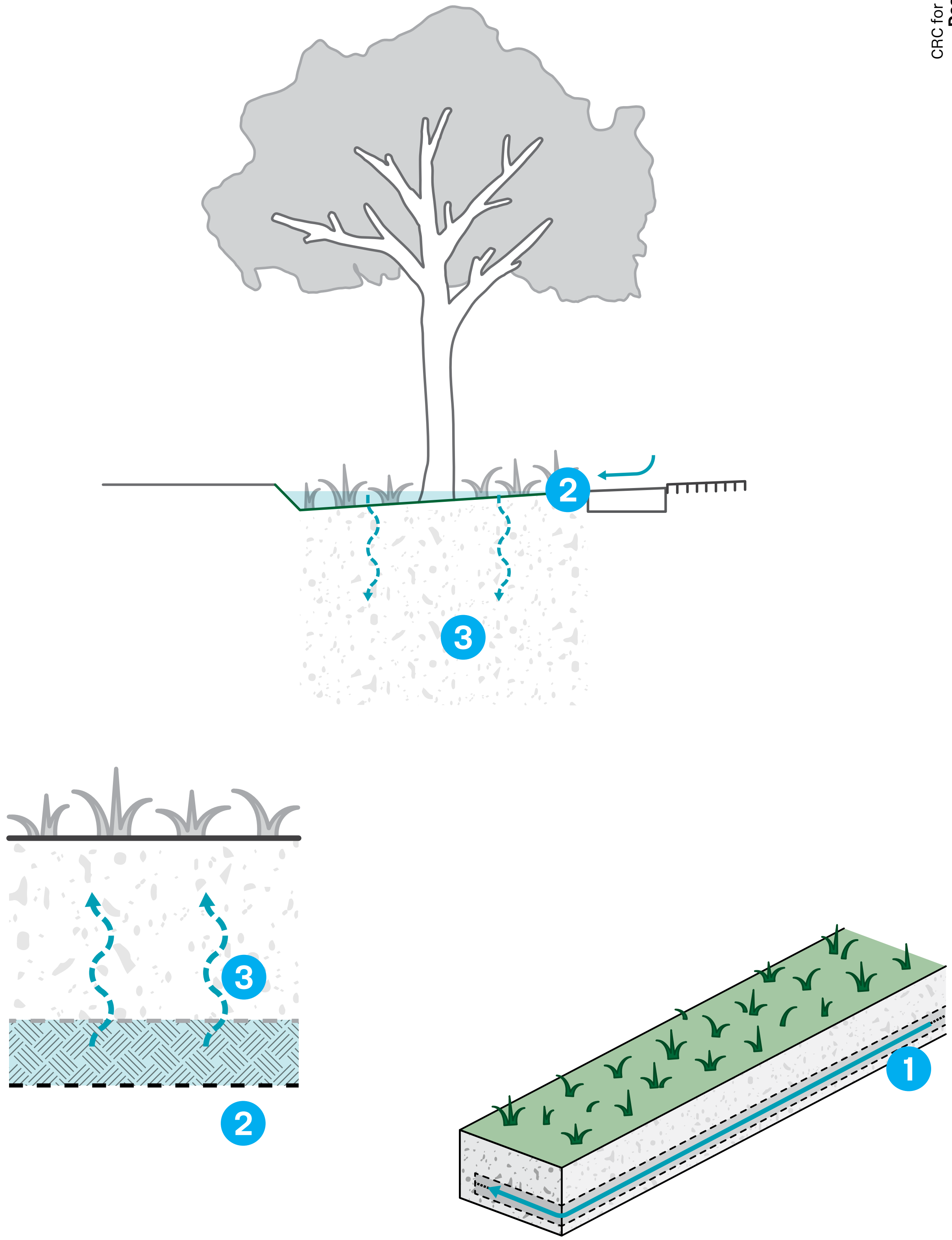
Figure 9 – Representation of the 3 key design principles for self-watered landscapes –

1. Passive irrigation
2. Soil moisture
3. Soil volume for both street trees (top) and wicking lawns (bottom)





Design considerations for self-watered landscapes in a cool city

The following sections provide a range of design considerations which may influence the self-watered landscape design response.

This includes:

1. What are the primary objectives you are designing the landscape to achieve?
2. Where are the landscapes going to be located?
3. What site conditions may influence the self-watered landscape design?
4. What is the soil moisture condition likely to be?

Design consideration 1 – Project objectives

The overarching objective for passively irrigated systems in this guideline is to cool the environment by providing shade, evapotranspiration and reducing the surface temperature. Providing adequate soil volume and soil moisture will encourage the growth of healthy trees with large canopies and increase evapotranspiration rates from trees, gardens and lawns which can cool the surrounding environment.

As these systems are designed to capture, filter and take up stormwater, this also results in improved stormwater quality entering downstream environments as well as helping to mimic a more natural hydrologic cycle.

All passively irrigated landscapes will provide both cooling and stormwater management outcomes. The extent to which these outcomes are achieved will depend on the design. For example, the catchment area and the soil media specifications will be particularly important where stormwater management is a key objective. Table 1 identifies the key design responses related to each objective.

While the dominant guideline purpose is urban cooling, investigations or analysis of systems or situations where passively irrigated landscapes are under consideration should also assess the additional benefits accruing from the hydrologic and water quality improvements.

Table 1 – Passively irrigated landscape key design considerations to achieve different objectives

Objective	Healthy tree / landscape (cooling)	Stormwater management
Key passively irrigated landscape function	• Shade • Evapotranspiration	• Filtering • Plant uptake
Key design considerations	• Adequate clearance to allow soil volume required for selected tree species growth to maturity • Adequate soil moisture / infiltration • Location and spacing of passively irrigated landscapes for cooling as well as road design requirements	• Volume of stormwater captured • Soil volume / surface area • Soil media

Design consideration 2 – Location of self-watered landscapes

Passively irrigated street trees

Self-watered street trees can be used in a range of settings from city streets to residential and industrial streets, as well as on public and private land. These may also be in retrofit or greenfield situations. The location setting will likely influence the design response in several ways as shown in the examples below and Section 3.

Example cross sections showing different locations of street trees and the associated design responses

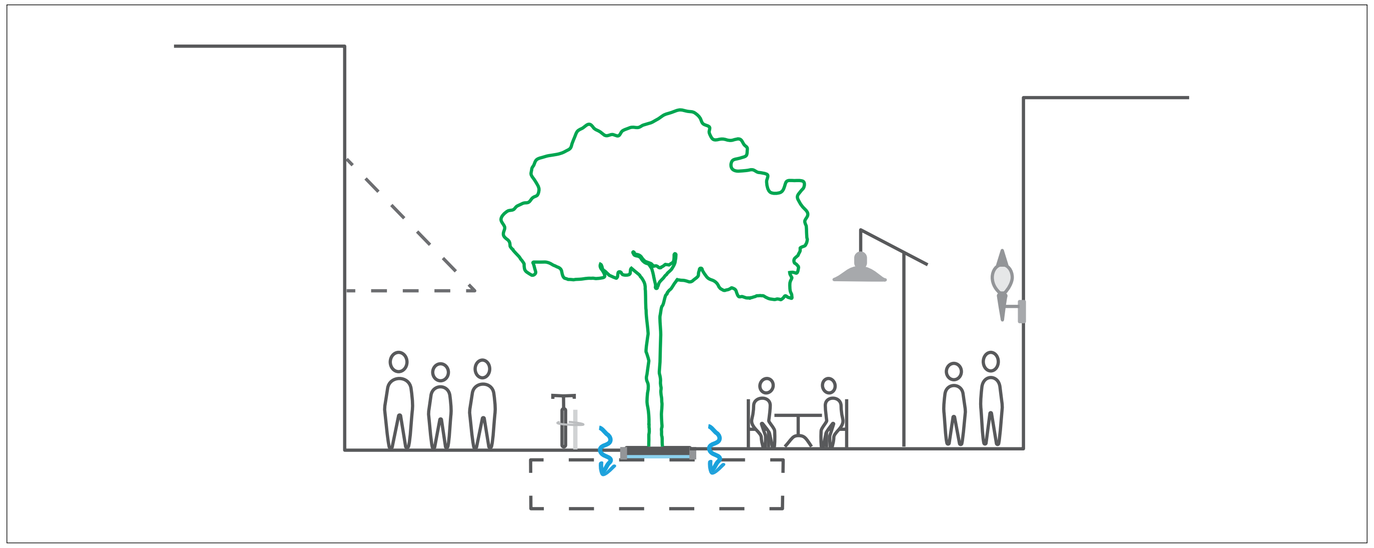
Setting

- Plaza

Typical design response

- High pedestrian movement requiring paving around tree pit and a tree grate
- No kerb and channel so water enters the system via permeable paving or stormwater pipes
- Structural soil systems may be required to achieve adequate soil volume under pavements

Photo credit: E2Designlab



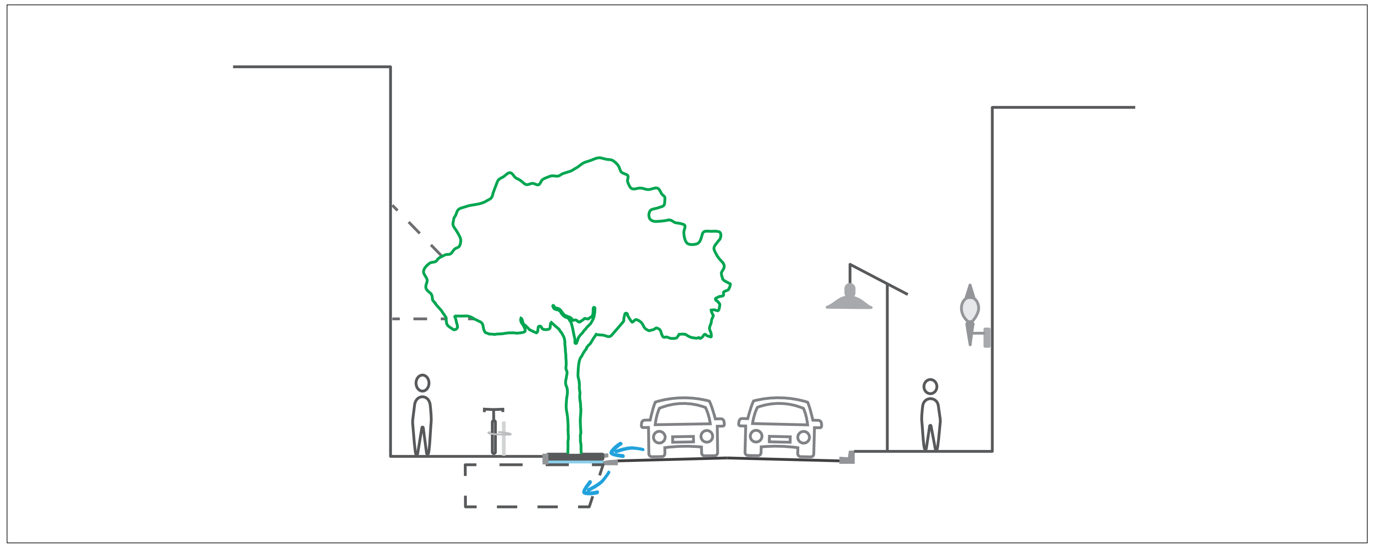
Setting

- City street

Typical design response

- High pedestrian movement requiring paving around tree pit and a tree grate
- Design needs to consider below ground conflicts (located in the road verge) and interface with the road
- Water typically enters from road kerb and channel
- Structural soil systems may be required to achieve adequate soil volume under pavements

Photo credit: E2Designlab



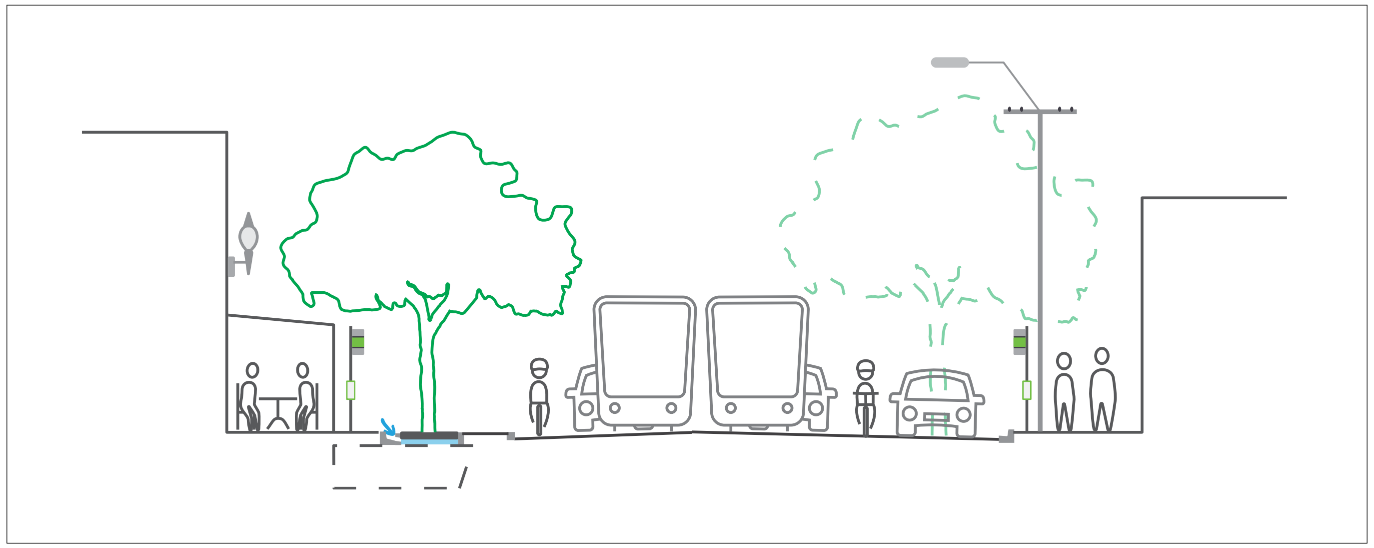
Setting

- City street bump out

Typical design response

- High pedestrian movement requiring paving around tree pit and a tree grate
- Design needs to consider below ground conflicts (located in the road verge) and interface with the road
- Water typically enters from road kerb and channel
- Structural soil systems may be required to achieve adequate soil volume under pavements

Photo credit: E2Designlab



Setting

- Residential street bump out

Typical design response

- Low pedestrian movement so open/ground level planted system can be used
- Design needs to consider below ground conflicts and interface with road
- Water can enter from road or from kerb behind system
- Structural soil systems may be required to achieve adequate soil volume under pavements

Photo credit: E2Designlab

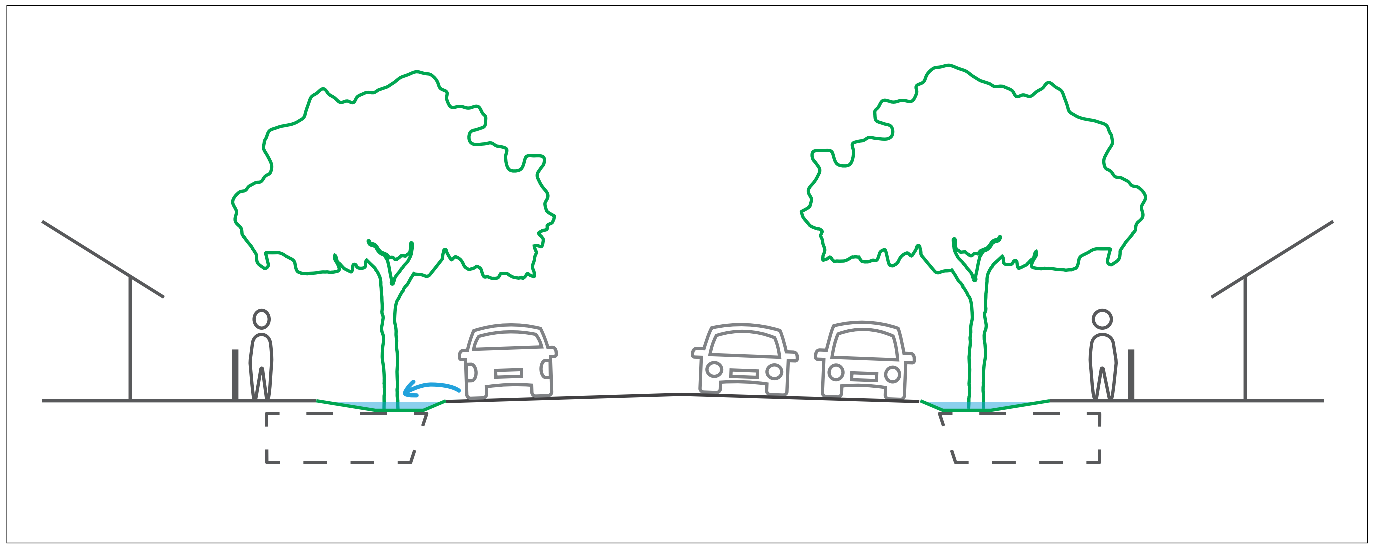
Setting

- Residential / industrial street

Typical design response

- Low pedestrian movement so open system can be used
- Design needs to consider below ground conflicts and interface with road
- Water can enter from road surface with flush kerb and channel/kerb cut-outs
- Structural soil systems may be required to achieve adequate soil volume under pavements

Photo credit: E2Designlab



Setting

- Boulevard (central median)

Typical design response

- Low pedestrian movement so open system can be used
- Road needs to be graded to allow water to enter system via sheet flow
- Structural soil systems may be required to achieve adequate soil volume under pavements

Photo credit: E2Designlab

The location of the systems within streets may also be influenced by cooling requirements or other landscape requirements which will set what side of the street or the spacing between trees. The CRCWSC Trees for a Cool City: Guidelines for Optimised Tree Placement recommends tree placement based on street widths, orientation and building heights (see Figure 10).

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Figure 10 – Example recommended street tree placement for cooling an east-west orientated 20 m wide street in the southern hemisphere with different building heights. This shows that 20 m streets with low buildings would benefit from trees on both sides of the street to provide shading, while the same street with tall buildings would prioritise trees on the southern side as the building will provide shade to the northern side of the street. These sections also show that the trees that are planted to provide cooling would also benefit from irrigation and suitable soil volume. (source: CRCWSC Trees for a Cool City: Guidelines for Optimised Tree Placement)

When locating street trees (especially in retrofit situations), there are a number of potential barriers which should be considered. Most of these barriers can be overcome with appropriate design responses which are discussed further in Section 3. These potential barriers may include:

- Space – underground services and above ground infrastructure (powerlines, awnings, seating etc) increase design complexity may reduce space available for trees.
- Infrastructure - proximity of footings or other infrastructure which roots and water might be seen to compromise.
- Sightlines and safety – need to ensure road safety is not compromised.
- Maintenance – vegetated landscapes require maintenance.
- Costs – can be more expensive than other types of landscaping.

Designing and choosing locations that avoid clashes with existing infrastructure is preferred but sometimes clashes are unavoidable. When resolving clashes the strategic priorities for the project should be considered to determine the best outcomes. Reconfiguration of existing infrastructure may be required in some circumstances.

Once the location of the street trees has been determined, the catchment area will then also be influenced by the crossfall of the street, the location of side entry pits and the roof drainage of adjacent buildings. This catchment area will have a large influence on the soil moisture of the system (see design consideration 4).

Wicking lawns:

The driver for designing a turf wicking lawn is to provide a reliable source of non-potable water for irrigation (using stormwater / roofwater as a resource) resulting in healthy, resilient turf and cool surface temperatures. The design for turf wicking lawns is scalable and can be applied to large sports fields through to small house scale lawns or podium landscape areas. The surface of a wicking system needs to be flat (i.e. less than 100 mm surface level difference across the system) to provide equal access to soil moisture. Terraced lawns can also be designed to have wicking, however sloping lawns are not appropriate for wicking. The area is often determined by landscape and open space design processes and by physical constraints of the site, rather than the achievement of a target soil volume (as is the case with trees) or stormwater treatment outcome.

The benefits of using wicking lawns when compared with surface irrigated lawns are:

- Turf can access water while the space is occupied during the day; irrigation does not need to be scheduled.
- There is physical separation between people using the space and the stormwater resulting in a very safe form of stormwater harvesting.
- Very efficient, no loss due to evaporation of aerial spray and the turf will not be over irrigated as it will use only the volume of water required.
- Encourages deep high-growth root zones for stronger, more resilient turf. This facilitates quicker wear recovery.
- Turf colour is even, increasing visual amenity.
- Nutrients within the stormwater support turf growth, reducing the need for fertiliser applications .
- Overflow relief and drainage increases the usability of the space after heavy rainfall and provides improved access for mowing and maintenance .
- Healthy and well-watered turf has also been found to increase CO_2 capture and also have a significantly lower surface temperature.

The following are examples of different scales of wicking systems and the associated design responses.

Example cross sections showing different locations of wicking lawns and wicking garden beds and the associated design responses.

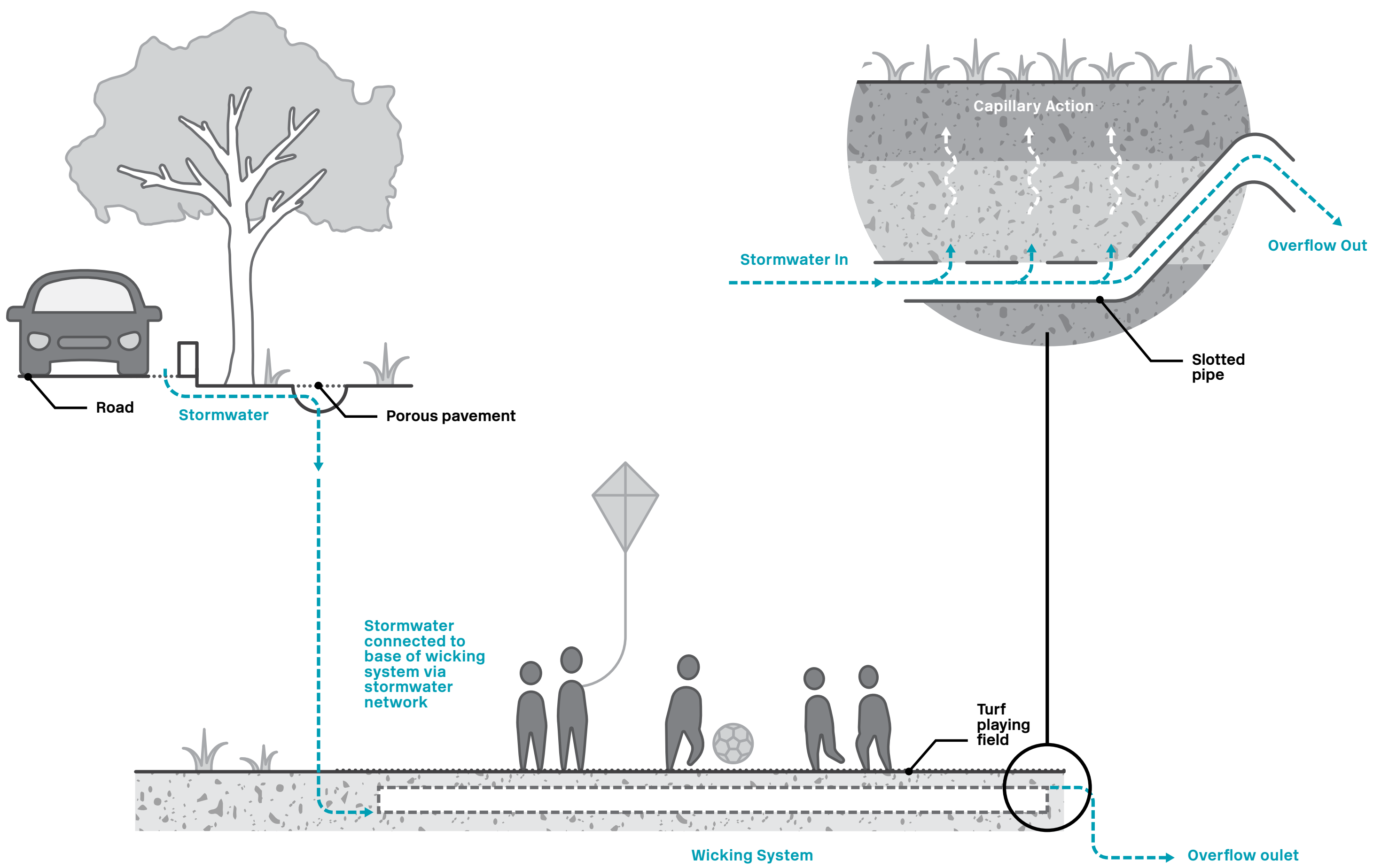
Setting

- Parkland / sportsfield

Typical design response

- Stormwater from surrounding impervious surfaces requires pre-treatment for sediment and litter prior to flows entering the wicking zone
- Effective subsurface flow distribution required
- Adequate wicking zone overflow capacity to ensure turf doesn't become waterlogged
- Soil profile needs to be relatively free draining yet maintain adequate capillary rise (e.g. sandy loam or loamy sand with underlying wicking zone)
- Wicking storage zone can be provided by clean sand (natural capillary rise with less volume) or proprietary storage cells (larger volume but rely on geotextile wicks to provide capillary rise action)
- An impermeable liner may be required to retain water in the wicking zone

Photo credit: E2Designlab



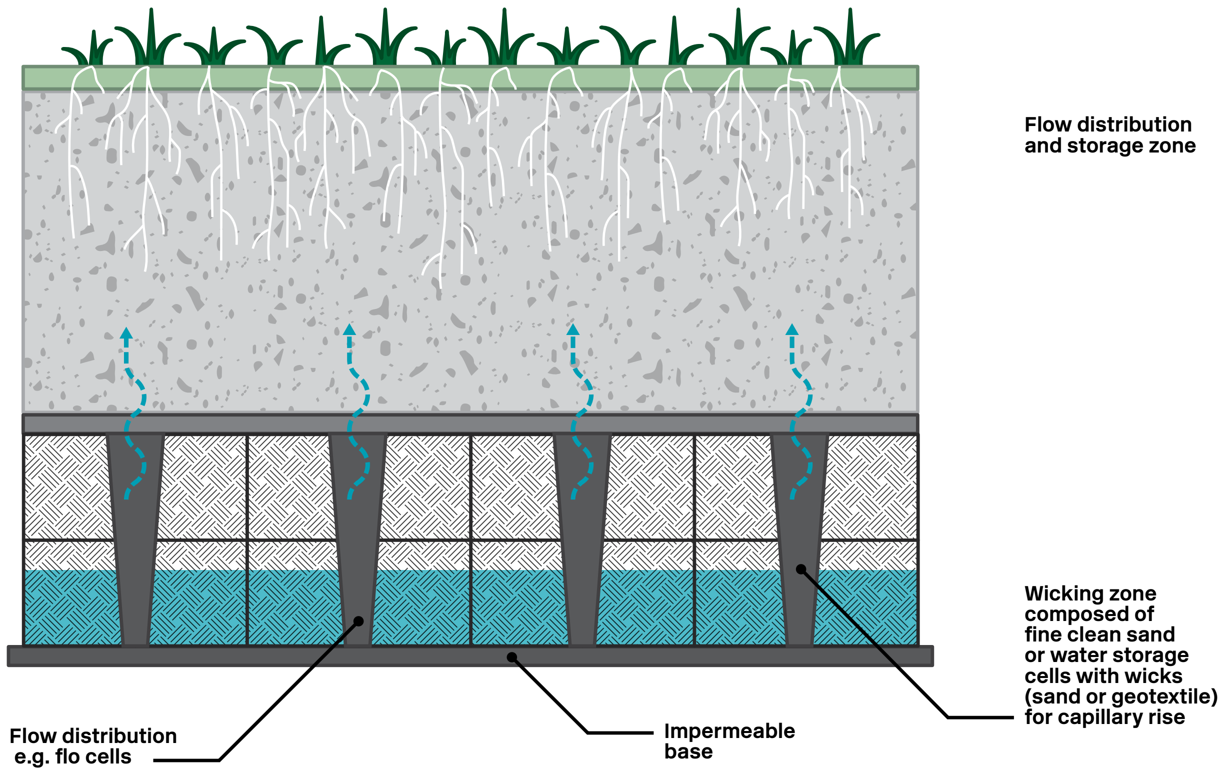
Setting

- Plaza/podium

Typical design response

- Impermeable liner to avoid water leaks
- Structural design for loading of podium platform
- Wicking zones need to be allowed for in the building design or an assessment required to understand structural design requirements for retrofit
- Roofwater and ground level inflows

Photo credit: E2Designlab



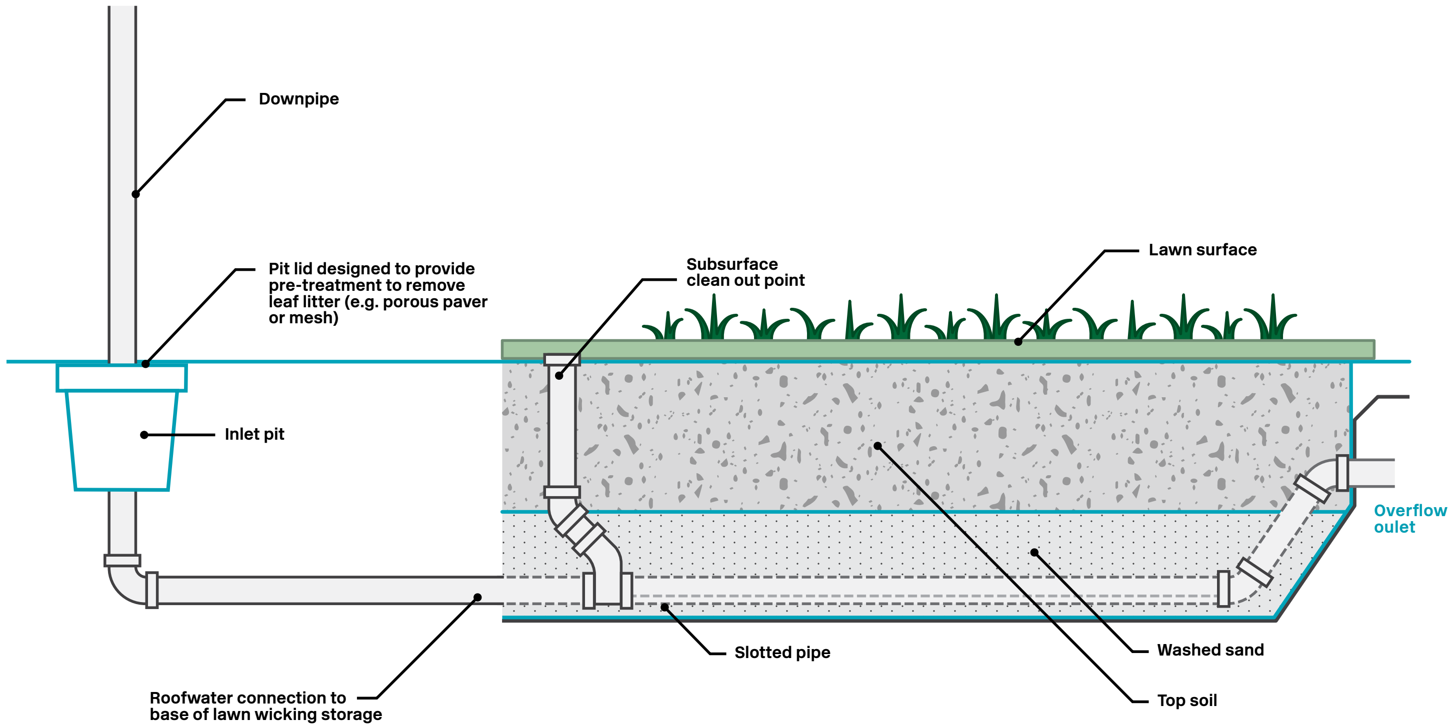
Setting

- Residential

Typical design response

- Receives water from roof downpipes and air-conditioning condensate
- Fine clean sand wicking layer provides capillary rise capability
- System is fully lined to protect building foundations

Photo credit: E2Designlab



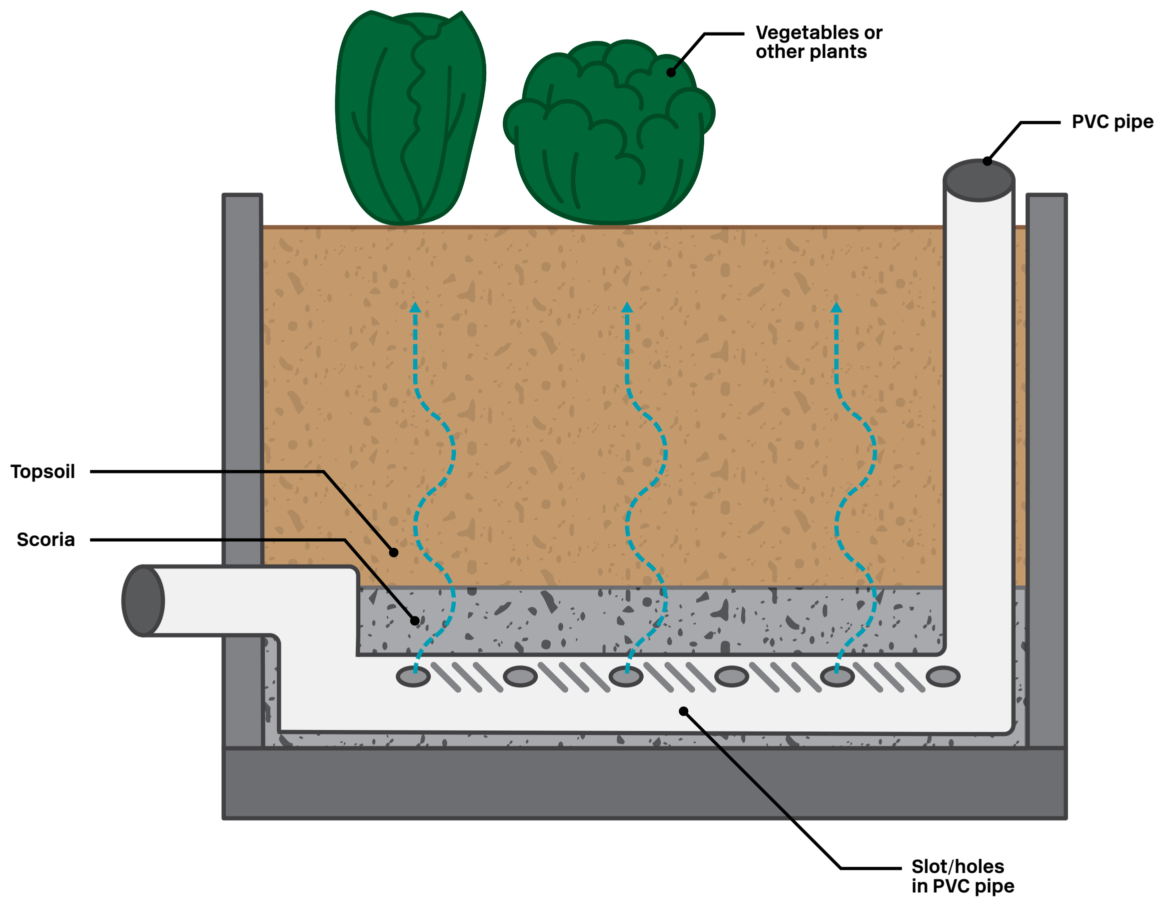
Setting

- Garden bed

Typical design response

- Receives water from roof downpipes and air-conditioning condensate
- Suitable soil to support selected plant types
- High organic soils and use of fertilisers may result in some nutrient leaching from the system
- Provision for occasional flushing of wicking zone to avoid build up of organic fines

Photo credit: E2Designlab



Design consideration 3 – Site conditions

Site conditions such as slope, in-situ soils, underground and above ground service conflicts will influence the design response of passively irrigated landscapes.

Designers should always consider opportunities for integrated solutions that achieve the best strategic outcomes for the site.

Table 2 presents a summary of typical site conditions and outlines how this might influence the design of the self-watered landscapes.

Table 2 – Passively irrigated landscape design responses for typical site conditions

Site condition	Design considerations	Potential design response	
Catchment and site slope	Passively irrigated landscapes are ideally suited to flat sites. Design of these systems on steep sites will need to consider the grade of the planting surface as well as high stormwater velocities which can result in bypass, erosion and scour.	Site slope <2%	Ideal for all passively irrigated landscapes. Note that wicking lawns need a relatively flat surface to allow equal access to soil moisture.
		Site slope <5%	Ideal for passively irrigated trees.
		Site slope 5-8%	Consider orientation of asset to get flat surface and inclusion of energy dissipation interventions.
		Site slope >8%	Reconsider use of passively irrigated trees.
Catchment area	The catchment area is the area of land that will direct surface runoff to the asset. The catchment may comprise just a road and footpath to kerb and channel or include allotments draining directly to the kerb.	Small catchment	May require additional water storage to improve soil moisture to sustain healthy vegetation.
		Large catchment	Restrict inflows or use underdrainage and/or overflow weirs to ensure landscape doesn't flood / waterlog vegetation.
Existing stormwater drainage	Tree pit inlets located upstream of existing stormwater inlet pits.	Existing stormwater drainage present	Locate tree pit inlet upstream of an existing stormwater inlet pit to ensure stormwater flows enter the tree pit before they fill and then bypass to the downstream pits.
Road slope	Centre or one-way crossfall	Road crossfall	Locate passively irrigated trees ensuring they are connected to stormwater inflows (i.e. locating systems on the low side of a one-way crossfall street will maximise catchment inflows).
Overhead conditions	Trees can potentially conflict with other overhead infrastructure assets such as powerlines, tram lines, street awnings, traffic lights etc.	No overhead conflicts	No impact on design.
		Existing or planned overhead conflicts	Vegetation height, placement and maintenance will need to be considered. Also consider opportunities to relocate or bundle services. Designers should check with utility providers to discuss these opportunities.

Table 2 – Passively irrigated landscape design responses for typical site conditions (continued)

Site condition	Design considerations	Potential design response	
On-ground conditions	Tree pits can conflict with street facilities and activities including footpaths, seating, dining, post/phone boxes, bins, cycling paths, bike/car parking, kerbs and channels, bollards, fences, driveways, signage, tram/bus stops, market stalls, electricity/water services.	No on-ground conflicts	No impact on design.
		Existing or planned on-ground conflicts	Need to consider the location, surface treatment and subsurface structural integrity of the passively irrigated system. Grated systems and structural cells can be used to allow large soil volumes to be provided under high traffic areas.
Underground services	Passively irrigated assets such as street tree pits and wicking lawns require a deep underground soil media layer to grow roots and treat, retain and drain stormwater. Underground services can therefore be a major constraint.	No underground conflicts	No impact on design.
		Existing or planned underground conflicts	A Dial Before You Dig (DBYD) check should be undertaken once a preferred project location has been confirmed to provide early notice of services that may need to be factored into the design process. Service proving should occur as soon as possible if the DBYD search indicates services may impact design works.
Road pavements and structural footings	Passively irrigated landscapes direct water into the soil profile within streetscapes.	Road pavements or structural footings close to landscape	Liners, underdrainage and gravel trenching can be used where changes to soil moisture might otherwise adversely impact structural footings or road pavements. Excavation for the landscapes should be located out of the zone of influence of the structural footings and road pavements.
Sunlight and shade	Limited sunlight availability due to shading from buildings or other structures can stunt tree growth, impact canopy cover and impact the health of turf.	Location and species	Vegetation placement and species selection need to be considered relating to site suitability.
Groundwater	Passively irrigated landscapes, which are unlined, can provide points for groundwater recharge. These systems should improve the water quality entering groundwater systems. Shallow groundwater may however intercept the systems which can be problematic.	Shallow groundwater	An understanding of groundwater quality and seasonal groundwater levels will inform the design of passively irrigated trees in terms of overall site suitability, the need for a liner and outlet configuration (i.e. level of underdrainage pipes).

Table 2 – Passively irrigated landscape design responses for typical site conditions (continued)

Site condition	Design considerations	Potential design response	
In-situ soils	Passively irrigated systems may or may not incorporate underdrainage. This will be influenced by the in-situ soils.	High permeable in-situ soils	Lower risk of waterlogging of the vegetation if underdrainage is not used. Exfiltration can help to restore natural water cycle in this area. If wicking is included in the design, a liner will be required.
		Highly impermeable in-situ soils	Underdrainage will be required to reduce the risk of waterlogging in the tree pit systems and guarantee an aerobic soil zone for the tree.
Safety and sight lines	Careful consideration must be given to how street tree systems interact with their environment, particularly with pedestrians, cyclists and vehicles.	Edge treatment and sight lines	Tree guards, bicycle hoops and bollards are commonly used protection devices. The asset interface should include batters and edge treatments to minimise the tripping risk to pedestrians. Ensure traffic sight lines are preserved. For high speed traffic conditions, safety barriers between the road and tree may be required. Safety in design is an essential part of the design process. This should include but not be limited to sight lines, grade separation, turning radius, speed etc.
Climatic conditions	Passively irrigated landscapes rely on rainfall and stormwater runoff to provide water to support healthy vegetation growth. The climatic region and the associated rainfall volumes and patterns will therefore influence design.	Extended dry seasons	Wicking zones (see pages 42 and 44) can be used to provide a longer term water source for the vegetation.
		High rainfall or persistent rainfall	Ensure an aerobic soil zone is always provided for the tree, e.g. by ensuring the top 400-500 mm of soil is free draining.
Local debris and leaf litter	Street debris such as litter, sediment and organics (i.e. leaves) can be washed into tree pits during rainfall events. After multiple events, this accumulation can reduce the effectiveness of self-watered systems resulting in stunted growth and reduction in street amenity.	Maintenance	In areas with high litter loads, regular street cleaning and maintenance of tree pits is required. The inlet design should also limit sediment and organic matter entering the system. Pre-treatment of flows is required before stormwater enters subsurface wicking bed systems as access is not available to these systems.

Design consideration 4 – Catchment flows and soil moisture

The location of the passively irrigated trees, the size of the catchment draining to it and the size of the landscape (soil volume) will influence its soil moisture. This is important as trees will not grow to their full canopy potential if they are too dry and they are also at risk for windthrow or poor health if they are too wet and waterlogged. Soil volume should be set by what is required by the tree for optimal growth. It is then important to understand the volume of inflows entering the system and the likely soil moisture conditions so that the design response for the passively irrigated landscape can optimise the tree health.

The following table provides a summary of design responses for different catchment flow and soil moisture conditions.

Figure 11 provides an example of how catchment and soil volume can be modified to improve soil moisture conditions.

Table 3 - Summary of design responses for different soil moisture conditions in tree pits

Catchment flows entering tree pit	Likely soil moisture condition	Potential design responses
Small catchment area	Dry	• Ensure the tree pit is not lined (i.e. connect to underlying and surrounding soils for access to adjacent soil moisture stores) • Incorporate a wicking zone in the base • Allow for additional irrigation • Increase catchment area if possible • Improve soil moisture holding capacity of soil • Look for additional alternative water sources • Select drought tolerant tree species • Increase extended detention / capture volume
Large catchment area	Wet	• Ensure the top 400-500 mm of soil is free draining (most important) • Increase the soil volume • Ensure the soil is free draining • Reduce the amount of water entering the system (e.g. reduce the capture volume or reduce the catchment area) • Provide water storage zone outside of the drip zone to reduce risk of waterlogging and windthrow

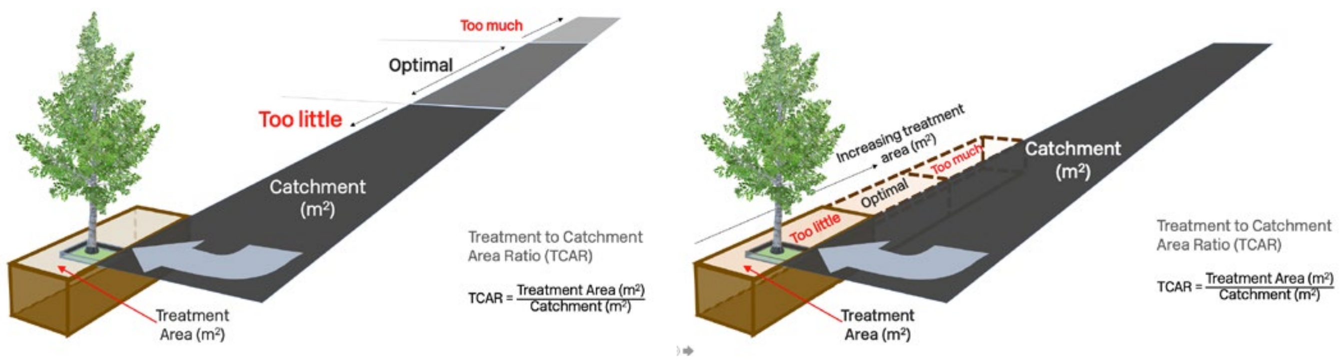


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Figure 11 – Example of how catchment and soil volume can be modified to improve soil moisture conditions

Part B of this guideline presents modelling outcomes which present more detailed recommendations for the design of passively irrigated trees that are not too wet or too dry and can achieve the local stormwater treatment targets.

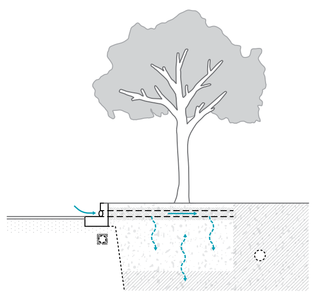
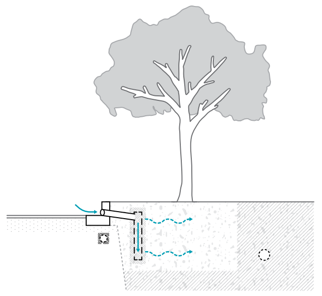
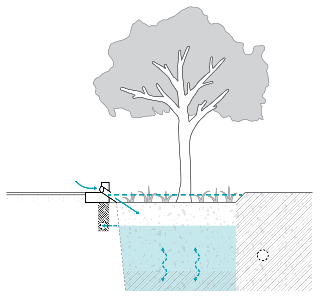
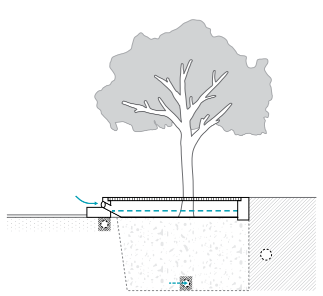
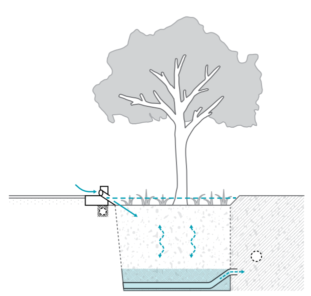
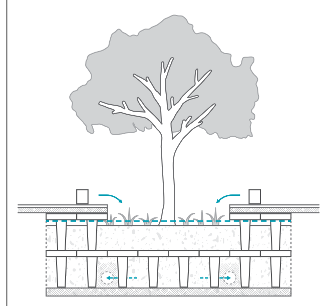
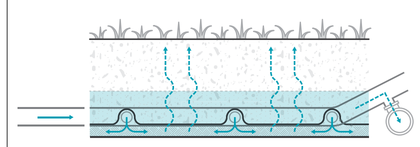
Section 3

Examples of typical passive irrigation design components

This section presents information on the design components of passively irrigated tree pits and wicking systems. A summary is provided in Table 4 and further detail on the examples that follow. These design components can be combined in a number of different ways to respond to your site and design objectives.

- ● (green) High Benefit
- ● (yellow) Moderate/High Benefit
- ● (orange) Moderate/Low Benefit
- ● (red) Low Benefit

Table 4 – Passively irrigated landscape design components

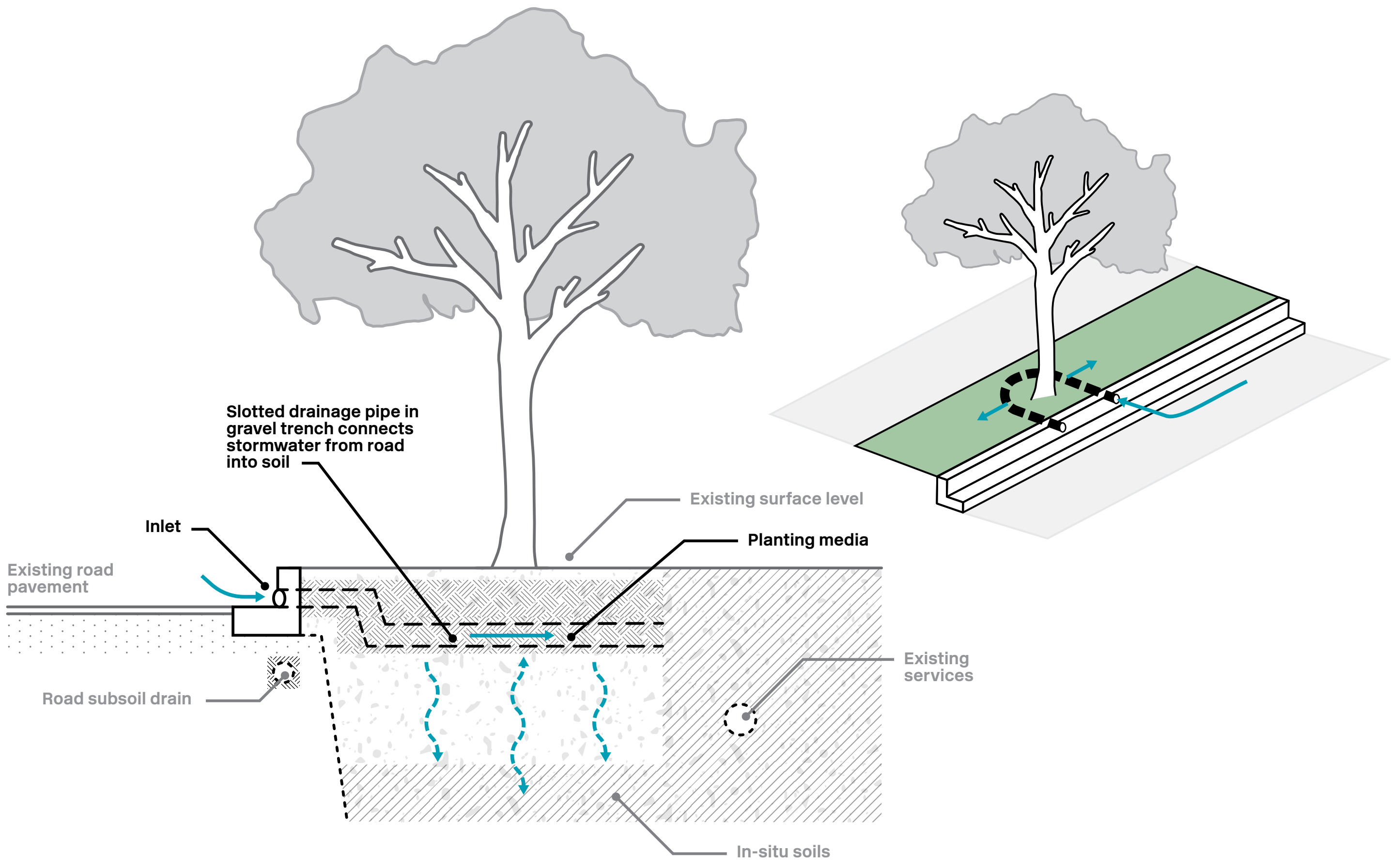
		1. No underdrainage	2. Infiltration well	3. Elevated underdrainage	4. With underdrainage	5. With wicking zone	6. With structural cells	7. Wicking lawn
Section								
Benefits and constraints	Shade (cooling)	High Benefit	High Benefit	High Benefit	High Benefit	High Benefit	High Benefit	High Benefit
	Stormwater treatment	Low Benefit	Low Benefit	Moderate/High Benefit	High Benefit	High Benefit	High Benefit	Moderate/High Benefit
	Risk of waterlogging	Low Benefit	Low Benefit	Moderate/High Benefit	High Benefit	High Benefit	High Benefit	High Benefit
	Soil moisture retention for extended dry periods	Low Benefit	Low Benefit	Moderate/Low Benefit	Low Benefit	High Benefit	Moderate/Low Benefit * can be designed with wicking zone to improve soil moisture retention	High Benefit
	Ease of delivery / cost	High Benefit	High Benefit	Moderate/High Benefit	Low Benefit	Low Benefit	Low Benefit	Low Benefit
	Recharge of in-situ soil moisture stores	High Benefit	High Benefit	High Benefit	Moderate/High Benefit	Low Benefit	Low Benefit	Low Benefit
	Ease of retrofit	Moderate/High Benefit	High Benefit	Moderate/High Benefit	Low Benefit	Low Benefit	Low Benefit	Low Benefit
Typical site conditions driving design		• Good quality in-situ soils with reasonably high permeability • No stormwater network • Cost sensitive retrofit	• Good quality in-situ soils • No stormwater network • Cost sensitive retrofit	• Connection to existing roadside drainage to ensure the upper soil layer cannot become water logged • In-situ soil suitable for tree growth but with low permeability	• Large catchment area • Existing stormwater network which can be connected to easily • Stormwater treatment objective • High rainfall regions	• Long dry season • Poor water holding capacity of in-situ soils • Stormwater treatment objective	• Pavement required above soil	• High profile or high use turf areas • Where an alternative irrigation water source for turf is sort • Retrofit of turf areas for improved health and resilience • Stormwater treatment objective
Important design components		• Soil media – it is important to understand the conditions of the in-situ soils to ensure waterlogged conditions don't persist near the trunk and roots • Inlet – needs to be designed to avoid blockage with sediment and debris. Subsurface inlet pipes should be located to convey water around the tree drip line. • Plant selection – plants which can tolerate wetter conditions	• Soil media – it is important to understand the conditions of the in-situ soils to ensure waterlogged conditions don't persist near the trunk and roots • Inlet – needs to be designed to avoid blockage with sediment and debris • Plant selection – plants which can tolerate wetter conditions	• Soil media – it is important to understand the conditions of the in-situ soils to ensure waterlogged conditions don't persist near the trunk and roots • Plant selection – plants which can tolerate wetter conditions • Ensure there is no barrier between the tree media and in-situ soils. This will ensure recharge of and access to deep soil moisture stores is retained.	• Underdrainage – to connect with stormwater network • Soil media – soil media within the tree pit needs to be free draining so waterlogging conditions don't persist near the trunk and surface roots • Ensure there is no barrier between the tree media and in-situ soils (e.g. place drainage gravel around the slotted pipes only, not across the entire base of the tree pit). This will ensure recharge of and access to deep soil moisture stores is retained.	• Wicking storage volume – adequate volume to provide extended soil moisture • Liner used for high permeability soils • Soil media – soil media within the tree pit needs to be free draining so waterlogging conditions don't persist near the trunk and surface roots	• Structural cells – to provide required structural integrity • Soil media – soil media within the tree pit needs to be free draining so waterlogging conditions don't persist near the trunk and surface roots	• Wicking storage volume – adequate volume to provide extended soil moisture • Soil depth and soil media – needs to be able to support wicking to surface level through capillary rise

Example 1 – No underdrainage

Typical site characteristics:

- No stormwater network
- Limited budget for retrofit

Example section:

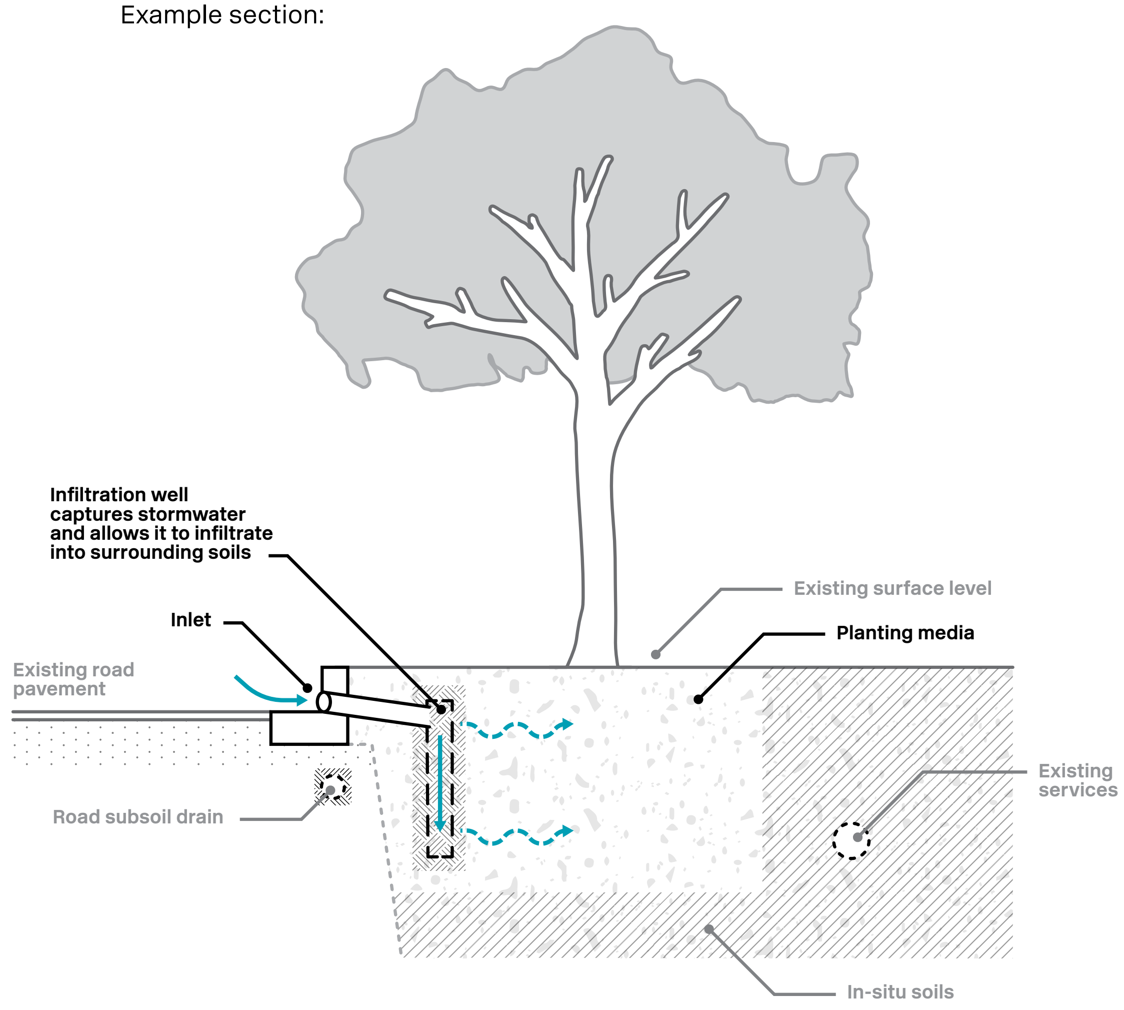


Example 2 – Infiltration trench/pit

Typical site characteristics:

- No stormwater network
- Limited budget for retrofit

Example section:



Key design components:

Soil media / in-situ soils

While this approach can be used in any soil type, 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. There is a reduced risk of waterlogging where there is high permeability in-situ soils. Organic matter content should be <5% w:w (weight for weight) particularly at depths greater than 300 mm to avoid anaerobic breakdown.

Inlet

The inlet on these systems is typically a kerb adapter connected to a slotted drainage pipe which is looped around the tree pit and located within the surface soil profile. This allows flows to enter and infiltrate through the soil. The slotted pipes are typically surrounded by gravel to avoid soil ingress. The design of this should consider how much water should be directed into the system (based on in-situ soils and tree water demand) and also the longevity of the pipes being used (see page 51).

Tree selection

The tree selection should be informed by an understanding of the in-situ soils and potential soil moisture conditions. If the system is likely to get quite wet, trees which can handle these wet conditions as well as extended dry periods in between rain events will be required. The tree pit planting media should be in contact with in-situ soils to provide a connection to deep soil moisture storage. This allows moisture exchange between the tree pit and surrounds. Ensure there is no barrier between the tree media and in-situ soils.

See Section 4 for more details on design components.

Key design components:

Soil media / in-situ soils

While this approach can be used in any soil type, 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. There is a reduced risk of waterlogging where there is high permeability in-situ soils. Organic matter content should be <5% w:w (weight for weight) particularly at depths greater than 300 mm to avoid anaerobic breakdown.

Inlet

The inlet on these systems is typically a kerb adapter connected to a pipe which conveys stormwater flows into an infiltration well / leaky well. These wells can be filled with gravel or other media which provides a storage volume. This water then infiltrates into the surrounding soil. This allows flows to enter and infiltrate through the soil. The design of this should consider how much water should be directed into the system (based on in-situ soils and tree water demand).

Tree selection

The tree selection should be informed by an understanding of the in-situ soils and potential soil moisture conditions. If the system is likely to get quite wet, trees which can handle these wet conditions as well as extended dry periods in between rain events will be required. The tree pit planting media should be in contact with in-situ soils to provide a connection to deep soil moisture storage. This allows moisture exchange between the tree pit and surrounds. Ensure there is no barrier between the tree media and in-situ soils.

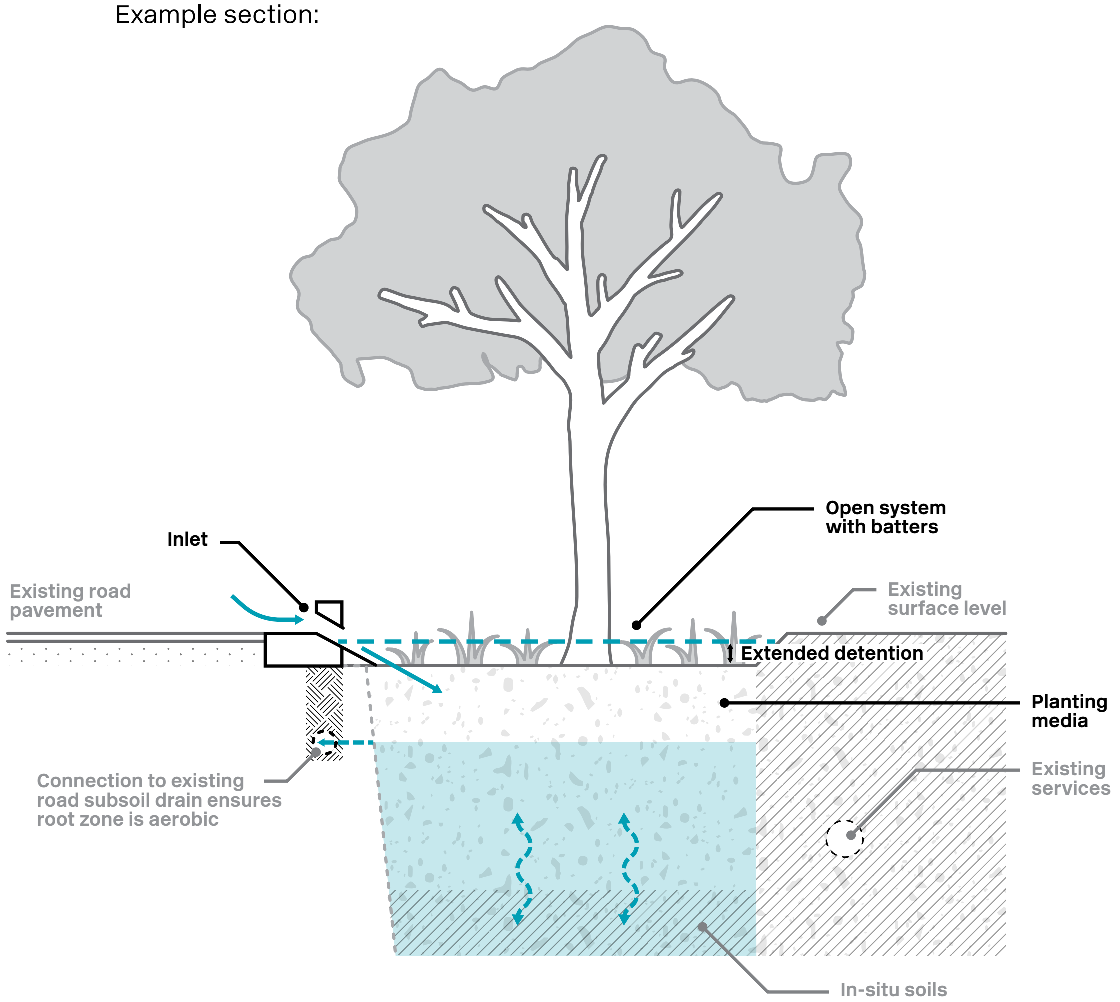
See Section 4 for more details on design components.

Example 3 – Elevated underdrainage

Typical site characteristics:

- Existing road subdrain
- Limited budget for retrofit

Example section:



Key design components:

Inlet

The inlet connects the kerb and channel to the surface of the tree pit. The finished surface of the tree pit must be below the kerb invert level at the inlet to allow water to enter. This is critical for correct function of the tree pit. The inlet should be graded down into the tree pit to prevent build-up of sediments.

Outlet

Connection to existing roadside drainage (back of kerb ag-drain) ensures the upper 300 mm (min) soil layer within the tree pit cannot become waterlogged. This connection may happen naturally in freely draining soils. In less permeable soils, this connection can be improved with the use of a french drain. There is potential leaching of nutrients if the topsoil remains saturated. Raising the underdrainage above the base of the system increases the storage and water available for the tree, acting like an informal wicking zone. For high to moderate permeability in-situ soils, this water can either be absorbed by the tree after the rainfall event, or exfiltrate into the underlying and surrounding soils to recharge surrounding soil moisture. In low permeability soils, suitable trees will need to be selected which can tolerate saturated conditions in the tree pit base.

Soil media

If using in-situ soils they must be of good quality to support a healthy tree. If installing planting media, a sandy loam with good infiltration capacity (e.g. >30 mm/hr) and moisture retention capacity (e.g. 20-25%) is recommended. Organic matter content should be <5% w:w particularly at depths greater than 300 mm to avoid anaerobic breakdown. As water is being directed to the surface of the system, it is important that water does not pond on the surface long term as this will impact tree health.

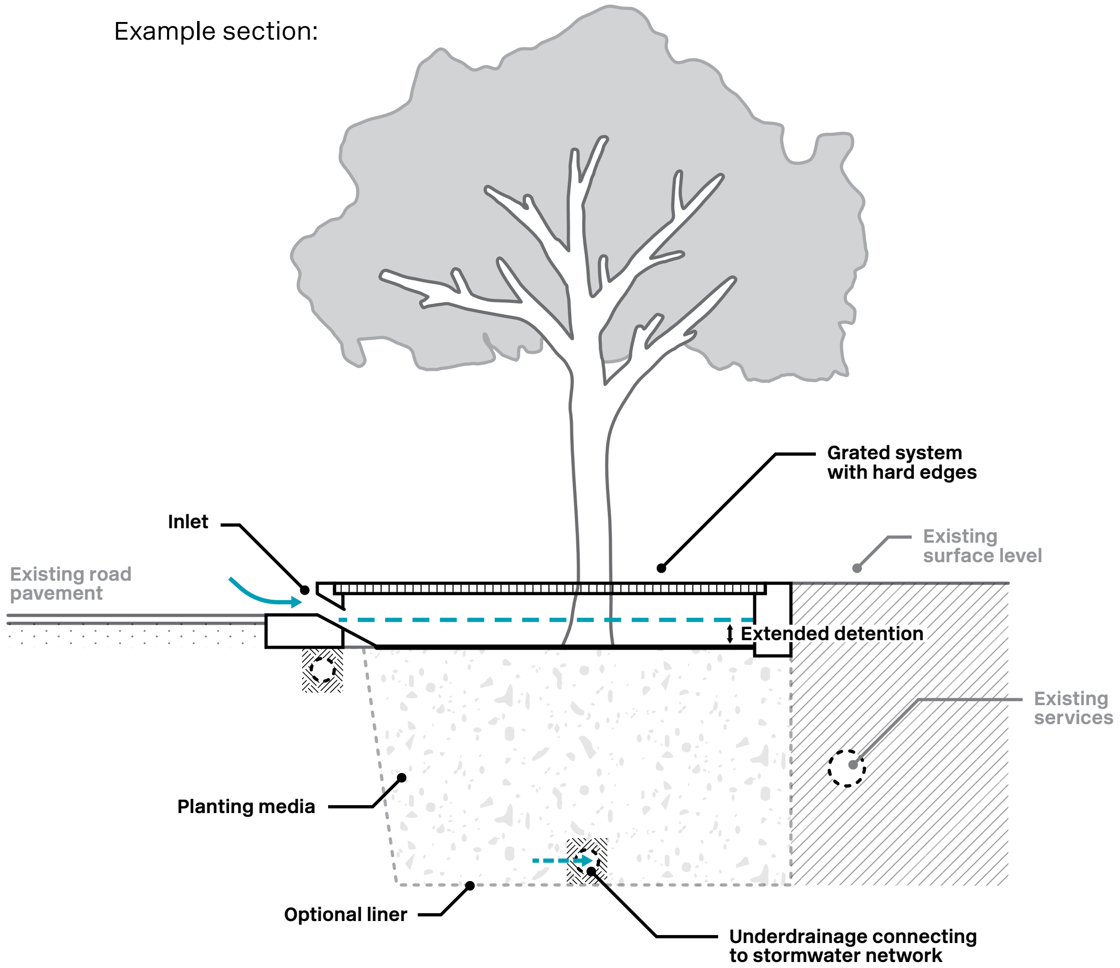
See Section 4 for more details on design components.

Example 4 – With underdrainage

Typical site characteristics:

- Existing road stormwater network
- High rainfall climatic zone
- Large catchment area

Example section:



Key design components:

Soil volume

For unlined tree pits, the soil volume available for the tree will include the soil installed above the underdrainage plus the in-situ soils surrounding the pit, assuming they are of good quality to support the tree into maturity. For lined pits, the installed soil volume above the underdrainage will need to be of a suitable volume and quality to enable to tree to grow to its full potential. Generally to support trees, soil surface area should be a minimum one third of projected canopy, with a minimum depth of 1 m.

Underdrainage

Slotted pipes allow excess water that infiltrated through the tree pit soil volume to be collected and discharged at the base of the tree pit. This prevents waterlogging and is effective in high rainfall climates or where there is a large catchment connected to the tree pit.

Lining

Impermeable liners are only required where the tree pit is located adjacent to infrastructure that needs to be protected from water (e.g. building footings) or where poor quality in-situ soils (e.g. sodic soils), or areas with high water tables may impact tree health. Linings prevent exfiltration of water and the recharge of deep soil moisture reserves, so should be avoided where possible.

Soil media

Planting media should have good infiltration to ensure water does not pond on the surface long term as this will impact tree health. Organic matter content should be <5% w:w particularly at depths greater than 300 mm to avoid anaerobic breakdown.

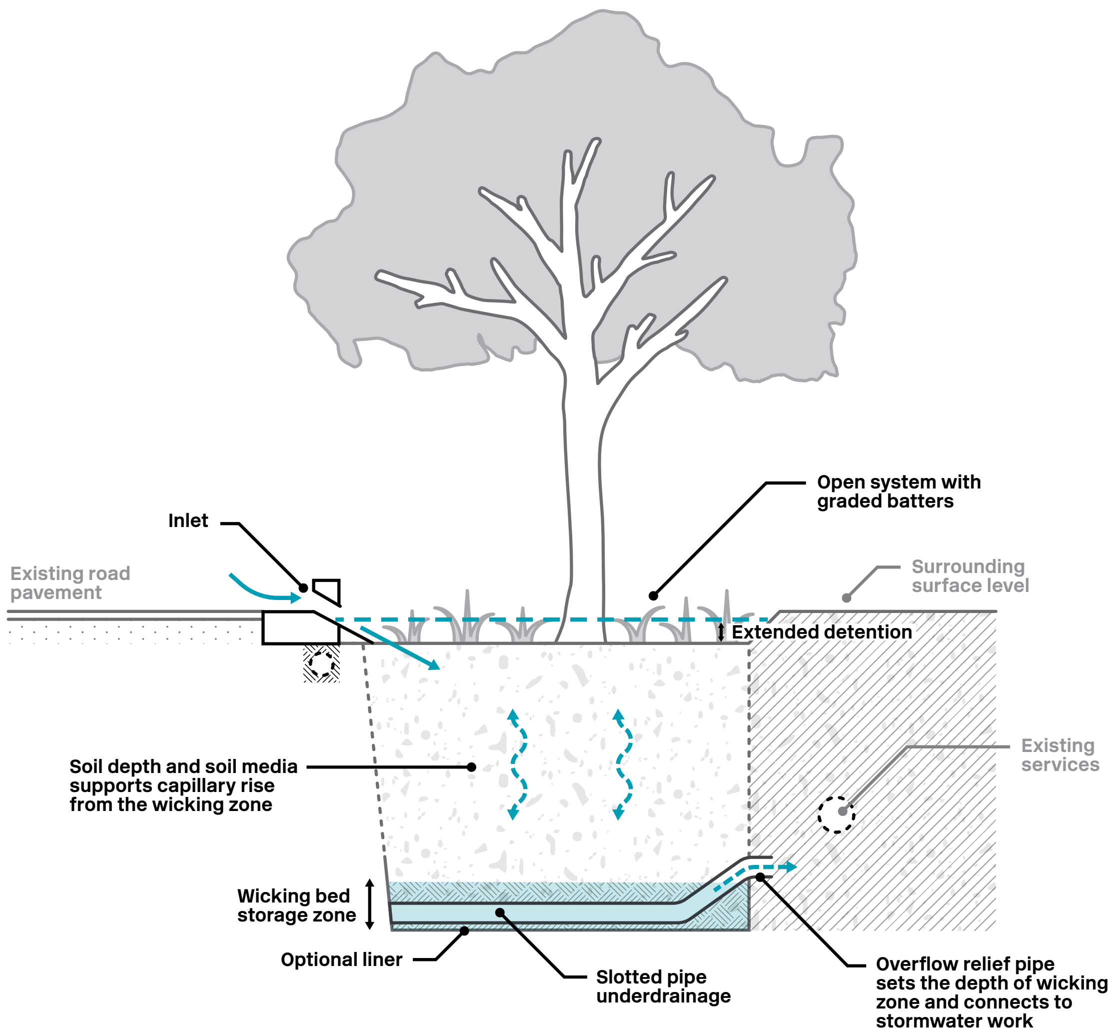
See Section 4 for more details on design components.

Example 5 – With wicking bed

Typical site characteristics:

- Extended dry seasons

Example section:



Key design components:

Wicking bed composition and storage volume

The wicking bed storage zone must enable capillary rise, to sustain soil moisture, even when the water level in the storage zone is low. Fine sand or geosynthetic wicks enable water to rise up into the topsoil zone. Gravel does not permit water to rise and thus should be avoided. The volume of the wicking zone is determined by the porosity of the sand in the zone or volumetric capacity of storage cells incorporating wicks.The acceptable depth range of the storage zone is determined by two factors: the capillary rise or wicking ability of the soil media, which sets the maximum possible depth; and the minimum depth needed to incorporate a flow distribution network. The wicking zone should be free from organics and nutrients (e.g. clean washed sand) to avoid nutrients leaching out of the pit.

Lining

An impermeable liner can be used to retain water within the wicking zone. This is necessary where in-situ soils are highly permeable and in climatic zones with long dry periods to maximise the benefits of the wicking bed.

Soil media

Planting media should have good infiltration to ensure water does not pond on the surface long term as this will impact tree health. Organic matter content should be <5% w:w particularly at depths greater than 300 mm to avoid anaerobic breakdown.

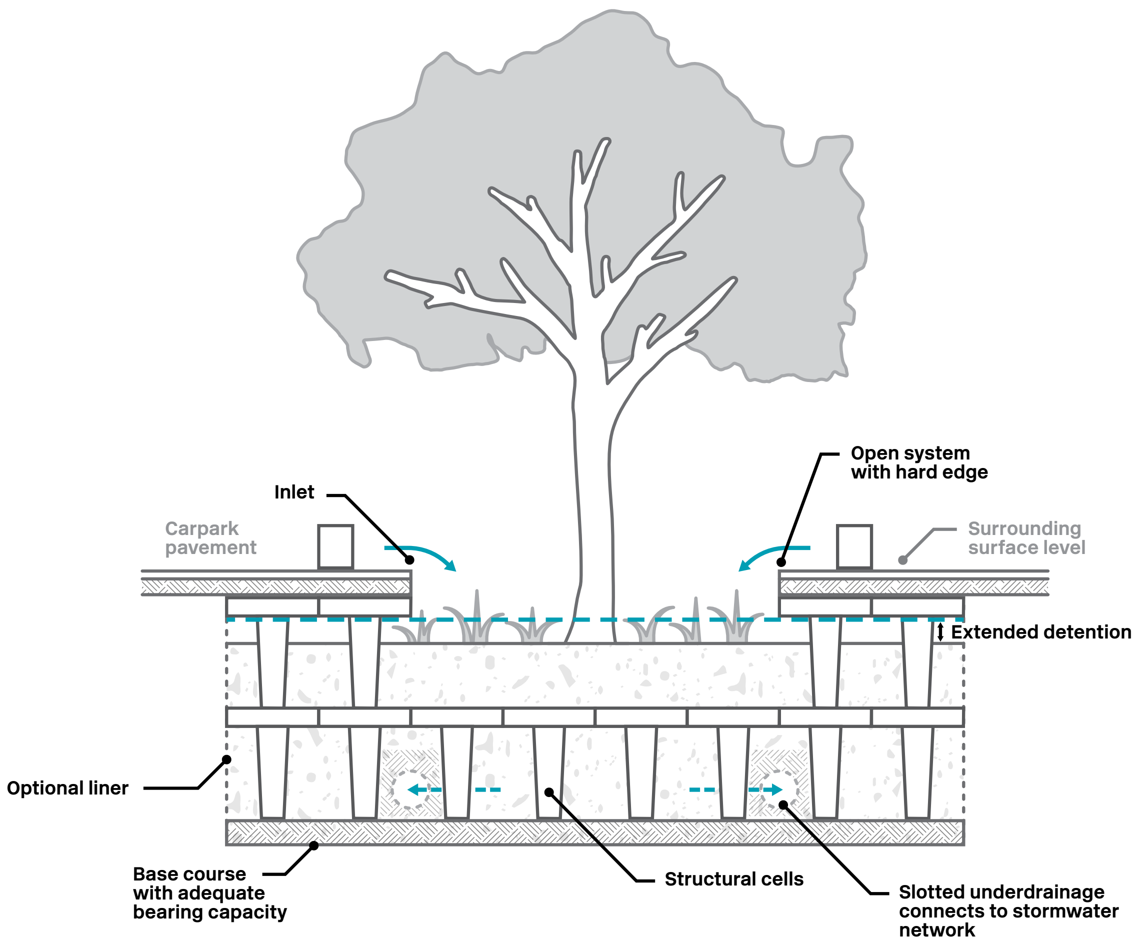
See Section 4 for more details on design components.

Example 6 – With structural cells

Typical site characteristics:

- Pavement required over system

Example section:



Key design components:

Structural cells

Structural cells are designed to provide support to pavements surrounding the system while ensuring an adequate volume of uncompacted soil will allow the tree to reach its full growth potential. The structural integrity of the cells rely on adequate bearing capacity of the base course.

Out let and underdrainage

Drainage arrangements from examples 3, 4 and 5 are all compatible with structural cells. The outlet can either be within the system or as part of the surrounding carpark / plaza drainage.

Lining

Structural cells will often be adopted in constrained locations adjacent to infrastructure and footings which may need to be protected from water through the use of a liner. A liner will also assist the retention of a wicking zone.

Soil media

Backfill soil for these systems should be a high quality sandy loam with good infiltration capacity (e.g. >30 mm/hr) and moisture retention capacity (e.g. 20-25% by volume) is recommended. Organic matter content should be <5% w:w particularly at depths greater than 300 mm to avoid anaerobic breakdown. The soil should be lightly tamped during installation to reduce voids.

Extended detention

Stormwater capture volume can be increased by providing extended detention underneath the pavement. This is achieved by retaining an air void under the pavement (i.e. don't completely fill the structural soil cells with soil). Gravel can be placed to avoid litter washing under the pavement. The air void created also improves conditions for tree health.

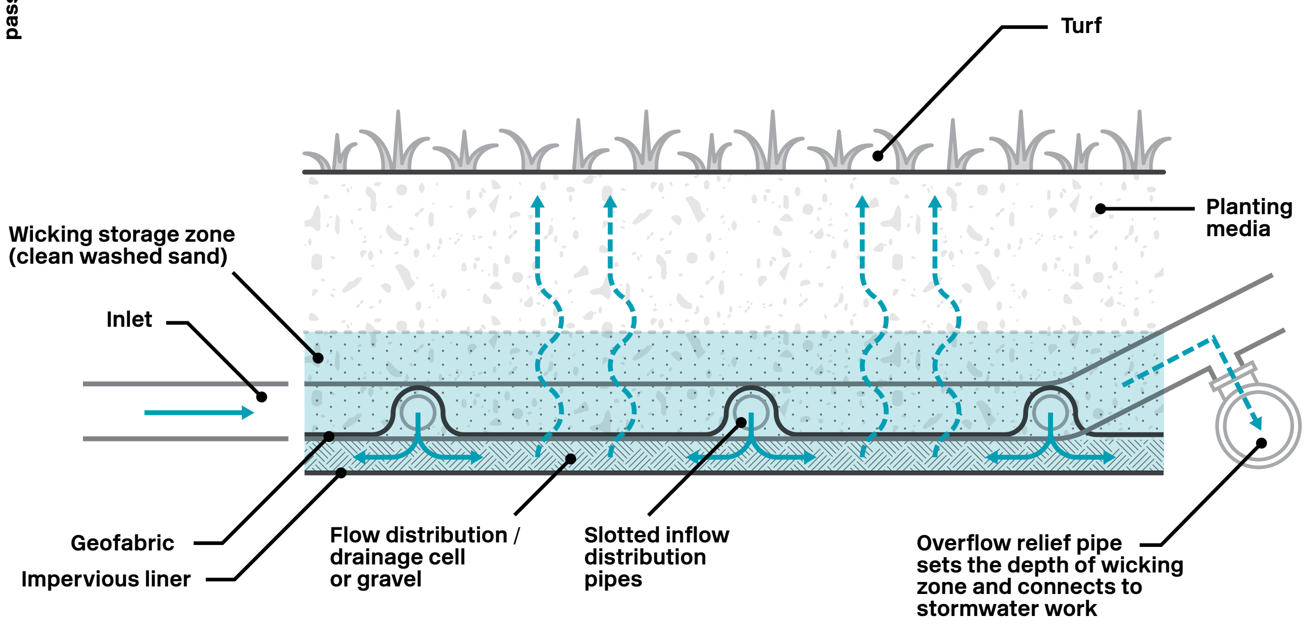
See Section 4 for more details on design components.

Example 7 – Wicking lawn

Typical site characteristics:

- High profile or high use turf/lawn areas

Example section:



Key design components:

Catchment area

The area of wicking lawn is typically large compared with the contributing catchment area. The catchment area required to ensure a reliable source of irrigation for these systems (i.e. >70% reliability) can be as little as 2 times the surface area of the lawn. When designing wicking beds, consideration needs to be given to the wicking zone storage volume, the source of the water (i.e. catchment size), rainfall patterns (frequency of top up) and the water demand of the turf. Pre-treatment of stormwater for litter and sediment removal is required prior to being piped directly to the wicking storage zone. To enable regular top-up of the wicking bed storage, it is important that runoff from rainfall events reaches the storage zone (i.e. no low flow bypass).

Storage

The storage zone for the wicking lawn extends under the full surface area of the system, such that all turf can have equal access to the soil moisture stores. The depth of the storage zone and the porosity of the wicking media will determine the volume of water that can be stored. The maximum depth of the storage zone is determined by the capillary rise or wicking ability of the media while minimum depth is required to incorporate a flow distribution network

Wicking bed composition

The wicking storage zone must enable capillary rise, to sustain soil moisture, even when the water level in the storage zone is low. Fine sand or geosynthetic wicks enable water to rise up into the topsoil zone. Gravel does not permit water to rise and thus should be avoided. The wicking zone should be free from organics and nutrients (e.g. clean washed sand) to avoid nutrient leaching out of the pit.

Flow distribution and outlet

An overflow outlet set at the top of the wicking storage zone is required to avoid the topsoil from becoming waterlogged. The wicking zone should include an impermeable liner or be located on compacted clay to ensure water is retained in the wicking zone and is not lost through exfiltration.

See Section 4 for more details on design components.

Section 4

Design catalogue

Inlet

Designed to connect system to adjacent catchment

Key design considerations:

- Inflows may naturally bypass when storage capture zone is full.
- The width of spillways and inlets should be maximised to avoid scour and blockage.
- Pre-treatment to capture litter and sediment - Street debris such as litter, sediment, and organic (i.e. leaves, sticks, weeds) are often washed into tree pits during rainfall events.

Side kerb opening

Pros:

- Kerb opening is less prone to blockage.

Cons:

- Litter will enter system which will require manual removal.

Modified kerb opening

Pros:

- Clear spillway less prone to blockage.

Cons:

- Lintel (concrete section spanning the opening) must be structurally sound with the use of reinforcement.
- Alternatively, a steel lintel can be adopted (see grill plate example below).

Photo credit: E2Designlab

Pre-treatment with porous pavers

Pros:

- Ensures sediment does not enter the system.
- Recommeded for wicking systems to reduce cleanout frequency of underdrainage.

Cons:

- Requires regular maintenance to retain hydraulic capacity.

Photo credit: Luke Galea (Mackay Regional Council)

Kerb inlet to ag-drain

Pros:

- Lower cost option.
- Can be installed around existing trees.

Cons:

- Limited capture volume (i.e. less water directed to tree and prevented from entering stormwater network).

Photo credit: E2Designlab

Grill plate

Pros:

- Flow from the channel may be directed to the surface of the system while litter is restricted from blocking system.

Cons:

- Grill may become blocked, restricting flows into the system.
- There is no standard configuration as shape is unique to each kerb profile.

Photo credit: E2Designlab

Channel inlet

Pros:

- High inflow capacity.
- Trash basket may be installed in the pit as a pre-treatment device.

Cons:

- Depth of pit.
- This would require customised stormwater pit, and only capable of directing flows to a wicking zone.

Photo credit: Jack Mullaly (Ideanthro)

Pre-treatment with removeable porous rubber bung

Pros:

- Ensures sediment does not enter the inlet pipe.

Cons:

- Requires maintenance to ensure the bung doesn't clog.
- High volume of flow bypass.

Photo credit: Tim Johnson (City of Mitcham)

Pre-treatment with inlet structure

Pros:

- Depression in the kerb combined with an elevated inlet allows sediments to settle before entering the system.

Cons:

- Inlet may become blocked, restricting flows into the system.

Photo credit: Jack Mullaly (Ideanthro)

Pre-treatment with gutter corrugations

Pros:

- Corrugations slow flows and trap sediment.

Cons:

- Requires maintenance to clean out sediment.

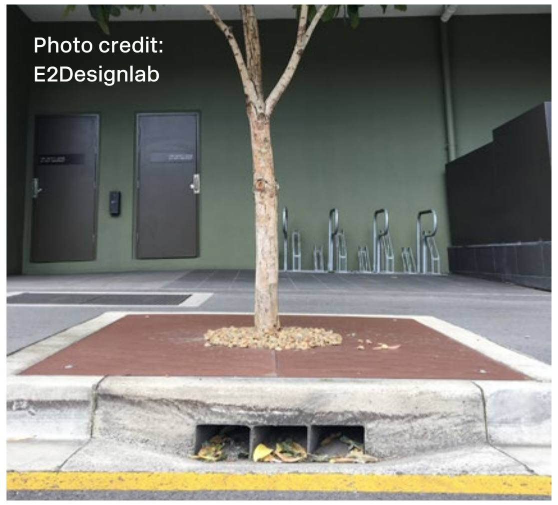


Photo credit: E2Designlab

Rectangular hollow sections

Pros:

- Rectangular steel sections can be used to provide an inlet to the surface of a tree pit.
- The steel sections will provide structural support to the kerb and/or tree grill over.

Cons:

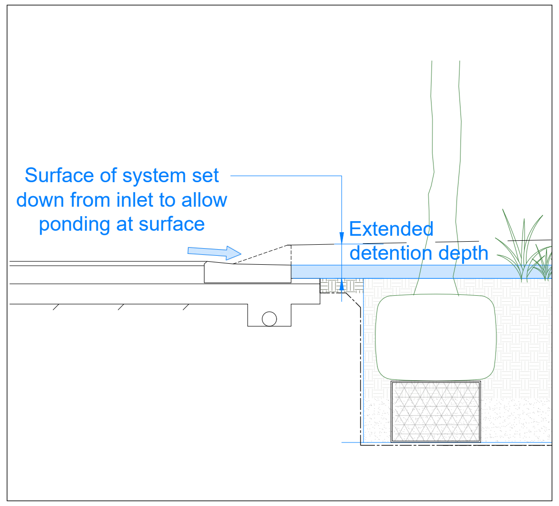
- The sections are prone to blocking with debris.

Capture storages

Stormwater capture for soil moisture and water quality will be limited by the capture volume of the system

Key design considerations:

- Capture volume is defined by the open surface area (window) and depth of extended detention of the system.
- Flows which exceed the capture volume will bypass the system.
- Extended detention can also be provided under paved areas using structural soil systems with gravel in the top layer, to create void space for water storage.



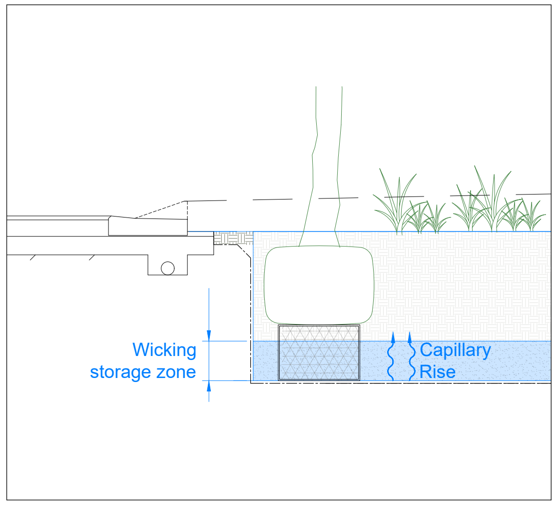
Extended detention

Pros:

- Most common form of achieving stormwater capture.

Cons:

- Deep extended detention creates a step into the system which may require tree grill or barrier to avoid public safety hazard.



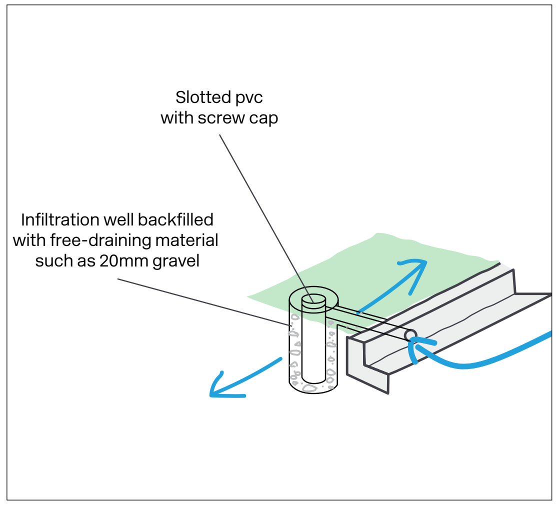
Wicking zone

Pros:

- As the plants remove water from the soil it is replaced by water replenished from the storage below by capillary action thereby ensuring optimal soil moisture conditions for healthy growth.

Cons:

- System will require a liner to retain wicking zone (unless in-situ soils are impermeable).



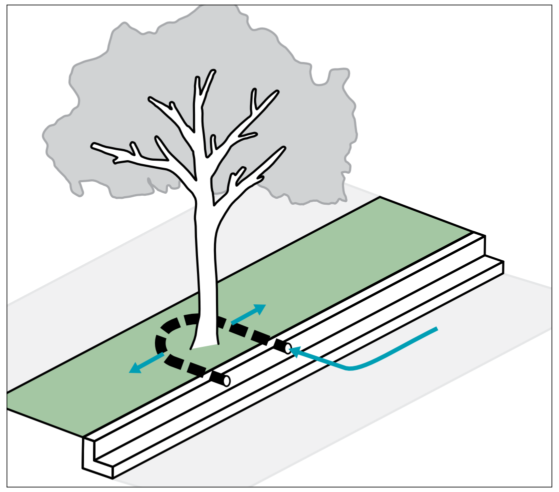
Infiltration well

Pros:

- Infiltration well may be used to connect adjacent stormwater pits to a soakage within the tree soil volume.

Cons:

- Volume of capture storage is dictated by the void space and total volume of soakage well.



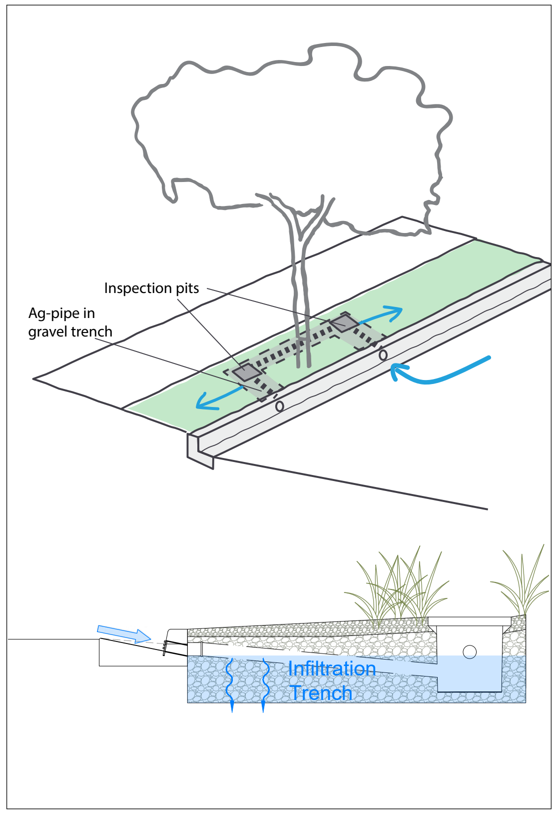
Ag-pipe in gravel infiltration trench with inspection pits

Pros:

- Gravel trench and slotted ag-pipe that allows water into the trench via the pipe, and provides water storage in the voids of the gravel.

Cons:

- Volume of capture is limited by the void ratio of the gravel.



Ag-pipe infiltration trench

Pros:

- Can be installed around existing trees for retrofit projects.
- Cheap and simple way to achieve infiltration.

Cons:

- Prone to blockage if debis enters pipe.
- Limited water storage capacity.

Tree grates

Improve safety where accessible by pedestrians or vehicles

Key design considerations:

- Aesthetic and cost.
- Structural support for tree grate is required across spillway/inlet.
- Surface area (window) will be limited to standard tree grate sizing which is approximately 1.5 m x 1.5 m

Additional design considerations:

- Designers should include void under the grate or plate to allow airflow.
- Structural support for tree the grate.
- Grate should include rings that can be removed as tree trunk expands.

Pros:

- Well suited to high pedestrian traffic, urban areas.
- Can lower surface levels under grate to provide ponding and extended detention.
- Prevent litter and debris entering system and can lift grate to clean underneath.

Cons:

- Costly.


Photo credit: E2Designlab


Photo credit: E2Designlab

Underdrainage

Designed to ensure soil is not waterlogged

Key design considerations:

- Should ensure at a minimum that the top 400-500 mm of soil is free draining.
- Pipe size and spacing based on soil infiltration rate and system surface area.
- Slots within pipe adequately sized to allow infiltration of water.
- Underdrains will ensure road pavement and structural subgrades adjacent to tree pit do not fail due to saturation.
- Constrained systems may have no underdrainage if in-situ soils are free draining and capture volume is small.


Photo credit: E2Designlab

Slotted PVC

Pros:

- Can be uniformly laid at flat grades or up to 1% grade.
- Smooth internal face assists flushing.

Cons:

- Higher cost.
- Bend and fixtures must be installed adding to cost and reducing inflow capacity.
- Shape is unique to each kerb profile.


Photo credit: E2Designlab

Flexible ag-pipe

Pros:

- Flexible pipe -improved ease of installation.

Cons:

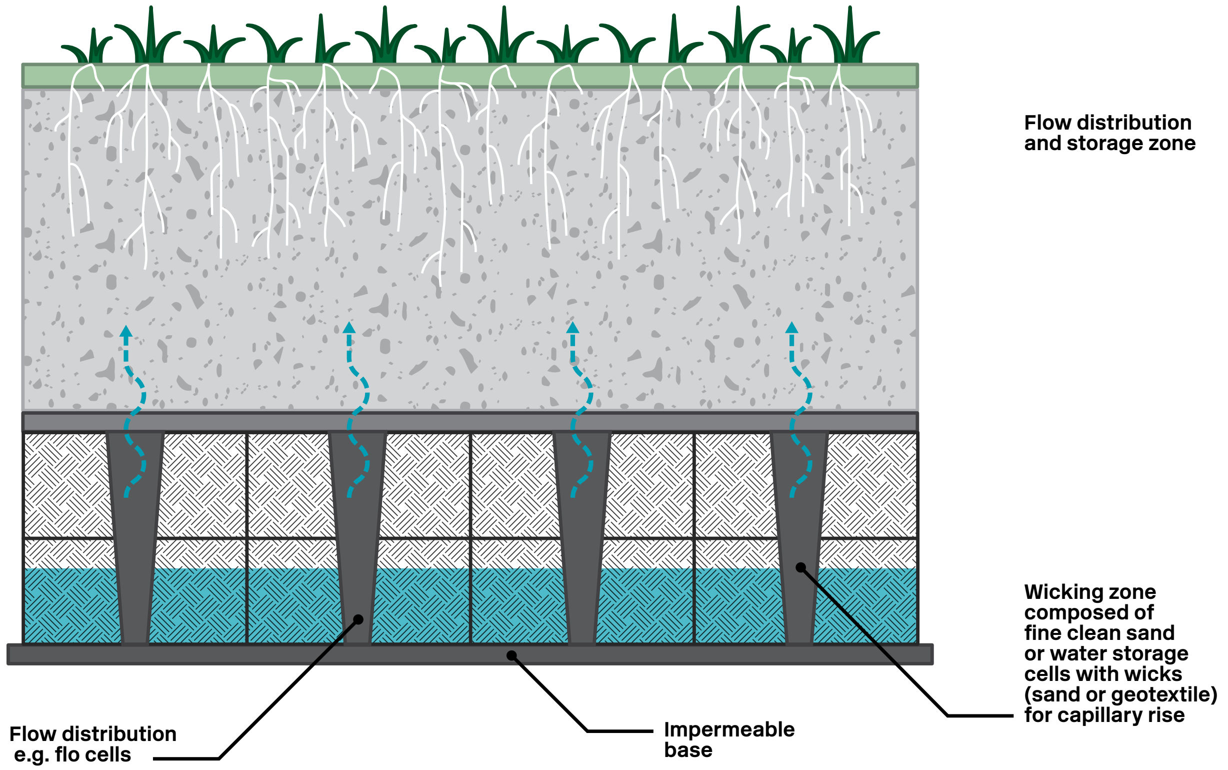
- Difficult to flush.

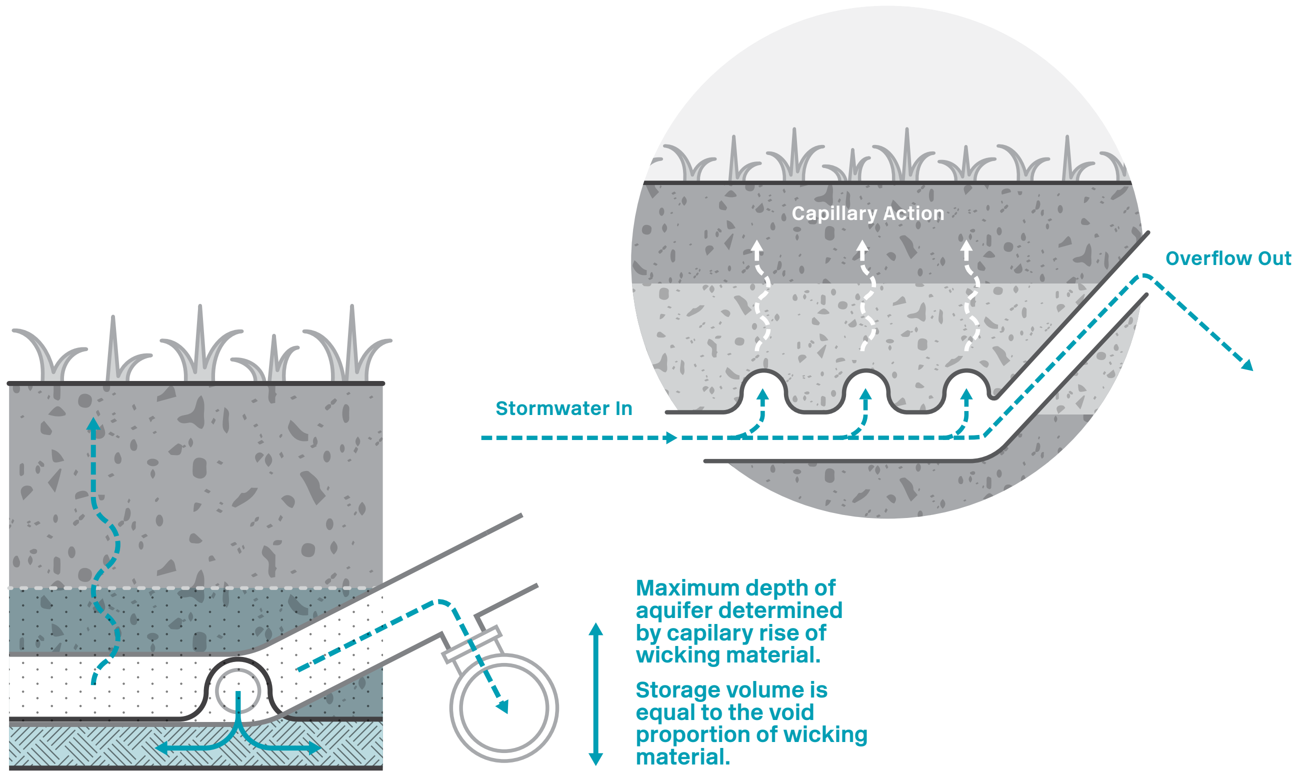
Subsurface storage zone and wicking bed media

For turf wicking beds and to support tree growth during dry periods

Key design considerations:

- Water storage defined by the void ratio of storage media.
- Maximum depth defined by the capillary rise of storage media.
- Subsurface storage zones are more likely to be required in arid climates or those with long dry seasons.
- Systems with small catchments will also benefit from storage zones.





Fine sand

Pros:

- Height of capillary rise is higher in fine media so the allowable depth of the system is greater.

Cons:

- Lower void ratio will provide a lesser water storage volume.

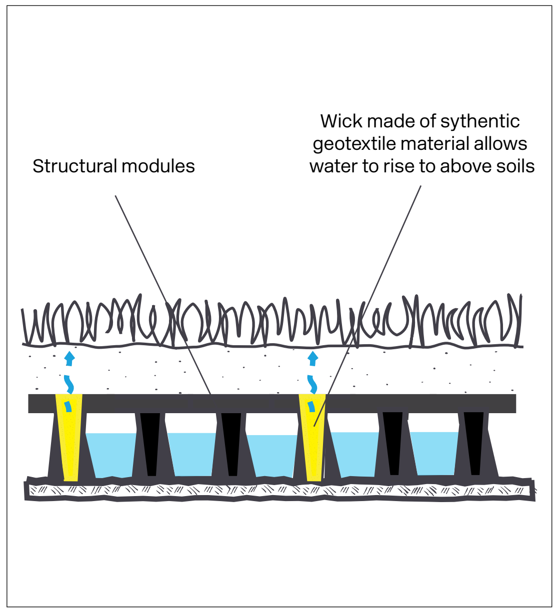
Coarse sand

Pros:

- Greater void ratio will provide a larger water storage volume.

Cons:

- Height of capillary rise is lower in coarse media so the allowable depth of the system is less.



Synthetic geotextile wick

Pros:

- Can be combined with structural modules to create high storage volume system.

Cons:

- Testing of the capillary rise of the sythetic material adopted is required to confirm allowable depth of the system. The ability of the wick to evenly supply soil moisture throughout the soil profile also requries testing to confirm wick spacing.

Outlets

Underdrainage should connect to a legal point of discharge (outlet)

Key design considerations:

- Utilise existing or proposed pipes close to the systems where possible.
- Can be freely draining or elevated to create upstream storage zone.
- Constrained sites may utilise road subsoil drains.
- Excess flows will bypass system.

Overflow pits

Pros:

- High flow capture efficiency.
- Connects to underground stormwater drainage.

Cons:

- Should be raised above the surface level of the tree to create extended detention for ponding.

Kerb overflows

Pros:

- Outlets at downstream of the system can be designed to allow excess stormwater to pass out of the system and continue downstream.

Cons:

- The surface level should be lower than the surroundings to ensure regular stormwater inflows pond within the system, and do not quickly pass through and exit.

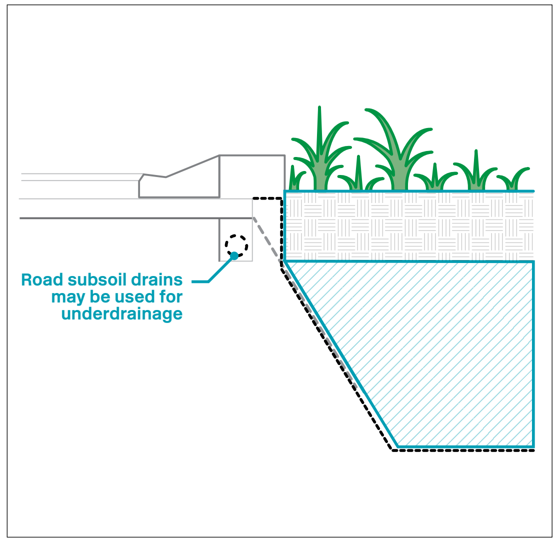
Inlet controls

Pros:

- In systems with extended detention, inlets may also act as a stormwater outlet whereby flows backwater into the kerb and channel once extended detention is reached. This may occur for designs with kerb edges, where an opening is provided on the downstream edge.

Cons:

- The tree pit surface level should be lower than the overflow and the surroundings to ensure regular stormwater inflows pond within the system, and do not quickly pass through and exit.



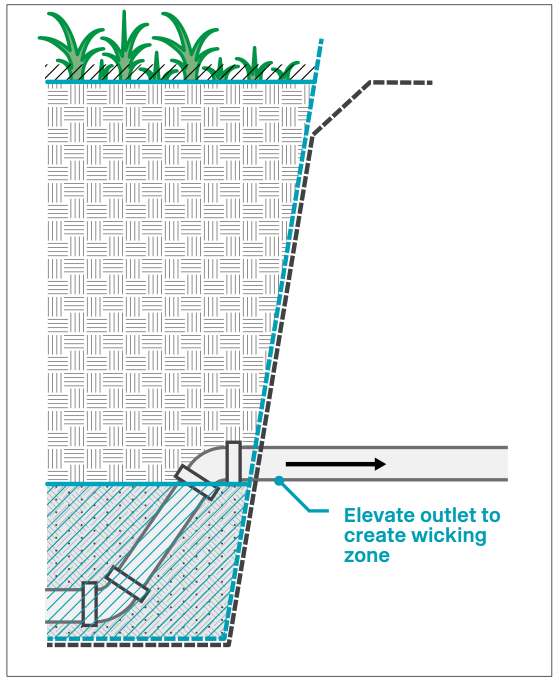
Existing subsoil drain

Pros:

- Low cost opportunity to utilise existing infrastructure which is commonly found.
- Should ensure top 400-500 mm of the systems can freely drain.

Cons:

- Base of the system will remain saturated as subsoil drains are typically located at a high level.
- Need to confirm with road engineers that the drain has adequate capacity.



Elevated outlet to create wicking zone

Pros:

- Can provide water storage during extended dry periods.
- Good for tree health as plant can access water as required.

Cons:

- Liner may be required to confine storage zone.

Tree selection

Ensure the tree selected is suitable to the local soil type, climatic conditions and the site's spatial, access and infrastructure constraints

Key design considerations:

Effective nutrient removal

Where passively irrigated tree pits form part of the stormwater quality management strategy for a site, it is important to select tree species that will be effective at nutrient removal. Previous research has identified the key plant characteristics that provide effective nutrient removal. An extensive and fine root system is a trait which is particularly important for nitrogen removal. The CRCWSC's Adoption Guidelines for Stormwater Biofiltration Systems (2015) provides a good summary of effective nutrient removal vegetation.

Further research into the nutrient removal effectiveness of a variety of tree species would be beneficial to demonstrate and confirm the nutrient removal performance of passively irrigated tree pits.

High and Low Water Use Trees

All trees will increase their transpiration in hot urban environments when there is a good supply of soil moisture. The typical tree characteristics below can be used as a guide to determine the water use of a selected tree species.

Characteristics of low water use trees:

- Leaves with thick and/or waxy cuticles
- Reduced leaf surface area
- Reduced number of stomata and/or stomata located on underside of leaves
- Known to be very drought tolerant/ drought adapted

Characteristics of high water use trees:

- Large and/or relatively soft leaves
- Large leaf surface area
- Known to be a "thirsty" tree or one that naturally occurs in ephemeral (e.g. Melaleuca) or moist soil environments (e.g. Rainforest species)

Soil media

Ensure the soil is horticulturally suitable for plants

Key design considerations:

- Soil volume should be large enough to support fully mature tree. Where in-situ soils are of adequate quality, the system should be designed to allow tree roots to grow beyond tree pit and also to access deep soil moisture.
- Organic matter should not leach nutrients when saturated.
- Particle size distribution should be well graded and ensure the soil retains hydraulic conductivity between 50-100 mm/hr ksat.
- Where tree pits are being designed to achieve stormwater management objectives, reference should be made to the adjacent table to inform soil media specifications in consultation with soil specialist to ensure media will support healthy plant growth, maintain infiltration and won't leach nutrients.

Based on Appendix C - Adoption Guidelines for Stormwater Biofiltration Systems (Version 2) Cities as Water Supply Catchments – Sustainable Technologies (Project C1.1)

Soil media	
Property	Specification to be met
Material	Loamy Sand or Sandy Loam. Either a naturally occurring soil or engineered material, possibly a mixture.
Hydraulic Conductivity	50 – 100 mm/hr. Determine using ASTM F1815-11 method
Clay & Silt Content	2-6% (w/w)
Nutrient Content	Low nutrient content Total Nitrogen (TN) < 1000 mg/kg Available phosphate (Colwell) < 80 mg/kg
Organic Matter Content	3-5% (w/w) to support vegetation (lower organic content acceptable at depths greater than 300mm to avoid anaerobic breakdown)
pH	5.5 – 7.5 – as specified for 'natural soils and soil blends' in AS4419 – 2003 (pH 1:5 in water)
Electrical Conductivity	< 1.2 dS/m – as specified for 'natural soils and soil blends' in AS4419 – 2003
Horticultural Suitability	Assessment by horticulturalist – media must be capable of supporting healthy vegetation. Note that additional nutrients are delivered with incoming stormwater
Particle Size Distribution (PSD)	Note that it is most critical for plant survival to ensure that the fine fractions are included (see PSD table below). Smooth grading – all particle size classes should be represented across sieve sizes from the 0.05mm to the 3.4mm sieve (as per ASTM F1632-03(2010)
Once-off Nutrient amelioration	Added manually to top 100 mm once only. Particularly important for engineered media

	(% w/w)	Retained
Clay & silt	< 3%	(< 0.05 mm)
Very fine sand	5-30%	(0.05-0.15mm)
Fine sand	10-30%	(0.15-0.25 mm)
Medium sand	40-60%	(0.25-0.5 mm)
Coarse sand	< 25%	(0.5-1.0 mm)
Very coarse sand	0-10%	(1.0-2.0mm)
Fine gravel	< 3%	(2.0-3.4 mm)

The contractor is to arrange for batches of media to be tested by a NATA accredited lab to ensure compliance with the parameters above. Filter media should be tested at a rate of 1 per 500m^3.

Structural soil cells

Allow increased soil volumes where surface areas are constrained by pavements

Key design considerations:

- Structural integrity requires base course to provide adequate bearing capacity.
- Can provide support within the zone of influence of existing or proposed services.

Pros:

- Allow room for high quality soils underneath pavements.
- Less volume needed to support a healthy tree than alternative structural soil mixes.

Cons:

- Costly.
- Cells may be damaged when undertaking maintenance works for existing services.

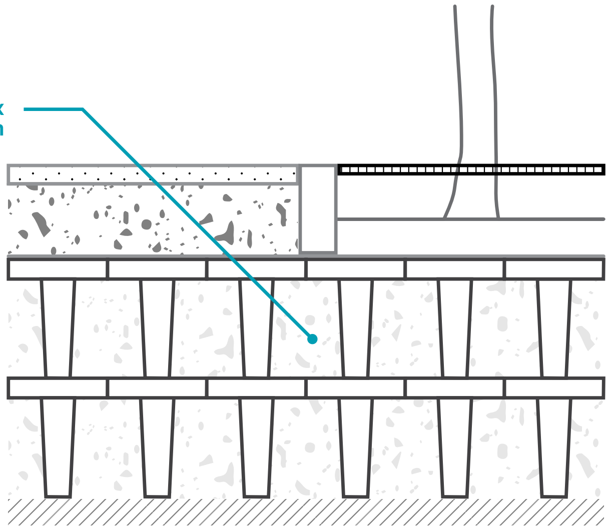



Photo credit:
E2Designlab

Impervious liner

Liner may be proposed in a system for a number of reasons including:

- **To protect tree from adverse soil conditions (i.e. salinity or contamination)**
- **Contain water storage within storage zone**
- **Protect adjacent infrastructure and buildings from seepage**

Key design considerations:

- Impervious liner should only be specified where required to meet a specific design purpose.
- Alternatively, in good soils, trees should have access to deep moisture and adjacent in-situ soils.
- Should be certified to ensure a maximum hydraulic conductivity of 1x10-9 m/s.


Photo credit:
E2Designlab


Photo credit:
E2Designlab

Photo credit: E2Designlab

In-situ clays may be used subject to Geotech analysis

Pros:

- Cost effective and sustainable option.

Cons:

- Geotechnical testing required.

Photo credit: E2Designlab

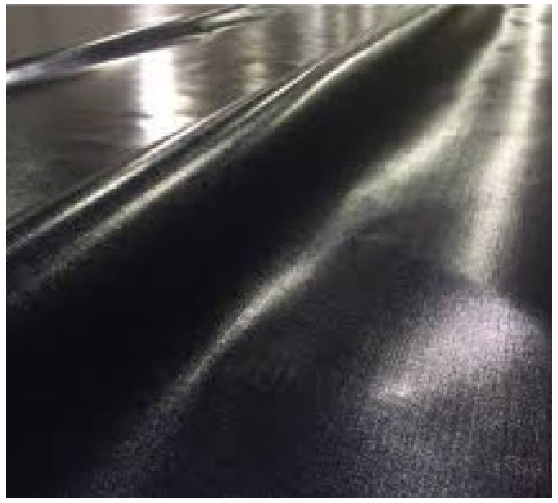
Geosynthetic clay liner

Pros:

- Flexible material suitable to many system shapes.

Cons:

- Material is heavy and can be difficult to use in small areas.
- GCL requires a soil backfill as material is dispersive in open water.



PE liner

Pros:

- Lightweight and durable.

Cons:

- Requires on-site welding of joints to ensure it is sealed and doesn't leak.
- Prone to puncture if rocks or tree roots are present.
- Prone to UV degredation.

Photo credit: E2Designlab

Bentonite paste used to seal protrusions

Pros:

- Easy to apply on site.

Cons:

- Must be used at all protrusions to ensure liner does not leak.

Open systems

Allow planting of understory species

Key design considerations:

- Surface of system should be flat where extended detention is proposed.
- Suitable in locations which have few space constraints. Will be less expensive and have greater capture volume than systems with tree grate or soil modules.

Photo credit: E2Designlab

Edge treatment

Structurally sound to support adjacent pavement or structures

Key design considerations:

- Height drops from adjacent pavements should be minimised to improve integration with tree pit.
- Batters may be used in lieu of edge restraints where space allows.
- All edge treatments must be fit for purpose and respond to safety in design reviews.

Vegetation

Pros:

- Can be used to create flush visual effect when garden bed is sunken below the adjacent land.
- Allow water to sheet into system.
- Buffers and slows flows entering system.

Cons:

- Surface level beneath vegetation should typically be sloped on the edges (e.g. 1 in 3 batters), to avoid a tripping hazard in case someone should step into the garden bed.

Kerb edges

Pros:

- Effective in separating pedestrians, cyclists and vehicles from system.
- Cut-outs can be included in edge to allow surface flows to enter system.

Cons:

Retaining structures and seating

Pros:

- Formal seat furniture can be included (which may not provide structural retaining), separating pedestrians from garden.
- Tall retaining structures can deter pedestrian from walking over the tree pit, while providing seating.

Cons:

- High cost solution.

Staggered planted buffers

Pros:

- For larger set-downs, staggered planted buffers can be used to deter pedestrian traffic and enhance amenity outcomes while providing a lowered surface (extended detention) for ponding stormwater.
- Creates safe set-downs.

Cons:

- Requires adequate space to adopt.

Broken concrete edge

Pros:

- In this photo example, a broken concrete edge separates trees from vehicles along a central median strip.
- Breaking the concrete edge allows runoff to enter the asset across the entire length of the system.
- Can also be used along one edge for solutions within nature strips, where they sit flush with adjacent land.

Cons:

- Potential trip hazard.

Surface treatments

There is a wide variety of surface treatments to complement system locations

Key design considerations:

- Durability requirements to suit pedestrian and vehicle traffic.
- Maintenance frequency.
- Cost and aesthetics required for locations.

Photo credit: E2Designlab

Resin-bound gravel

Pros:

- Available in permeable or non-permeable form.

Cons:

- Expensive.
- Will require cleaning to maintain permeability.

Photo credit: E2Designlab

Porous asphalt, no-fines concrete

Pros:

- Low-cost solution.

Cons:

- Concrete prone to cracking, which produces dangerous edges.
- Will require cleaning to maintain permeability (pressure washing).

Photo credit: E2Designlab

Permeable pavement

Pros:

- Suited to high profile sites with heavy pedestrian traffic.

Cons:

- Typically requires cleaning to maintain permeability (e.g. pressure washing).
- Permeability testing should be undertaken to inform frequency of maintenance.

Photo credit: E2Designlab

Vegetation

Pros:

- Maximum vegetation and aesthetic benefits.
- Stormwater nutrients removal.
- Vegetation also provides natural mulch and surface stabilisation.

Cons:

- Requires maintanance and replacement if plants die.

Photo credit: E2Designlab

Bare soil

Pros:

- Low-cost soil surface finish.
- Best suited to flat sites.

Cons:

- Design may be susceptible to erosion and weeds.

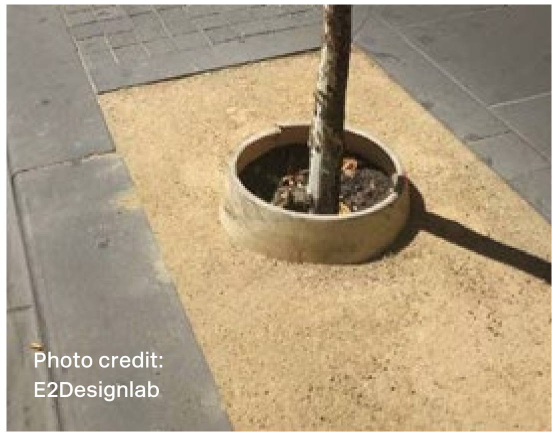


Photo credit: E2Designlab

Stabilised sand

Pros:

- Cheap and easy to install and replace.

Cons:

- Can be damaged by street sweepers, and the sand can deposit in drains.
- Not ideal adjacent to permeable pavement, as the sand can clog the pavement.

Photo credit: E2Designlab

Mulch

Pros:

- Helps to retain soil moisture.
- Weed suppression.

Cons:

- Light mulches can wash into stormwater networks unless pinned down with a biodegradable netting.

Energy dissipation

Systems which experience high inflow velocities should be designed to avoid scour

Key design considerations:

- Rocks should be adequately sized or grouted to ensure stability and discourage vandalism.
- Vegetation is effective however subject to die off which would make the system vulnerable to scour.
- Many systems will naturally backwater when storage volume is full, which will naturally reduce inflow velocities.

Bands of dense vegetation

Pros:

- Highest landscape asthetic.

Cons:

- If vegetation fails the bare soils are prone to scour.

Drop structure

Pros:

- Energy dissapation can occur over a confined length.

Cons:

- Higher-cost solution (note this is likely to be less cost than addressing extensive scour).

Rocks

Pros:

- Provides long term stability.
- Suits the natural asthetic of a vegetated system.

Cons:

- Should be adequately sized for flows.

Section 5

Construction, establishment and maintenance

Construction

The sucessful construction of passively irrigated landscapes will require coordination between the design team, and civil and landscape contractors. Table 5 presents the construction phases which may be required to deliver a passivly irrigated landscape. It is important that there are hold points at each stage to ensure systems are delivered according to original design intent. Example sign-off forms have been provided in Appendix A.

Table 5 – Typical passively irrigated landscape construction phases

Construction phase	Design elements
Pre-start meeting	Confirmation of responsibilities and clarity of design
Bulk Earthworks	Set out system Location of existing services Base course preparation
Impervious Liner	Installation to specification
Underdrainage	Layout and size as per design
Structural Cell / Soil	Layout and installation to specification
Soil Media	Material delivered to site meets specification Testing of in-situ material
Finished Levels and Hard Landscape Features	Levels as per design and flush with adjacent areas
Protective Measures	Ensure systems are protected during construction phase prior to landscape installation
Landscape Installation	Plants are healthy and meet specification
Landscape Establishment	Additional maintenance required during establishment period

Construction and establishment

The construction and establishment phases will be important to ensure the passively irrigated landscape is well established for long term survival. In greenfield developments adequate erosion and sediment control must be in place to reduce the risk of sediment laden stormwater flows entering the passive irrigation system to reduce the risk of the tree pit surface clogging or the water storage reservoir filling with sediment. It is recommended that stormwater from the development site is bypassed around the systems until construction is 80-90% complete.

During the establishment phase, the landscapes will likely require additional irrigation until the tree or grass is established (first 1-2 growing seasons, depending on the vegetation type). During this time regular watering, weeding, pruning/mowing and monitoring for pests and disease will be important.

Maintenance

Passively irrigated landscapes should be designed to be resilient and robust by incorporating species that thrive in the local area and under the design conditions. However, vegetated systems will require ongoing monitoring and maintenance to ensure they are operating in accordance with the design intent. Typical maintenance activities include:

- Removal of organic matter
- Leaf litter removal
- Minor sediment removal
- Plant densities – infill planting
- Weed removal
- Pruning
- Plant health check
- Minor surface level adjustments.

These assets are typically located in high profile and high traffic areas, and as such, maintaining a high level of function and aesthetics is important. It is therefore suggested that routine inspections and maintenance should be undertaken every 2 months and after significant rainfall events to ensure the system is operating as required.

Regular inspection of the systems may occasionally identify issues that require more significant corrective maintenance. These assets require more comprehensive works to reconfigure some of the key features to ultimately reinstate the function of the asset. Reasons that rectification or resetting might be required include poor design or construction, inadequate establishment phase maintenance or altered/unforeseen site conditions. These activities may require special equipment or skills. Examples of potential corrective maintenance actions include:

- Major sediment removal
- Drainage review (e.g. standing water present)
- Extensive vegetation replacement
- Major scour or erosion repair
- Planting media reinstatement
- Algae or moss management.

Keeping and maintaining records on the condition of the systems and all maintenance works required will be important to inform and schedule future maintenance works.

Part B

Designing for a cool city – Climatic zone sizing guides for passively irrigated trees

Soil moisture modelling using MUSIC has been completed to help inform the design of passively irrigated street trees in different climatic zones of Australia[2]. The results of this modelling can be used to inform passive watering system design to achieve optimal tree health and stormwater quality and quantity management.

Modelled climatic regions

Soil moisture modelling has been undertaken for climatic zones in Queensland, New South Wales and South Australia (see Table 6 and Figure 12). These locations represent a diverse range of climatic zones as shown by the varying rainfall and evapotranspiration rates in Figure 13. Additional climatic zones will be modelled over time to add to the suite.

Table 6 – Climatic regions with soil moisture modelling outputs

Queensland	New South Wales	South Australia
• Wet Tropics (Cairns) • Dry Tropics (Townsville) • Central Coast- North (Mackay) • Central Coast- South (Rockhampton) • South East Queensland- North (Sunshine Coast) • South East Queensland-West (Ipswich)	• City of Blacktown (Western Sydney) • Sydney	• Adelaide

—

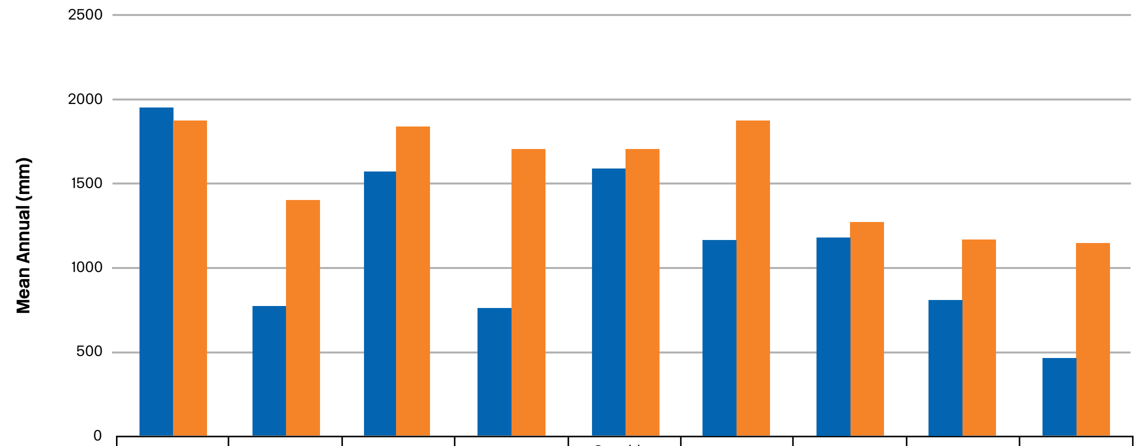
[2] This work was possible due to the support of Healthy Land and Water, the Queensland Government funding through the Urban Stormwater and Erosion and Sediment Control Capacity Building Project for the Great Barrier Reef, participating local governments and the CRCWSC.

↓

Figure 12 – Location of climatic zones with soil moisture modelling outputs

→

Figure 13 - Comparison of climatic zone annual rainfall and evapotranspiration rates



	Cairns	Ipswich	Mackay	Rockhampton	Sunshine Coast	Townsville	Sydney	Blacktown	Adelaide
Rainfall	1949	765	1564	761	1582	1165	1176	808	450
Evapotranspiration	1872	1393	1832	1704	1704	1856	1261	1169	1159

Modelled methodology

The modelling and analysis were undertaken using the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) and post processing and analysis. The methods are outlined below.

Rainfall data collection

For each climatic zone, a rainfall station with a minimum 10-year period of 6 minute rainfall data was chosen for the modelling analyses. This data selection was based on a review of recommended local rainfall templates and to ensure that the data met the following criteria:

- <10% of accumulated data
- <2% of missing data
- 10-year average annual rainfall closely resembles the long term average of the station (mm).

Table 7 summarises the rainfall stations and data periods which were used for each climatic zone.

Table 7 - Rainfall stations and rainfall period adopted

Location	Station	Date	
		Start	End
Cairns	31011 CAIRNS	01/01/1975	31/12/1984
Townsville	32040 TOWNSVILLE	01/01/1970	31/12/1983
Mackay	33119 MACKAY	05/01/1990	10/01/2000
Rockhampton	39083 ROCKHAMPTON	05/01/1980	16/01/1990
Sunshine Coast	40282 SUNSHINE	06/01/1985	05/01/1999
Ipswich	40004 AMBERLEY	10/01/1990	04/01/2000
Sydney	66062 SYDNEY (OBSERVATORY HILL)	01/01/1978	29/12/1987
Blacktown	67033 RICHMOND RAAF	02/01/1966	23/12/1975
Adelaide	23013 PARAFIELD AIRPORT	01/01/1979	31/12/1988

Tree pit modelling parameters

MUSIC models were created to model the soil moisture and stormwater treatment performance of tree pit systems in each climatic zone. Given self-watered tree pits typically accept flows onto their surface and discharge excess flows that pass vertically through the soil profile from their base (as per bioretention systems), the bioretention node was adopted and the parameters adjusted to reflect the characteristics of a passively irrigated tree pit.

The following parameters (Figure 14) were modified to assess the influence on soil moisture and stormwater treatment performance:

- Size of tree pit compared with catchment area: 1% to 10% tree pit to catchment area ratio
- MUSIC Potential Evapotranspiration (PET) factor : 1.50 (low to medium water use trees/ drought tolerant species) and 1.85 (high water use trees)[3]
- Planting media: Filter media/loamy sand (100 mm/hr hydraulic conductivity) and landscape topsoils/sandy loam (50 mm/hr hydraulic conductivity)
- Wicking storage zone (0.3 m deep): with and without
- Underdrainage: with and without
- Extended detention: 10 mm and 100 mm

The modelling was limited to 16 design configurations which use different combinations of the above variables. These designs and their configurations are described in Tables 8 and 9. Table 8 presents the design configurations which all had underdrainage and 100 mm extended detention and tested different tree PET, planting media and wicking storage options. Table 9 presents the design configurations which all had 10 mm extended detention and no wicking zone and tested different tree PET, planting media and underdrainage options.

Using these 16 designs, various catchment sizes were then tested for each design.

In addition to these varying parameters, each tree pit was modelled with the following fixed parameters:

- 85% impervious fraction for the contributing catchment
- 3 month ARI for the high flow bypass.

Both of these parameters were previously assessed and found to be insensitive to changes in design. All tree pits were modelled with 0.36 mm/hr exfiltration rate (similar to clay) to provide a conservative comparison with systems with underdrainage (which can also represent free-draining in-situ soil conditions).

–

[3] Water loss from vegetated systems is largely through evapotranspiration. MUSIC includes a "PET scaling factor" to represent this avenue of water loss. The default value adopted in MUSIC is 2.1, based on a densely vegetated raingarden with vigorously growing Carex appressa. For the purposes of this project, this factor was reviewed and subsequently changed based on the expert advice of Dr David Doley (Honorary advisory position with the Center for Land Mine Rehabilitation following 30 years at Department of Botany, University of Queensland) and supporting literature (Stibbe et.al.; Cohen; Fine; Shashua-Bar et.al 2011) to better reflect the PET of street trees in urban environments.

Note, the evapotranspiration factors reported in the literature are based on pan evaporation. A conversion to potential evapotranspiration was undertaken to satisfy the requirements of the MUSIC model.

The PET scaling factors adopted are:

- 1.5 – low to moderate water use trees (drought tolerant species)
- 1.85 – high water use trees (trees such as rainforest species and Melaleuca quinquenervia which will transpire water when available and can also show some drought tolerances).

All plants will increase their transpiration in hot urban environments when there is a good supply of soil moisture.

All modelling scenarios in this guideline also assume the tree pit surface area is the same as the area available for extended detention (Figure 14). Scenarios where the area available for extended detention ponding is smaller than the tree pit surface area (i.e. part of the tree pit soil surface is located directly under pavement) have not been modelled.

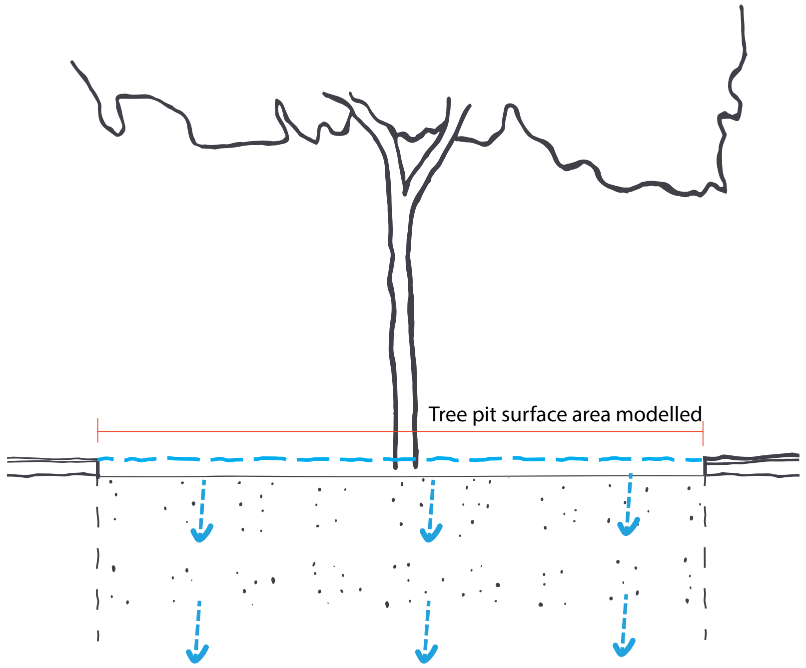


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Figure 14 - Modelled scenarios assume the tree pit surface area is the same as the extended detention surface area (left) and doesn't include scenarios where the extended detention surface area is smaller than the tree pit surface area (bottom right)

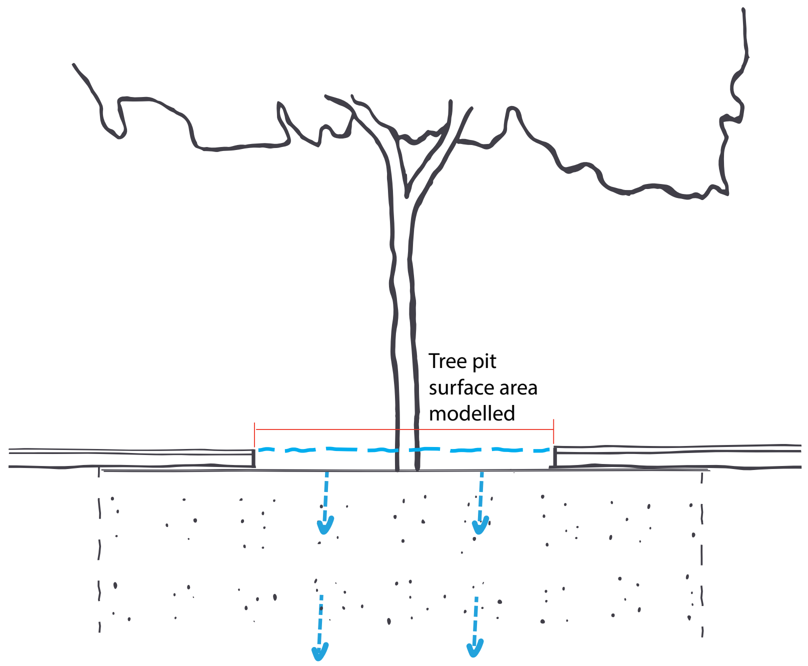


Table 8 – Model Run 1 parameters

Design	Tree water use	Planting media	Wicking storage	Underdrainage	Extended detention
1a	Low	Sandy Loam	Yes	Yes	100 mm
2a	High				
3a	Low	Loamy Sand			
4a	High				
5a	Low	Sandy Loam	No		
6a	High				
7a	Low	Loamy Sand			
8a	High				

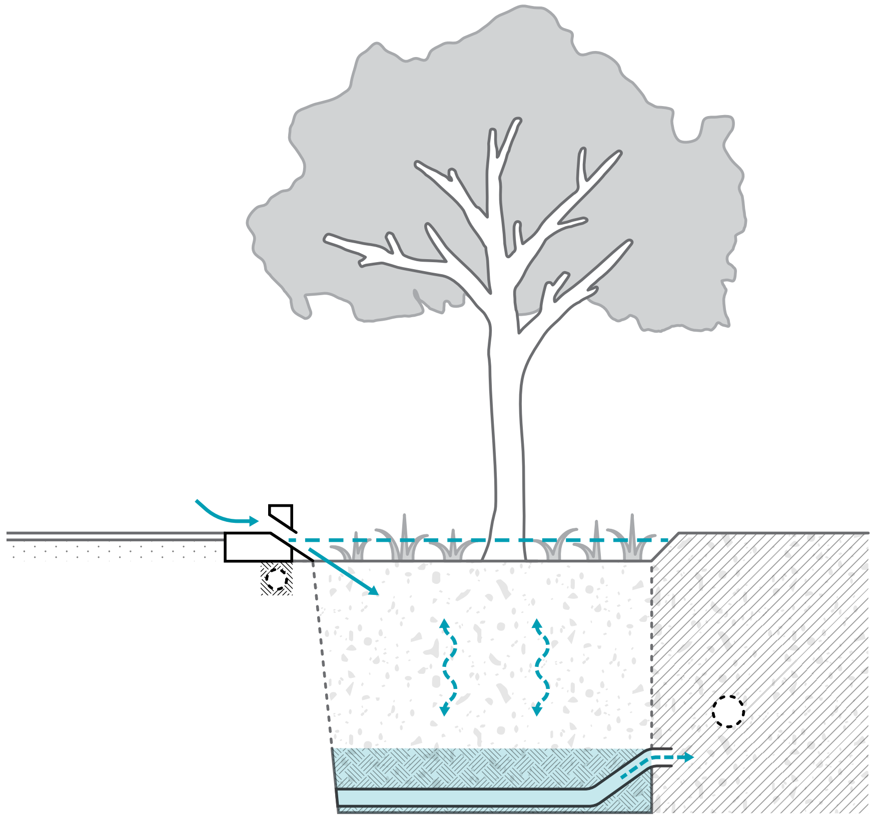


Figure 15 - Typical cross section through Design Type 1a-4a passively watered street trees (with wicking storage)

Table 9 – Model Run 2 parameters

Design	Tree water use	Planting media	Wicking storage	Underdrainage	Extended detention
1b	Low	Sandy Loam	No	Yes	10 mm
2b	High				
3b	Low	Loamy Sand			
4b	High				
5b	Low	Sandy Loam		No	
6b	High				
7b	Low	Loamy Sand			
8b	High				

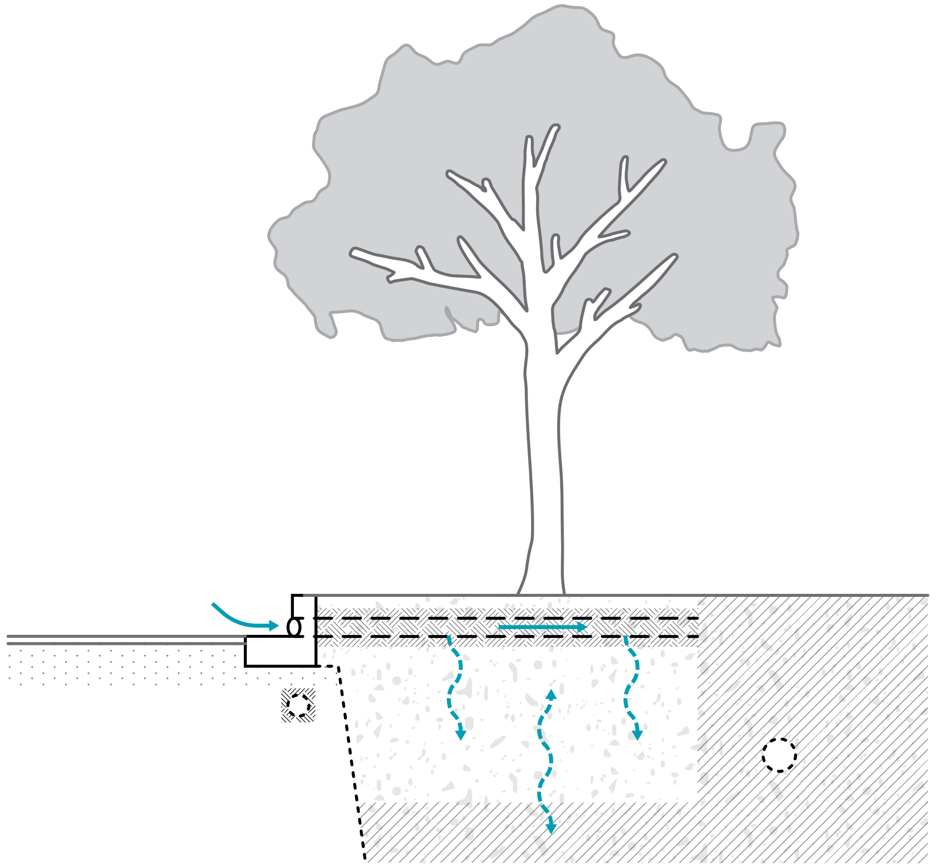


Figure 16 - Typical cross section through Design Type 5b-8b passively watered street trees (10 mm extended detention and no underdrainage)

Post-modelling data analysis

Through additional software processing, soil moisture curves were created for the 16 configurations at 1-10% tree pit to catchment area sizes for each climatic zone. This was completed to gain an appreciation of how the soil moisture conditions varied between the design configurations and if they could support healthy tree growth. Extended dry and wet soil periods were also identified via wet and dry spell histograms to select configurations that were most resilient to the climatic zones seasonal variations.

The benchmarks for optimal soil moisture were defined as:

- Ensure dry soil spell events greater than 35 days do not occur more than once per year. A dry spell event is defined as a period where soil moisture drops to 0.11 (11%).
- Ensure wet soil spells don't exceed more than 5 days in duration. A wet spell event is defined as a period where soil moisture is greater than or equal to 0.8 (80%).

These objectives were selected based on consideration of vegetation tolerances of extended dry and wet conditions. The intent is to minimise the need for active management and irrigation with potable water.

As an example of how climatic regions may affect the soil moisture of a system, soil moisture curves and dry spell histograms are provided on the following pages for two different climatic zones. These represent another way to view the modelling results which informed the tree pit sizing guides presented in on page 84.

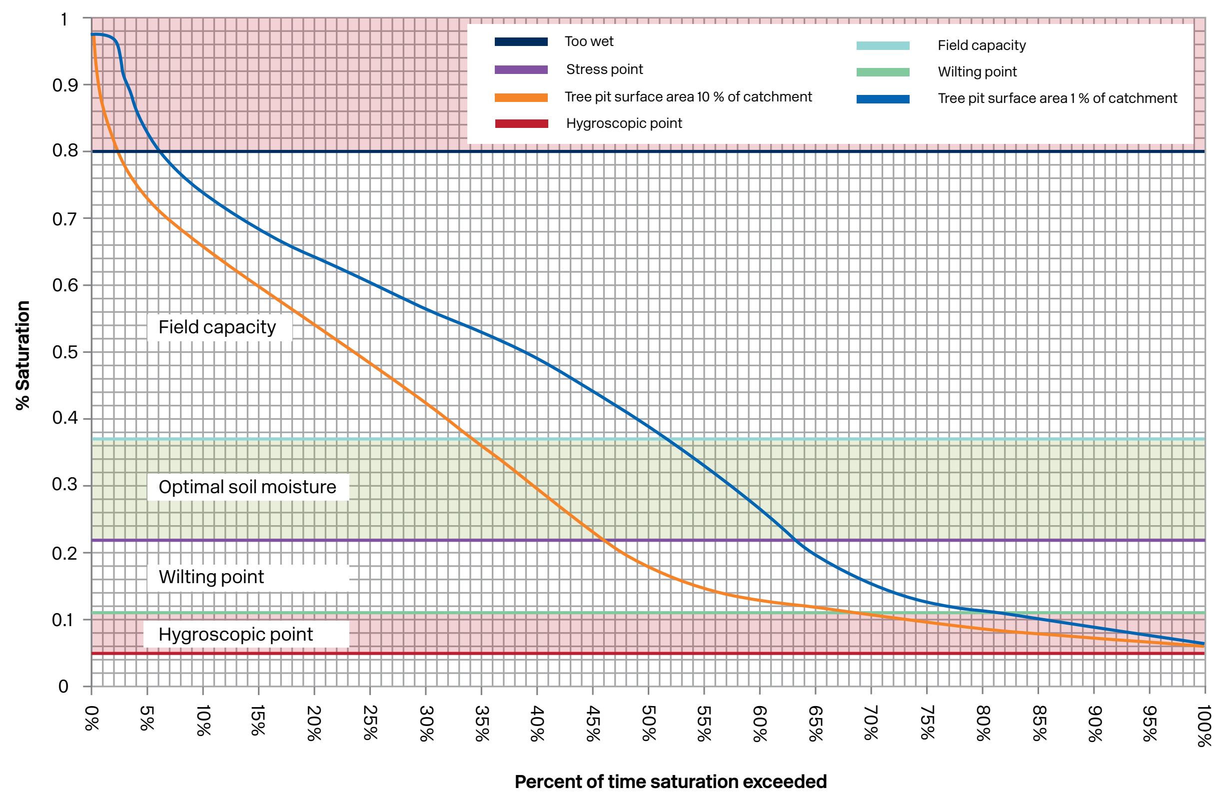
Example – Soil moisture and dry spells analysis of Townsville, QLD vs Blacktown, NSW

Soil moisture and dry spells graphs were developed for Townsville and Blacktown to demonstrate the different soil moisture conditions for the following tree pit design in both locations:

- Soil type: loamy sand (100 mm/hr)
- High water use tree (1.85 PET)
- No wicking zone
- Both 1% and 10% of catchment shown.

The following graphs demonstrate how this tree pit design would experience dry conditions if adopted in Townsville due to the long dry season.

Figure 17 - Townsville soil moisture curve showing tree pits with loamy sand, a high water use tree and no wicking zone will experience dry conditions (wilting point) more than 20-35% of the time depending on the tree and catchment areas



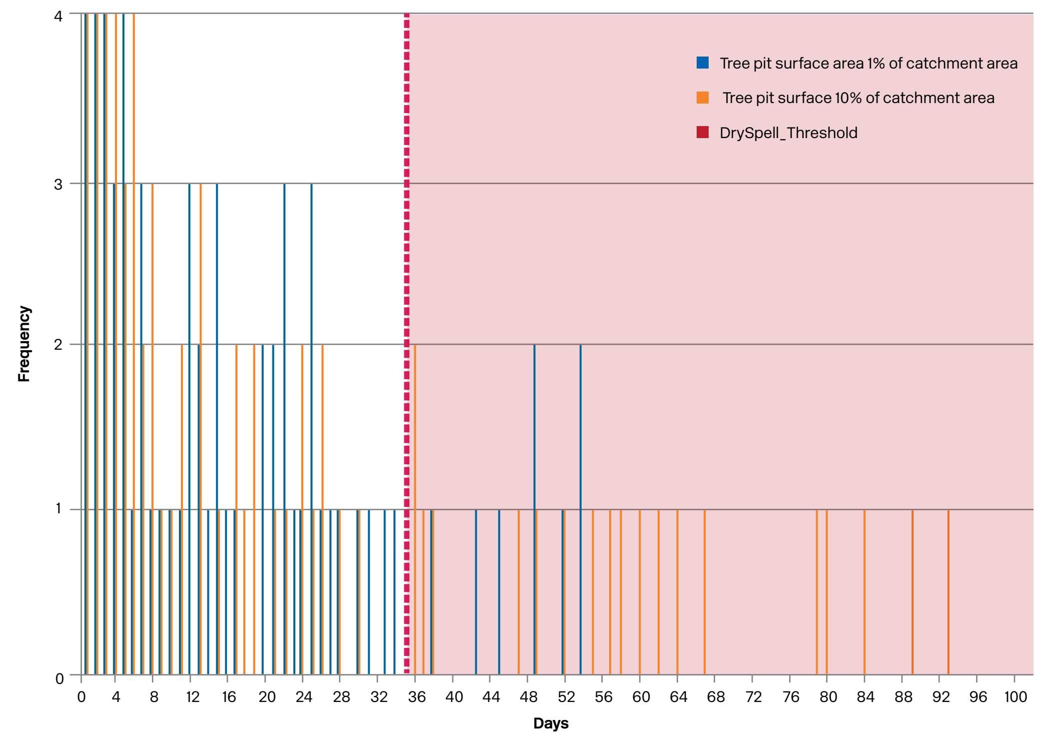
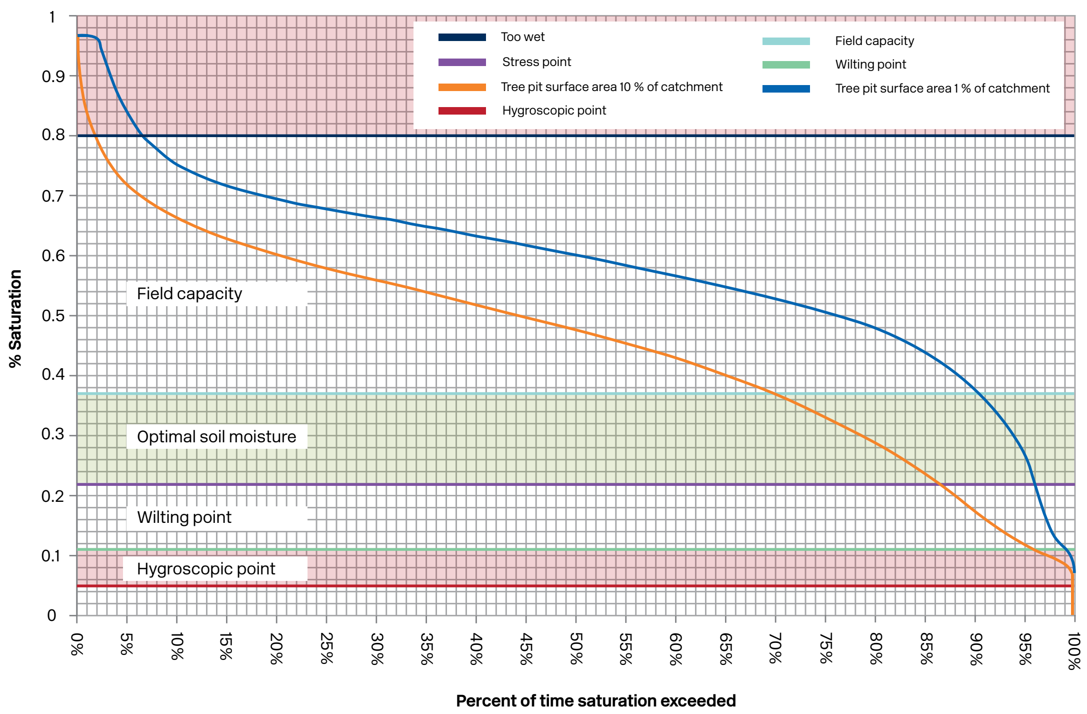


Figure 18 - Townsville dry spell analysis showing tree pits with loamy sand, a high water use tree and no wicking zone will likely experience numerous dry spell events over 35 days within a 10-year period.

This same tree pit design in Blacktown however would be okay (i.e. not get too dry) due to the more consistent rainfall pattern.



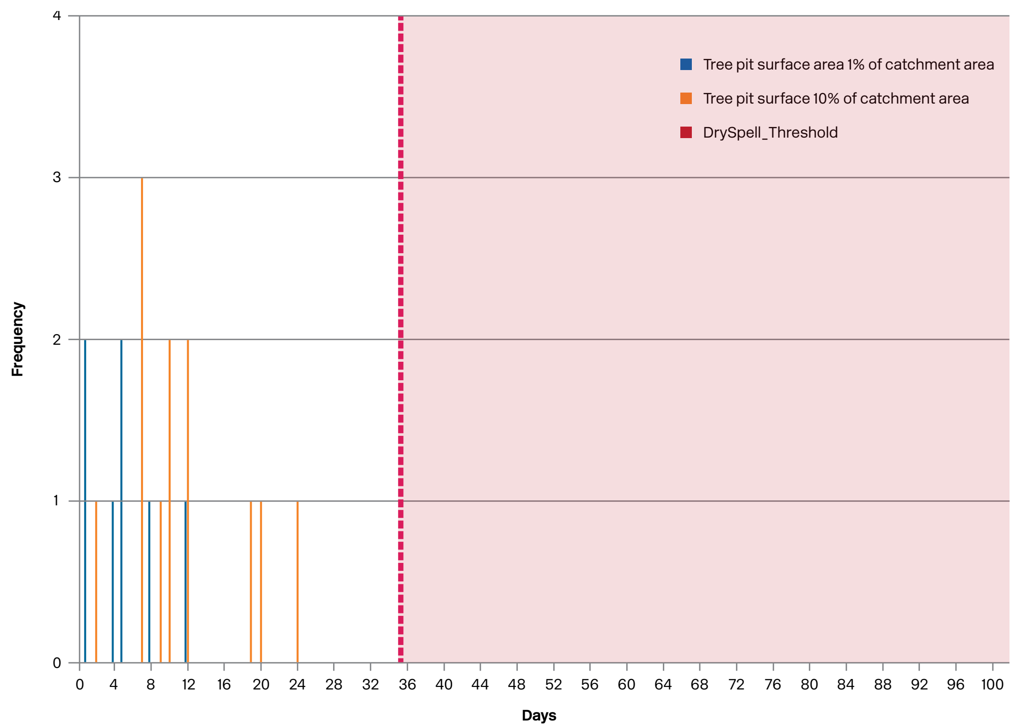


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Figure 19 - Blacktown soil moisture curve showing tree pits with loamy sand, a high water use tree and no wicking zone will experience dry conditions (wilting point) less than 5% of the time

←

Figure 20 - Blacktown dry spell analysis showing tree pits with loamy sand, a high water use tree and no wicking zone are unlikely to experience dry spell events longer than 35 days

Results

Tree pit sizing guides have been developed for each of the climatic zones based on the modelling results. These tables are presented in the Tree Pit Sizing tables on page 84.

How to interpret results

The Tree Pit Sizing provide the designer with an understanding of the suitable size range based on the modelling outcomes to ensure the system is not too wet or too dry and can achieve the local stormwater treatment targets, if this is required.

The following examples demonstrate how the tables can be used.

How to interpret results — Townsville tree pit sizing example

Table 10 presents the sizing table for Townsville street trees with 100 mm extended detention and underdrainage. This shows that Townsville's low water use trees in a pit with sandy loam soil media and no wicking zone (Design 5a) will have suitable soil moisture if they are sized between 4% and 6% of the contributing catchment area. Ideally they will be sized at 5% to ensure they will not be too dry, too wet and can achieve the local stormwater treatment requirements. If the tree pit was outside of these ideal conditions, other design options could be used to improve the soil moisture conditions (e.g. add a wicking bed or additional irrigation source to address risk of system drying out if sized over 6%).

What does this mean for a designer?

For tree pits with 20 m_3 of soil volume, the catchment should be between 330 m_2 and 500 m_2. To put this in perspective, if trees were placed along each side of a 10 m wide road with two-way crossfall, and only received runoff from the road, trees should be spaced between 66-100 m apart to achieve ideal soil moisture conditions through passive irrigation. If spaced more frequently, designers should consider including a wicking bed to improve moisture retention or look for additional water sources to support the tree through dry periods (e.g. additional inflows such as roof runoff or supplementary irrigation).

Table 10 - Tree pit sizing table for Townsville tree pits with 100 mm extended detention and underdrainage

Location	Design	Tree water use	Soil type	Wicking bed	Too wet	SW tar.	Too dry
					as % of the catchment area		
Townsville	1a	Low	Sandy Loam	Yes	<4%	>4%	All OK
	2a	High			<4%	>4%	>7%
	3a	Low	Loamy Sand		All OK	>3%	>8%
	4a	High			All OK	>3%	>7%
	5a	Low	Sandy Loam	No	<4%	>4%	>6%
	6a	High			<4%	>4%	>4%
	7a	Low	Loamy Sand		All OK	>3%	>5%
	8a	High			All OK	>3%	>4%

How to interpret results for different permeability scenarios — Rockhampton tree pit sizing example

Table 11 presents the sizing table for Rockhampton street trees with 10 mm extended detention and no wicking storage. This shows that all designs modelled with 10 mm extended detention and underdrainage were suitable if they were sized between 1% and 5% of the catchment. All designs with no underdrainage (assuming heavy clay in-situ soils) were too wet, and therefore not recommended without some drainage solution. If the in-situ soils had higher hydraulic conductivity (than the tree pit media), it is likely some designs would have suitable soil moisture conditions without additional underdrainage required.

Table 11 - Tree pit sizing table for Rockhampton tree pits with 10 mm extended detention

Location	Design	Tree water use	Soil type	Underdrainage	Too wet	SW tar.	Too dry
						as % of the catchment area	
Rockhampton	1b	Low	Sandy Loam	Yes	All OK	>3%	>5%
	2b	High			All OK	>3%	>5%
	3b	Low	Loamy Sand		All OK	>4%	>5%
	4b	High			All OK	>4%	>5%
	5b	Low	Sandy Loam	No	Too Wet	N/A	N/A
	6b	High			Too Wet	N/A	N/A
	7b	Low	Loamy Sand		Too Wet	N/A	N/A
	8b	High			Too Wet	N/A	N/A

Low permeability - 0.36mm/hr

(Designs 5b, 6b, 7b, 8b)

Design response will depend on in-situ soils and risk of water logging

Underdrainage / high permeability in-situ soils (greater than planted soil media →100 mm/hr)

(Designs 1b, 1b, 3b, 4b)

Possible design responses to address soil moisture concerns

It is important to note that where modelling indicates that a system may experience periodic conditions which are either too wet or too dry, there are a number of design responses which could improve the soil moisture conditions. A summary of possible responses is provided in Table 12.

Table 12 - Possible design responses to address soil moisture concerns

Tree pit component	Design response	
	Too wet	Too dry
Directly connected catchment area	Reduce catchment area. This may be achieved by increasing the number of tree pits or diverting catchment away.	Increase catchment area. This may be achieved by decreasing the number of tree pits or connecting additional adjacent catchments such as roof downpipes. Alternative water sources may also be considered.
Surface area/soil volume of the system	Increase the size of the tree pit if space allows.	Propose a smaller tree species which requires less soil volume.
Plant selection	Select wet tolerant species.	Select dry tolerant species.
Hydraulic conductivity of the soil	Increase hydraulic conductivity (ensure soil is not too sandy to retain horticultural properties).	Increase the soil moisture retention of the soil.
Wicking Zone	NA	Wicking zones could be considered.
Stormwater capture volume	Reduce the extended detention depth.	Increase the extended detention or inlet capacity.
Underdrainage	Underdrainage is critical for these designs.	Underdrainage may not be required in some situations.

Also note that it is not always possible to achieve passively watered landscapes that can rely entirely on self-watering. It is important to recognise that some self-watering will still significantly improve the growth rate, health and resilience of the tree. Additional irrigation may be needed to help the tree through drier periods, but once the trees have matured their roots will be better equipped to seek moisture from the surrounding connected soils (if the pit is unlined).

Tree pit sizing tables

The following tables present the tree pit sizing recommendations based on the modelling undertaken. Design configurations which may not be appropriate are greyed out.

Cairns

Recommended tree pit designs:

- **100 mm extended detention, loamy sand — 7% to >10%**
  (unsure at what size the system would become too dry)
- **10 mm extended detention, loamy sand, with underdrainage — 6-8%**
  (wicking beds could potentially increase the size but this wasn't modelled)

100 mm extended detention

Location	Design	Tree water use	Soil type	Wicking bed	Too wet	SW tar.	Too dry
					as % of the catchment area		
Cairns	1a	Low	Sandy Loam	Yes	Too Wet	N/A	N/A
	2a	High			Too Wet	N/A	N/A
	3a	Low	Loamy Sand		<7%	>3%	All OK
	4a	High			<7%	>3%	All OK
	5a	Low	Sandy Loam	No	Too Wet	N/A	N/A
	6a	High			Too Wet	N/A	N/A
	7a	Low	Loamy Sand		<7%	>3%	All OK
	8a	High			<7%	>3%	All OK

10 mm extended detention

Location	Design	Tree water use	Soil type	Underdrainage	Too wet	SW tar.	Too dry
					as % of the catchment area		
Cairns	1b	Low	Sandy Loam	Yes	Too Wet	N/A	N/A
	2b	High			Too Wet	N/A	N/A
	3b	Low	Loamy Sand		<6%	>4%	>8%
	4b	High			<7%	>3%	All OK
	5b	Low	Sandy Loam	No	Too Wet	N/A	N/A
	6b	High			Too Wet	N/A	N/A
	7b	Low	Loamy Sand		Too Wet	N/A	N/A
	8b	High			Too Wet	N/A	N/A

Townsville

Recommended tree pit designs:

- **100 mm extended detention without wicking storage — 4-6% (sandy loam, depending on tree type) or 1-5% (loamy sand, depending on tree type)**
  (systems should be >3-4% if designed for stormwater treatment (depending on soil type)
- **100 mm extended detention with wicking storage — 4-10% (sandy loam, depending on tree type) or 1-8% (loamy sand, depending on tree type)**
  (systems should be >3-4% if designed for stormwater treatment (depending on soil type)
- **10 mm extended detention – None**
  (systems too dry with underdrainage (wicking beds could improve this) and too wet without underdrainage)

100 mm extended detention

Location	Design	Tree water use	Soil type	Wicking bed	Too wet	SW tar.	Too dry
					as % of the catchment area		
Townsville	1a	Low	Sandy Loam	Yes	<4%	>4%	All OK
	2a	High			<4%	>4%	>7%
	3a	Low	Loamy Sand		All OK	>3%	>8%
	4a	High			All OK	>3%	>7%
	5a	Low	Sandy Loam	No	<4%	>4%	>6%
	6a	High			<4%	>4%	>4%
	7a	Low	Loamy Sand		All OK	>3%	>5%
	8a	High			All OK	>3%	>4%

10 mm extended detention

Location	Design	Tree water use	Soil type	Underdrainage	Too wet	SW tar.	Too dry
					as % of the catchment area		
Townsville	1b	Low	Sandy Loam	Yes	N/A	N/A	Too Dry
	2b	High			N/A	N/A	Too Dry
	3b	Low	Loamy Sand		N/A	N/A	Too Dry
	4b	High			N/A	N/A	Too Dry
	5b	Low	Sandy Loam	No	Too Wet	N/A	N/A
	6b	High			Too Wet	N/A	N/A
	7b	Low	Loamy Sand		Too Wet	N/A	N/A
	8b	High			Too Wet	N/A	N/A

Mackay

Recommended tree pit designs:

- **100 mm extended detention, loamy sand — 1 to >10%**
  (unsure at what size the system would become too dry, size system >3% if used for stormwater treatment (assuming wicking zones aren't used as they are not required for soil moisture))
- **10 mm extended detention — None**
  (systems too dry with underdrainage and too wet without underdrainage)

100 mm extended detention

Location	Design	Tree water use	Soil type	Wicking bed	Too wet	SW tar. (as % of the catchment area)	Too dry (as % of the catchment area)
Mackay	1a	Low	Sandy Loam	Yes	Too Wet	N/A	N/A
	2a	High			Too Wet	N/A	N/A
	3a	Low	Loamy Sand		All OK	>3%	All OK
	4a	High			All OK	>3%	All OK
	5a	Low	Sandy Loam	No	Too Wet	N/A	N/A
	6a	High			Too Wet	N/A	N/A
	7a	Low	Loamy Sand		All OK	>2%	All OK
	8a	High			All OK	>2%	All OK

10 mm extended detention

Location	Design	Tree water use	Soil type	Underdrainage	Too wet	SW tar. (as % of the catchment area)	Too dry (as % of the catchment area)
Mackay	1b	Low	Sandy Loam	Yes	Too Wet	N/A	N/A
	2b	High			Too Wet	N/A	N/A
	3b	Low	Loamy Sand		N/A	N/A	Too Dry
	4b	High			N/A	N/A	Too Dry
	5b	Low	Sandy Loam	No	Too Wet	N/A	N/A
	6b	High			Too Wet	N/A	N/A
	7b	Low	Loamy Sand		Too Wet	N/A	N/A
	8b	High			Too Wet	N/A	N/A

Rockhampton

Recommended tree pit designs:

- **100 mm extended detention — 1 to >10%**
  (unsure at what size the system would become too dry, size system >3% if used for stormwater treatment)
- **10 mm extended detention, with underdrainage — 1-5%**
  (size system >3-4% if used for stormwater treatment)

100 mm extended detention

Location	Design	Tree water use	Soil type	Wicking bed	Too wet	SW tar. (as % of the catchment area)	Too dry (as % of the catchment area)
Rockhampton	1a	Low	Sandy Loam	Yes	All OK	>3%	All OK
	2a	High			All OK	>3%	All OK
	3a	Low	Loamy Sand		All OK	>3%	All OK
	4a	High			All OK	>3%	All OK
	5a	Low	Sandy Loam	No	All OK	>3%	All OK
	6a	High			All OK	>3%	All OK
	7a	Low	Loamy Sand		All OK	>3%	All OK
	8a	High			All OK	>2%	All OK

10 mm extended detention

Location	Design	Tree water use	Soil type	Underdrainage	Too wet	SW tar. (as % of the catchment area)	Too dry (as % of the catchment area)
Rockhampton	1b	Low	Sandy Loam	Yes	All OK	>3%	>5%
	2b	High			All OK	>3%	>5%
	3b	Low	Loamy Sand		All OK	>4%	>5%
	4b	High			All OK	>4%	>5%
	5b	Low	Sandy Loam	No	Too Wet	N/A	N/A
	6b	High			Too Wet	N/A	N/A
	7b	Low	Loamy Sand		Too Wet	N/A	N/A
	8b	High			Too Wet	N/A	N/A

Sunshine Coast

Recommended tree pit designs:

- **100 mm extended detention — 1 to >10%**
  (unsure at what size the system would become too dry, size system >3-4% if used for stormwater treatment, depending on soil type)
- **10 mm extended detention, with underdrainage — 1 to >10%**
  (unsure at what size the system would become too dry, size system >3-5% if used for stormwater treatment)

100 mm extended detention

Location	Design	Tree water use	Soil type	Wicking Bed	Too wet	SW tar.	Too dry
					as % of the catchment area		
Sunshine Coast	1a	Low	Sandy Loam	Yes	All OK	4%	All OK
	2a	High			All OK	4%	All OK
	3a	Low	Loamy Sand		All OK	3%	All OK
	4a	High			All OK	3%	All OK
	5a	Low	Sandy Loam	No	All OK	4%	All OK
	6a	High			All OK	4%	All OK
	7a	Low	Loamy Sand		All OK	3%	All OK
	8a	High			All OK	3%	All OK

10 mm extended detention

Location	Design	Tree water use	Soil type	Underdrainage	Too wet	SW tar.	Too dry
					as % of the catchment area		
Sunshine Coast	1b	Low	Sandy Loam	Yes	<1%	>3%	All OK
	2b	High			<1%	>3%	All OK
	3b	Low	Loamy Sand		All OK	>5%	All OK
	4b	High			All OK	>5%	All OK
	5b	Low	Sandy Loam	No	Too Wet	N/A	N/A
	6b	High			Too Wet	N/A	N/A
	7b	Low	Loamy Sand		Too Wet	N/A	N/A
	8b	High			Too Wet	N/A	N/A

Ipswich

Recommended tree pit designs:

- **100 mm extended detention — 2 to >10% (sandy loam) or 1 to >10% (loamy sand)**
  (unsure at what size the system would become too dry, size system >2-3% if used for stormwater treatment, depending on soil type)
- **10 mm extended detention, loamy sand with underdrainage — 1-3% (depending on tree type)**
  (Additional irrigation may be required to meet the stormwater target at 3%)

100 mm extended detention

Location	Design	Tree water use	Soil type	Wicking bed	Too wet	SW tar.	Too dry
						as % of the catchment area	
Ipswich	1a	Low	Sandy Loam	Yes	<2%	>3%	All OK
	2a	High			<2%	>3%	All OK
	3a	Low	Loamy Sand		All OK	>2%	All OK
	4a	High			All OK	>2%	All OK
	5a	Low	Sandy Loam	No	<2%	>3%	All OK
	6a	High			<2%	>3%	All OK
	7a	Low	Loamy Sand		All OK	>2%	All OK
	8a	High			All OK	>2%	All OK

10 mm extended detention

Location	Design	Tree water use	Soil type	Underdrainage	Too wet	SW tar.	Too dry
						as % of the catchment area	
Ipswich	1b	Low	Sandy Loam	Yes	<3%	>4%	<1%
	2b	High			<3%	>4%	>2%
	3b	Low	Loamy Sand		All OK	>3%	>2%
	4b	High			All OK	>3%	>1%
	5b	Low	Sandy Loam	No	Too Wet	N/A	N/A
	6b	High			Too Wet	N/A	N/A
	7b	Low	Loamy Sand		Too Wet	N/A	N/A
	8b	High			Too Wet	N/A	N/A

Sydney

Recommended tree pit designs:

- **100 mm extended detention — 1 to >10% (depending on soil type and tree type)** (unsure at what size the system would become too dry, size system >2-3% if used for stormwater treatment, depending on soil type)
- **10 mm extended detention, with underdrainage — 1 to >10%** (unsure at what size the system would become too dry, size system >3% if used for stormwater treatment)

100 mm extended detention

Location	Design	Tree water use	Soil type	Wicking bed	Too wet	SW tar. (as % of the catchment area)	Too dry (as % of the catchment area)
Sydney	1a	Low	Sandy Loam	Yes	<2%	>3%	All OK
	2a	High			<1%	>3%	All OK
	3a	Low	Loamy Sand		All OK	>2%	All OK
	4a	High			All OK	>2%	All OK
	5a	Low	Sandy Loam	No	<2%	>3%	All OK
	6a	High			<1%	>3%	All OK
	7a	Low	Loamy Sand		All OK	>2%	All OK
	8a	High			All OK	>2%	All OK

10 mm extended detention

Location	Design	Tree water use	Soil type	Underdrainage	Too wet	SW tar. (as % of the catchment area)	Too dry (as % of the catchment area)
Sydney	1b	Low	Sandy Loam	Yes	<1%	>4%	All OK
	2b	High			<1%	>3%	All OK
	3b	Low	Loamy Sand		All OK	>3%	All OK
	4b	High			All OK	>3%	All OK
	5b	Low	Sandy Loam	No	Too Wet	N/A	N/A
	6b	High			Too Wet	N/A	N/A
	7b	Low	Loamy Sand		Too Wet	N/A	N/A
	8b	High			Too Wet	N/A	N/A

Blacktown

Recommended tree pit designs:

- **100 mm extended detention — 1 to >10%** (unsure at what size the system would become too dry, size system >2% if used for stormwater treatment)
- **10 mm extended detention, with underdrainage — 1 to >10%** (unsure at what size the system would become too dry, size system >3% if used for stormwater treatment)

100 mm extended detention

Location	Design	Tree water use	Soil type	Wicking bed	Too wet	SW tar. (as % of the catchment area)	Too dry (as % of the catchment area)
Balcktown	1a	Low	Sandy Loam	Yes	All OK	>2%	All OK
	2a	High			All OK	>2%	All OK
	3a	Low	Loamy Sand		All OK	>2%	All OK
	4a	High			All OK	>2%	All OK
	5a	Low	Sandy Loam	No	All OK	>2%	All OK
	6a	High			All OK	>3%	All OK
	7a	Low	Loamy Sand		All OK	>2%	All OK
	8a	High			All OK	>2%	All OK

10 mm extended detention

Location	Design	Tree water use	Soil type	Underdrainage	Too wet	SW tar. (as % of the catchment area)	Too dry (as % of the catchment area)
Balcktown	1b	Low	Sandy Loam	Yes	All OK	>3%	All OK
	2b	High			All OK	>3%	All OK
	3b	Low	Loamy Sand		All OK	>2%	All OK
	4b	High			All OK	>2%	All OK
	5b	Low	Sandy Loam	No	Too Wet	N/A	N/A
	6b	High			Too Wet	N/A	N/A
	7b	Low	Loamy Sand		Too Wet	N/A	N/A
	8b	High			Too Wet	N/A	N/A

Adelaide

Recommended tree pit designs:

- **100 mm extended detention — 1 to >10%**
  (unsure at what size the system would become too dry, size system >1% if used for stormwater treatment)
- **10 mm extended detention, with underdrainage — 1 to >10%**
  (unsure at what size the system would become too dry, size system >1% if used for stormwater treatment)

100 mm extended detention

Location	Design	Tree water use	Soil type	Wicking bed	Too wet	SW tar.	Too dry
Adelaide	1a	Low	Sandy Loam	Yes	All OK	>2%	All OK
	2a	High			All OK	>2%	All OK
	3a	Low	Loamy Sand		All OK	>2%	All OK
	4a	High			All OK	>2%	All OK
	5a	Low	Sandy Loam	No	All OK	>2%	All OK
	6a	High			All OK	>2%	All OK
	7a	Low	Loamy Sand		All OK	>2%	All OK
	8a	High			All OK	>2%	All OK

10 mm extended detention

Location	Design	Tree water use	Soil type	Underdrainage	Too wet	SW tar.	Too dry
Adelaide	1b	Low	Sandy Loam	Yes	All OK	>1%	All OK
	2b	High			All OK	>1%	All OK
	3b	Low	Loamy Sand		All OK	>1%	All OK
	4b	High			All OK	>1%	All OK
	5b	Low	Sandy Loam	No	Too Wet	>7%	All OK
	6b	High			Too Wet	>6%	All OK
	7b	Low	Loamy Sand		Too Wet	>6%	All OK
	8b	High			Too Wet	>6%	All OK

Appendices:

Example construction sign-off forms

Appendix A:

Example construction sign-off forms

Example sign-off forms for each phase listed are provided below. These are typical examples which should be tailored to suit the design components adopted for each project.

Bulk Earthworks

Purpose: To ensure bulking out and base levels are in accordance with design specifications prior to the installation of infrastructure.

Bulk Earthworks Checklist	Initial
As constructed survey completed	
Installer must obtain accurate service locations from all providers, and discuss potential conflicts with tree pit location prior to commencement	
Set out of system is correct	
Base levels are at correct elevation	
Base at correct grading (0%)	
Base smooth/flat, free from any angular or sharp rocks, organics or other	
Compaction or subgrade in accordance with specification and/or as minimum no rutting caused by equipment/vehicles	
Continuous silt fences installed around perimeter of system	
If silt fences are deemed inadequate, other sediment and erosion control measures installed to ensure sediment does not enter basin	
Hold Point - Superintendent and designer inspection & sign off is required before proceeding	

Impervious Liner

Purpose: To ensure the impervious liner (if required) is correctly installed prior to backfill.

Bulk Earthworks Checklist	Initial
Base of system free from debris	
Liner correctly installed (as per manufacturers instructions)	
Liner adequately keyed in below finished surface	
All overlaps and penetrations are completely sealed (impervious)	
Depth of clay liner adequate and geotechnical testing results (Level 1) provided	
Hold Point - Superintendent and designer inspection & sign off is required before proceeding	

Underdrainage

Purpose: To ensure the underdrainage pipes (if required) have been correctly installed prior to backfill.

Underdrainage Checklist	Initial
100 mm diameter slotted pipes laid flat (0% grade) or Ag-Drains	
There is no fabric ‘sock’ around the underdrainage	
All pipe junctions and connections have been appropriately sealed using sealant	
Top of clean out points at design level	
All overflow junctions at correct level (confirm with survey)	
Penetrations through liner for pipes are completely sealed (impervious bentonite paste)	
Hold Point - Superintendent and designer inspection & sign off is required before proceeding	

Structural Cell

Purpose: Structural cell systems are highly engineered solutions that must be correctly installed to meet relevant design criteria. While the modules have very high strength capacity, the longevity of the pavement structure is contingent on all components being incorporated properly.

Structural Cell Checklist	Initial
All training requirements of manufacturer to be met by contractors prior to installation	
Structural cells to be transported and stored correctly on site	
Check and confirm all dimensions, and mark location of tree with spraypaint before commencing assembly of cells	
Complete assembly as per the construction specification	
Hold Point - Superintendent and designer inspection & sign off is required before proceeding	

Soil Media

Purpose: To ensure that the soils placed in the system match the soils that were specified and ordered. To ensure soil layers are placed according to specifications prior to any landscape works.

Supply Docket Check:

Sand layer (fine washed river sand) supply docket ID: ______________

Supply docket matches sand specification YES/NO (circle applicable)

2-5 mm Gravel layer supply docket ID: ______________

Supply docket matches gravel specification YES/NO (circle applicable)

Planting media/filler soil (AS4419) supply docket ID: ______________

Supply docket matches soil specification YES/NO (circle applicable)

Backfill Material Checklist	Initial
Method for placement of sand and soil media layers agreed	
Layer installed to correct depth	
Planting media/filler soil installed to correct depth	
Light, even compaction applied to remove air gaps	
Ensure that all required filler soil testing and certification is complete to satisfaction of superintendent prior to loading into tree pit When structural cell (if required) is fully assembled, with all specified piping and barriers in place, the filler soil can be loaded into the matrix Soil should be placed using an excavator bucket, and spread with rakes or shovels until the void spaces are filled. Use tamping to shake soil into all voids	
Hold Point - Superintendent and designer inspection & sign off is required before proceeding	

Finished Levels

Purpose: To ensure finished levels of system are correct and that surface is ready for planting.

Finished Levels Checklist	Initial
As constructed survey of surface	
Final constructed levels are consistent with design levels	
All civil construction items are complete and system is ready for planting by landscape contractor	
Hold Point - Superintendent and designer inspection & sign off is required before proceeding	

Protective Measures

Purpose: To ensure protective measures are correctly installed to protect the system until 80-90% of the catchment construction is complete.

Protective Measures Checklist	Initial
Existing kerb and channel may be retained until landscaping has been established to all allotments	
Continuous sediment fence is installed around perimeter of system	
Where landscape works are not to commence immediately then cover surface with filter cloth	
Hold Point - Superintendent and designer inspection & sign off is required before proceeding	

Landscape Installation

Purpose: To ensure the correct plants are supplied, installed and established.

Landscape Installation Checklist	Initial
Correct mulch (where specified) has been supplied	
Mulch applied to the correct depth and secured	
Supplied plants are correct species	
Supplied plants are in correct pot sizes and maturity	
Plants have been installed at correct planting densities	
Mulch is clear of plant stems by approximately 50 mm	
Hold Point – Superintendent and designer inspection & sign off is required before proceeding	

Landscape Establishment

Purpose: To ensure the correct plants are supplied, installed and established.

Landscape Establishment Checklist	Initial
Weeds being removed as required	
Watering occurring as required	
Replanting occurring as required to replace failed plants	
Plants successfully established and plant propagation is occurring	
Measure of successful establishment: Survivorship greater than 90% 80% coverage of system At least 5 plants per m^2 Plant height of at least 50% New growth visible No weeds	
Growth and maturity should be recorded through three-monthly photo logs every 500 m^2	
Hold Point – Superintendent and designer inspection & sign off is required before proceeding	

Appendix B:

Example maintenance checklist

Site Location / System Number	
Date	
Date of last Rainfall	
Name of Inspector	

What to look for	Performance indicators	Condition Rating (1)	Maintenance Undertaken (2)	Additional Corrective Maintenance Required
Surrounds				
Damage to adjacent landscape areas and footpath	No damage to adjacent path or areas which pose a risk to public safety or structural integrity			
Inlet and spillways				
Scour	Minor scour only that does not pose a risk to public safety or structural integrity and would not worsen if left unattended			
Damage to concrete	No damage which poses a risk to public safety or structural integrity			
Sediment, litter or debris	Inlet pillways should be clear of sediment, litter and weeds			
Surface				
Scour	Minor scour only that does not pose a risk to public safety or structural integrity and would not worsen if left unattended			
Crust of fine sediment	No surface crusting			
Depressions or mounds	No surface depressions or mounds >50 mm			
Hydraulic conductivity or permeability	Filter media is freely draining, whereby water is not ponded on the surface for more than 12 hours after rainfall and there is no obvious impermeable or clay-like surface on the filter media			
Underdrains and clean out points	Clean out points not damaged and end caps securely in place			
Surface ponding or boggy conditions	Ponded water should not be present on the bioretention basin surface during dry weather (i.e. 12 hours after rainfall) No surface ponding or boggy areas should be present in dry weather conditions			
Algal or moss growth	Maximum 10% of surface covered in moss No algal growth			
Litter	No litter			
Unusual odours, colours, or substances (eg oil and grease)	None detected			
Vegetation	Minimum 95% vegetation cover Plants healthy and free from disease Average plant height >500 mm No declared weeds Maximum 10% cover of weeds			
Outlet				
Scour	Outlet is structurally sound and there is no damage			
Damaged or removed structures eg caps or grates	No damage that poses a threat to public safety, structural integrity or system function			
Sediment Litter or Debris	No blockage			
Outlet freely draining	No downstream impediments to the release of water, no erosion or damage to the outlet and no evidence of malfunction (e.g. excessive sediment accumulated)			

(1) Condition Rating	1	Performace indicator met
	2	Performace indicator met following maintenance activity
	3	Additional maintenance needed
	4	Rectification may be needed
	NI	Not inspected
	NA	Not applicable
(2) Maintenance	Quantify where possible	

Appendix C:

Other relevant materials

Below is a list of other recent and relevant guidelines and documents. This is not an exhaustive list and it is recommended that you check for other relevant documents which could inform passively irrigated landscapes in your local area.

Summary of other guidelines / relevant documents

State	Document title	Author	Year	Description
QLD	Water Wise Street Trees - Concept design catalogue - DRAFT	Healthy Land and Water / Water by Design	2019	Provides description of passive watering, benefits, different types of water wise street trees and examples of built passively irrigated trees across Queensland. QLD Street Tree Design Factsheets Healthy Land and Water / Water by Design 2018 Overview of passive irrigation and tree pit sizing guidance for Queensland regions.
VIC	Embedding Green Infrastructure Best Practice Toolkit for Local Government – Design Guidelines	City of Yarra / E2Designlab	2018	Provides overview of green infrastructure and how these can be designed to be retrofitted into streets in the City of Yarra. This includes design guidance and worked examples.
NSW	Urban Green Cover in NSW - Technical Guidelines	NSW Government - Office of Environment and Heritage	2015	Provides in-depth descriptions of a variety of urban green infrastructure opportunities, including Green roofs and Cool Roofs, Green walls, Green pavements, streets and carparks, rain gardens and bioswales. Also includes detailed diagrams of the components of each piece of infrastructure.
NSW	Integrating Green Infrastructure	NSW Government - Transport for NSW	2017	In-depth outline of the incorporation of green infrastructure into future and existing transportation systems, along with detailed national and international case studies highlighting the benefits associated with green infrastructure, particularly in a transportation application.
NSW	Water Sensitive Urban Design Guideline - Applying water sensitive urban design principles to NSW transport projects	NSW Government - Transport Roads and Maritime Services	2017	Outline of the potential water sensitive urban design concepts that could be incorporated into future and existing transportation infrastructure and guidelines relating to assessing the suitability of sites for specific applications.
SA	Green Infrastructure Guidelines	Adelaide City Council	2014	Ways to incorporate green infrastructure into urban environments to increase liveability and sustainability. In-depth discussion of the social, economic, political and environmental benefits of green infrastructure in an urban setting.

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