Emerging assets for stormwater flow management

State of Knowledge

June 2026

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Enhancing Life and Liveability

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Glossary and acronyms

Term	Definition
AEP	Annual exceedance probability
ARI	Annual recurrence interval
Baseflow	The component of streamflow supplied by groundwater discharge and interflow.
BPEM	Best practice environmental management, specifically the *Best Practice Environmental Guidelines for Urban Stormwater* (Victorian Stormwater Committee, 1999)
Constructed ephemeral wetland	A constructed wetland that temporarily holds water following rain events with limited or no permanent ponding to manage stormwater flows.
Development	Includes construction or carrying out of works, including building and road construction.
EDD	Extended detention depth
EPA	Environment Protection Authority (Victoria)
Evapotranspiration	Water that is lost to the atmosphere via evaporation from land and water surfaces plus transpiration from vegetation.
Flow regime	The range of flows that a waterway experiences throughout the seasons and years, which may include baseflows, low flows, high flows, overbank flow and cease to flow (drying) events.
Groundwater dependent ecosystem (GDE)	Natural ecosystems that require access to groundwater to meet all or some of their water requirements to maintain their ecological processes.
Gross pollutants	Material that would be retained by a five-millimetre mesh screen.
Harvest	Rain that is captured for potential use and prevented from entering a waterway.
Hectare (ha)	Ten thousand square metres
Hydrologic regime	Changes with time in the rates of flow and in the levels and volumes of water in rivers, lakes, and WSUD assets; the hydrologic regime is closely related to seasonal

Term	Definition
	changes in climate but is also influenced by catchment vegetation, soils and urban development
Impervious	Impermeable; sealed surfaces that do not allow water to infiltrate or be absorbed.
Infiltrate/filter	Runoff from impervious surfaces that soaks into the ground (infiltrates) or is slowly released (filter) to the drainage system from a stormwater management asset (mimicking the infiltration rates of the surrounding soil).
Integrated water management	Integrated water management is a collaborative approach to planning that brings together organisations that influence all elements of the water cycle, including waterways and bays, wastewater management, alternative and potable water supply, stormwater management and water treatment. It considers environmental, social and economic benefits.
Low flow	Water that creates a continuous flow over the bottom of the waterway channel but does not fill the channel to any great depth. The term is most often used in relation to baseflows that occur over the drier periods of the year that are sustained for some period (weeks to months), due to water infiltrating and flowing slowly through the landscape following rainfall.
Passive irrigation rainwater tanks	A rainwater tank that releases water very slowly into an adjacent garden or lawn area.
NWL	Normal water level
Sediment pond	An open water pond with the function to capture coarse sediment carried by stormwater.
Stormwater	Rainfall that runs off roofs, roads, and other urban surfaces into gutters, drains, creeks and rivers, and eventually into the sea.
Surface runoff	The component of streamflow supplied by surface drainage and overland flows.
Treatment train	A sequence of stormwater treatment assets designed to manage potential impacts to downstream waterways.

Term	Definition
Urban	Areas that are developed for residential, industrial, or commercial activities, including roads.
Vegetated sponge	A vegetated area that filters and reduces the volume of runoff discharged via infiltration. They include dense planting into a soil or filter media that can drain stormwater runoff.
Wicking bed	A system that provides irrigation to a landscape via an underground reservoir of water (aquifer) from which water is drawn upwards like a wick to the topsoil layer above.
WSUD	Water sensitive urban design – an approach to urban planning and design that aims to minimise the hydrologic impacts of urban development on the surrounding environment.

Preface – Defining Emerging Assets

There is strong scientific and industry consensus that excess stormwater volumes are a primary driver of waterway degradation in Victoria. In response, there has been a deliberate shift towards stormwater harvesting and infiltration assets that directly reduce runoff volumes and help restore more natural flow regimes. While uptake has increased rapidly, this transition is still underway, and experience with these assets varies across organisations and contexts. At the same time, the knowledge base that supports their design, performance, and long-term use continues to develop and evolve, and expectations of how these assets function in practice are still being defined.

In this context, the term ***emerging assets*** is used to describe stormwater harvesting and infiltration assets that are increasingly implemented in practice, but for which design guidance, performance understanding, and long-term application are still evolving.

Purpose

The purpose of this document is to support currency of knowledge on emerging stormwater asset types that have the potential to contribute towards stormwater flow volume reduction targets as identified through the following documents:

- Healthy Waterways Strategy 2018-28 (Melbourne Water, 2018)[1] ("HWS")
- Environment Protection Authority's Urban Stormwater Management Guidance (EPA, 2021)[2] ("EPA Guidance")
- Healthy Waterways Strategy Stormwater Targets Practitioner's Note[3] (Melbourne Water, 2021) ("HWS Practitioner's Note")

The document provides information to the stormwater industry to inform the design, construction, operation and maintenance of these emerging asset types.

In doing so, this document contributes to the *state of knowledge* and understanding of what is reasonably practicable to eliminate or minimise risks to human health and the environment and from pollution or waste under the *General Environmental Duty* (GED) as part of the *Environmental Protection Act 2017*. This is the first resource document consolidating the current state of knowledge of these emerging assets.

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[1] https://healthywaterways.com.au/resources/documents
[2] https://www.epa.vic.gov.au/about-epa/publications/1739-1
[3] https://www.melbournewater.com.au/media/16916/download

This document is not intended to be a compliance document nor does it provide detailed engineering or deemed to comply guidance.

Future work will continue to improve and refine the information within this document or develop new documents as the state-of-knowledge evolves.

Background

In 1999 the *Best Practice Environmental Management Guidelines for Urban Stormwater* (Victoria Stormwater Committee, 1999)[4] (BPEM) were established to set out quality and basic flow objectives for stormwater management to protect and enhance the environmental values and beneficial uses of receiving waters.

The BPEM performance objectives are to reduce typical urban stormwater pollutant loads and flows as follows:

- 80% for total suspended solids (TSS)
- 45% for total phosphorus (TP)
- 45% for total nitrogen (TN)
- 70% for gross pollutants
- Maintain peak discharge flow rates for the 1.5 year annual recurrence interval (ARI) at pre-development levels

Since then, the scientific and industry understanding of stormwater impacts and management approaches has evolved. This has led to a shift in focus from primarily managing stormwater quality to also managing stormwater flows effectively, which includes the volume, frequency and intensity of stormwater runoff. Stormwater flow management approaches include harvesting for beneficial uses such as irrigation and non-potable indoor demands, evapotranspiration to provide urban cooling, and infiltration to maintain waterway baseflows.

In 2017, the *Environment Protection Act 2017* was amended. It introduced the *General Environmental Duty*, which came into effect on 1 July 2021. This duty requires all Victorians to "*minimise, so far as reasonably practicable, risks of harm to human health and the environment*". To do this, all Victorians have an obligation to practice under the *state of knowledge*. This includes the use of industry guidance. Industry guidance includes information from EPA, businesses, industry and government.

Figure 1 illustrates the initial steps of new stormwater industry guidance for stormwater flow management.

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[4] The latest BPEM information is available via the CSIRO website: https://www.publish.csiro.au/book/2190/#details

Figure 1: Timeline illustrating flow target establishment

In 2018, the community and industry co-designed the Healthy Waterways Strategy 2018-2028 (HWS) (Melbourne Water, 2018) and established flow-based stormwater targets for priority catchments as well as targets for 'other' areas across Melbourne based on rainfall bands. These targets have two elements:

- harvesting (that includes evapotranspiration) to prevent excess flows from entering waterways, and
- infiltration to maintain baseflows.

The targets are expressed in ML/yr per hectare impervious area.

In 2021, the EPA Guidance[5] was published. These introduced stormwater flow volume performance objectives for different rainfall bands across Victoria for harvesting/evapotranspiration and infiltration.

In 2021, the HWS Practitioner's Note[6] was published. This document provides further detail on flow targets (harvesting/evapotranspiration and infiltration) in alignment with the science that underpins the EPA and HWS flow targets and

[5] https://www.epa.vic.gov.au/-/media/epa/files/publications/urban-stormwater-management-1739-1.pdf?la=en&hash=297A34E91AFF7A774C472B9F338063C8
[6] https://www.melbournewater.com.au/media/16916/download

BPEM objectives. These are expressed in percent mean annual impervious runoff harvested/evapotranspired or infiltrated.

A key aspect of the HWS Practitioner's Note was the provision of harvesting/evapotranspiration and infiltration targets aligned to Melbourne's rainfall regions as defined in the Stormwater Modelling Guideline and used in common stormwater models[7]. These are expressed in both percent mean annual impervious runoff harvested/evapotranspired and percent infiltrated/filtered or ML/yr from one hectare of impervious area.

The flow targets differ from stormwater quality targets as they aim to protect:

- priority areas for enhanced stormwater management within high ecological value waterways
- Mitigate further degradation of waterways in other areas.

In 2024, obligations relating to the management of urban stormwater were set for councils in the Obligations of managers of land or infrastructure (Urban stormwater management and On-site wastewater management) (the OMLI). Clause 5 of the OMLI continues the requirement from the now expired *State Environment Protection Policy (Waters)* for councils to develop, review, and update stormwater management plans (or their equivalent). These plans must identify stormwater risks and outline actions to address them, in consultation with relevant stakeholders.
On 4th February 2026, Department of Transport and Planning introduced Amendment VC265 that updated all Victorian planning schemes to reference EPA's 2021 Urban Stormwater Guidance (1739.1) stormwater quality objectives.

Mitigating stormwater risks by achieving flow targets will require contributions from a range of stakeholders and solutions across a range of spatial scales. Common current solutions like rainwater tanks, wetlands and biofilters provide an important contribution. However, they are unlikely to be sufficient by themselves to meet the flow volume reductions targets. New asset types and improved designs to intentionally maximise harvesting, evapotranspiration, and infiltration will also be required.

Scope

This State of Knowledge document is a first look at some of the new and emerging assets that can help meet flow-based stormwater targets. These emerging assets differ from standard WSUD assets, and some good in-ground examples already exist throughout Australia. This document supports their

[7] https://www.melbournewater.com.au/media/23541/download

broader implementation in future developments. It does not provide an exhaustive list of emerging asset types, but focuses on six new and emerging assets:

1. Vegetated sponges
2. Constructed ephemeral stormwater wetlands
3. Wicking beds
4. Passive irrigation rainwater tanks
5. Passively watered street trees
6. Permeable or porous paving

The first four of these are documented more extensively while the last two have a brief summary of key design considerations and parameters.

These assets were chosen for the following reasons:

- potential to contribute to flow targets
- provision of multiple benefits
- amount of published information available
- provision of solutions for different scales and needs.

This State of Knowledge document provides an overview of each of the assets, initial high level design guidance, key operation and maintenance features, tips for implementation, and a case study demonstrating a built example of each asset. It is recognised that there are many possible different asset types and configurations of these. The intention of this document is to put forward six potential options and help users to start exploring their potential implementation. It is recognised that further work is needed to assess and test the appropriate design ranges and configurations for these assets in different contexts and conditions, including climate, soils, inflow patterns and design responses.

It is recognised that flow-based stormwater targets can be achieved in alternative ways:

- by increasing permeability across the development,
- through the use of other assets, such as alternative biofilter configurations, infiltration assets, stormwater harvesting and green roofs. Future versions of the document may consider guidance for these asset types.

This document forms part of a broader stormwater industry guidance program that Melbourne Water is developing with industry stakeholders to support the industry to collectively achieve the flow-based stormwater targets. It is anticipated that this document will be updated as the state-of-knowledge evolves.

Relationship with MUSIC Guideline and other guidelines

The Emerging assets for stormwater management document aims to provide an overview of these asset types along with case study examples.

As part of a wider stormwater industry guidance program, Melbourne Water regularly updates the *MUSIC Modelling Guideline*[8].

The 2026 update, released alongside this document, provides new modelling guidance to help address stormwater harvesting and infiltration targets and assess performance against these targets, as well as new guidance for modelling infiltration using conventional stormwater treatment assets and the assets described in this document.

As outlined in the Purpose statement, this document is not intended to provide detailed design or deemed-to-comply guidance such is in the *WSUD Engineering Procedures: Stormwater* (2005) document (Figure 2), but presents the industry state of knowledge of these assets.

8 https://www.melbournewater.com.au/media/4806/download

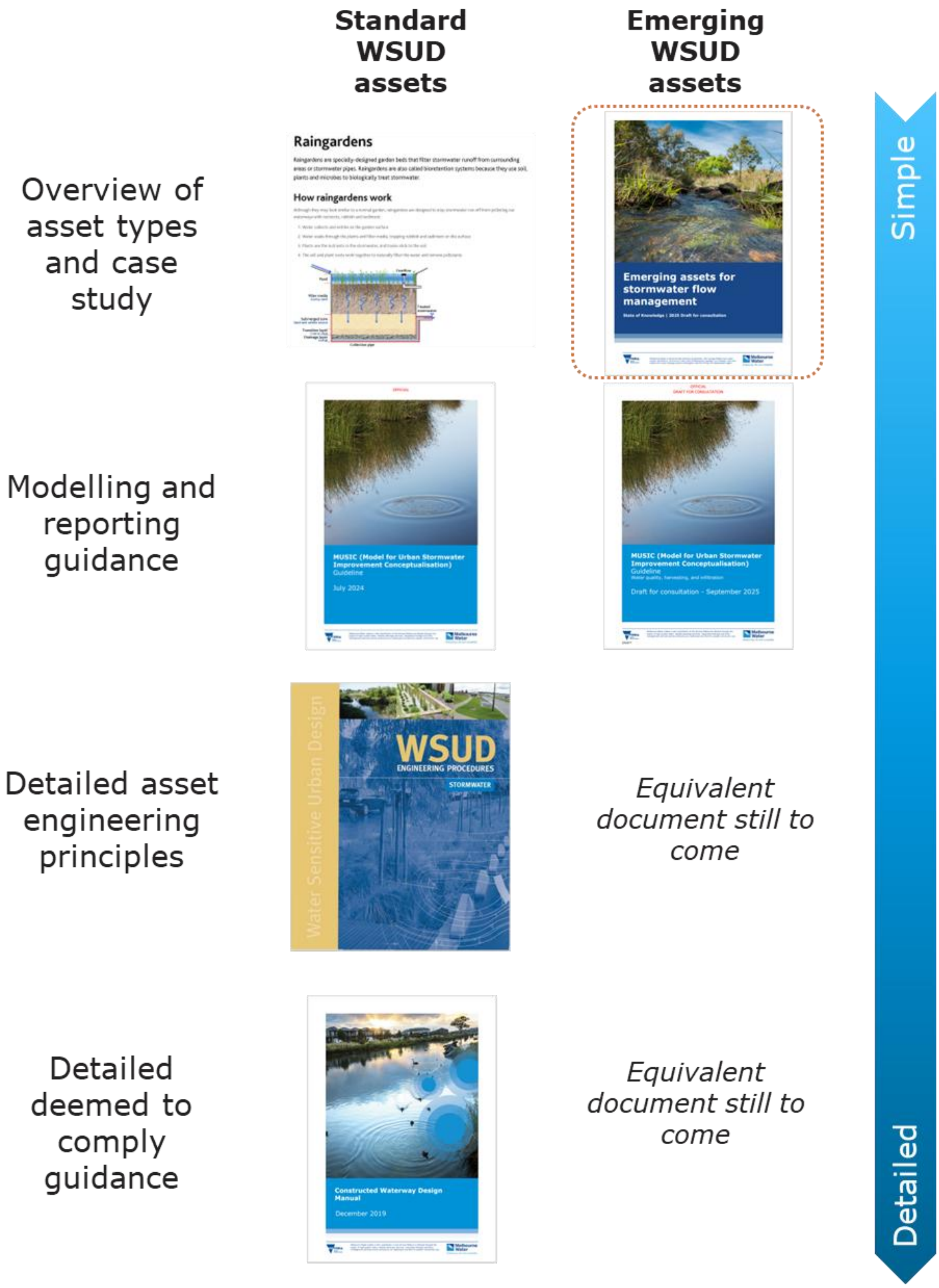


Figure 2 Emerging assets for stormwater flow management in relation to existing documentation

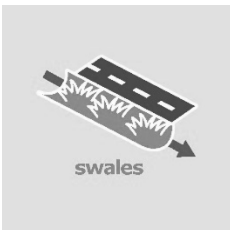
Assets overview

An overview of the emerging asset types covered in this guide is provided in Table 1. This overview includes standard constructed stormwater wetlands to provide a reference for comparison.

Table 1: Overview of emerging assets and their potential benefits, including potential contribution to stormwater flow targets

Asset	Pros	Cons	Potential benefits			
			Water quality	Harvesting/ ET	Infiltration	Flood mitigation
Standard constructed wetlands (for comparison)	• Effective stormwater quality treatment • Well tested and familiar • Reasonably robust • Can be aesthetically attractive • Minimal head required	• Limited stormwater volume reductions • Relatively large footprint	✓✓✓	✓	-	✓
Vegetated sponges	• Slow stormwater, increasing infiltration and evapotranspiration • Can potentially be integrated along degraded and modified riparian corridors • Improve stormwater quality	• Require relatively large, flat area to reduce stormwater flow volumes, • May be less effective in low infiltration soils (e.g. clays) • Weed prevention requires careful maintenance • Require driving head	✓✓✓	✓✓	✓✓✓	✓
Constructed ephemeral wetlands	• Promotes infiltration • Can be used to rehabilitate degraded landscapes and increase biodiversity • Reduced construction cost	• Require relatively large, flat area to reduce stormwater flow volumes • Requires a non-standard design that will vary according to context • Vegetation establishment may be more challenging • Stormwater pollutant reductions require further field validation	✓✓✓	√	✓✓✓	✓
Wicking beds	• Reliable source of non-potable water for irrigation (water saving) and irrigation does not have to be scheduled • Less fertiliser needed • Very safe form of stormwater harvesting • Stronger, more resilient turf • Water quality benefits	• Capital cost may be prohibitive for retrofit projects • Surface needs to be flat (i.e. less than 100 mm surface level difference across the system) to provide equal access to soil moisture. Stepped wicking cells can be used for gently sloping sites and terraced landscapes or lawns, however steeply	✓	✓✓✓	-	-

Asset	Pros	Cons	Potential benefits			
			Water quality	Harvesting/ ET	Infiltration	Flood mitigation
	• Low maintenance and operational cost, passive/ gravity fed, no pumps or energy requirements	sloping sites are not appropriate for wicking. • No infiltration				
Passive irrigation rainwater tanks	• Distributed throughout the catchment to deliver infiltration where it is most needed in groundwater recharge areas • Delivers multiple benefits: non-potable water supply, localised flood storage, infiltration, urban greening and cooling	• Requires good design to ensure overflow paths are provided and maintained • Possible infiltration risks to the stability of building foundations • Private ownership presents challenges to ensuring ongoing operation and maintenance	✓	✓✓✓	✓	✓✓
Passively watered street trees	• Supports healthy urban canopy, providing shade and cooling, reducing urban heat island • Can contribute to both harvesting and infiltration	• Requires more investment and maintenance than traditional street trees	✓	✓	✓	✓
Permeable or porous pavement	• Supports infiltration • Slows stormwater • Reduces urban heat	• Potential for clogging with sediments, reducing infiltration effectiveness over time unless maintained regularly. • May not be as strong as concrete or bitumen • Possible groundwater contamination	✓	✓	✓	✓

Asset type	Primary →		Secondary →	Tertiary
Vegetated sponge				

Asset type	Primary →		Secondary →	Tertiary
	gross pollutant traps	sediment forebay or pond		vegetated sponge in-situ
	gross pollutant traps	sediment forebay or pond		vegetated sponge with filter
Constructed ephemeral wetlands	gross pollutant traps	sediment forebay or pond		ephemeral wetland
	gross pollutant traps	sediment forebay or pond		ephemeral wetland
Wicking beds			permeable paving	wicking bed
	gross pollutant traps	sediment forebay or pond	biofiltration system	wicking bed
Passive irrigation rainwater tanks	passive irrigation rainwater tanks			vegetated sponge with filter

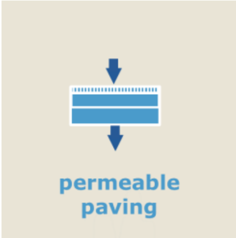
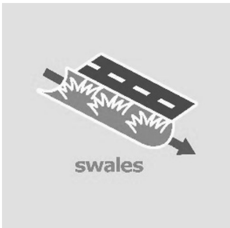
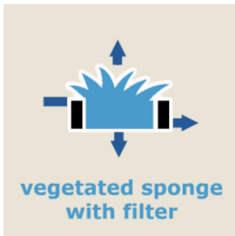
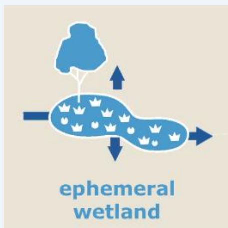
Asset type	Primary ➔		Secondary ➔	Tertiary
Porous pavement				

Figure 3Figure 3 shows examples of possible sequencing for the emerging assets within a treatment train. Other configurations may also be suitable. Primary and secondary treatments are included upstream of assets designed to promote infiltration. This is to ensure protection of infiltration capacity and a high standard of treatment prior to infiltration to protect groundwater. However, the need for these, particularly secondary treatment may vary depending upon catchment risks, the mitigation capacity of the asset and potential to protect groundwater through a vegetated root zone or similar within an infiltration asset.

Asset type	Primary ➔		Secondary ➔	Tertiary
Vegetated sponge				
				
				
Constructed ephemeral wetlands				

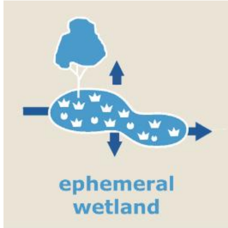
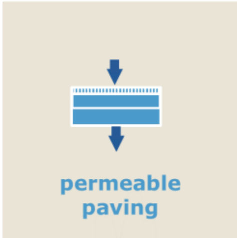
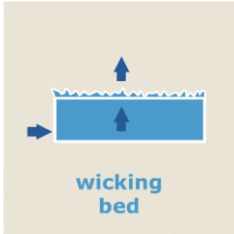
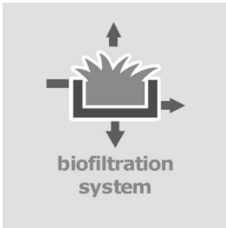
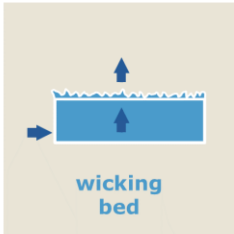
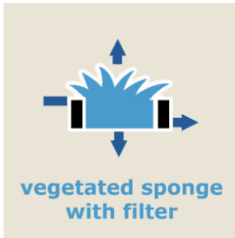
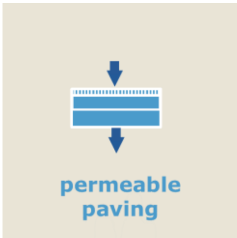
Asset type	Primary →		Secondary →	Tertiary
				
Wicking beds				
				
Passive irrigation rainwater tanks				
Porous pavement				

Figure 3 Examples of emerging assets within potential treatment trains (Note that the need for secondary treatments is site-specific.)

There is a broad range of potential WSUD assets and design configurations to provide reduced stormwater runoff volumes.

These have varying wetting and drying patterns within the soil or filter media and the surface water storage zones, as well as different plant communities.

The spectrum and characteristics are indicatively shown in Figure 4 and Figure 5. There are also a range of potential design configurations within each asset type. While an initial set of names, boundaries and configurations have been adopted, these will continue to evolve and develop as they are further researched and tested through industry implementation.

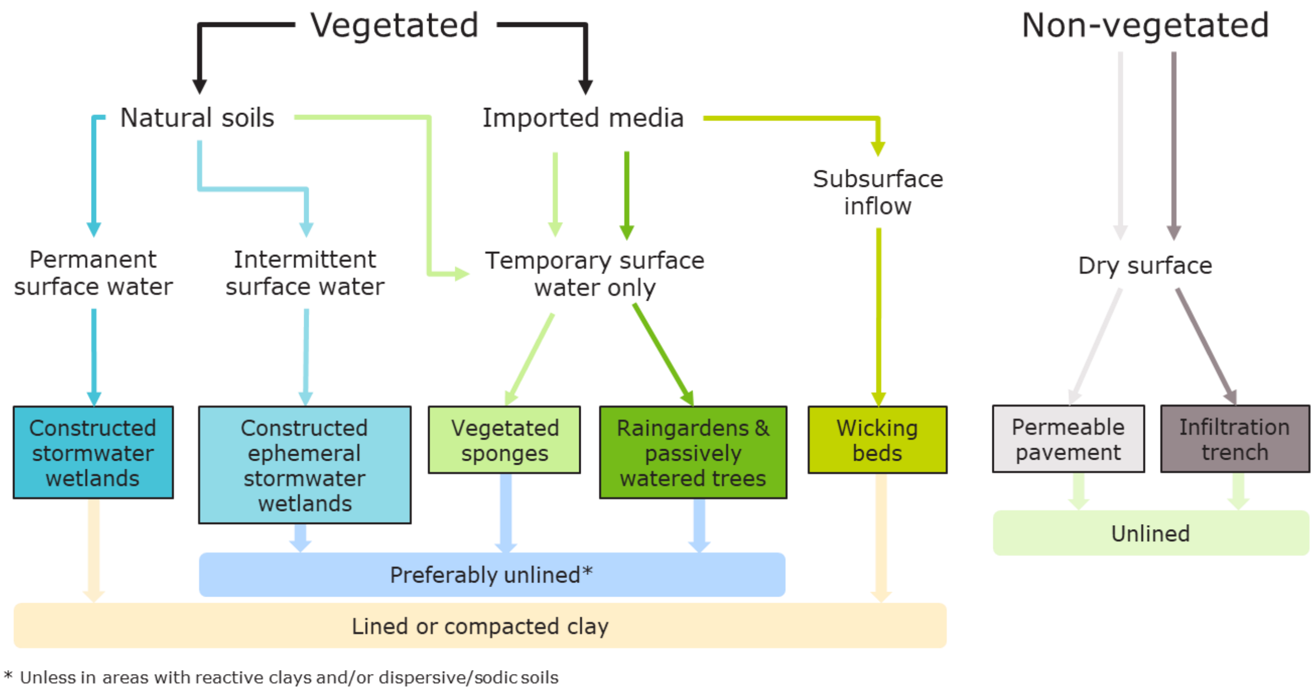


Figure 4 Key characteristics of different asset types

The asset types identified in Table 1 are shown along the spectrum. These may have broad and overlapping design ranges. Designers will need to carefully consider water levels and patterns, as well as soil aerobic and anaerobic zones and conditions. The configuration of outlets and overflows will need to appropriately balance stormwater volume reduction, treatment and plant health outcomes. Plant communities and species should be chosen to correspond with the expected conditions.

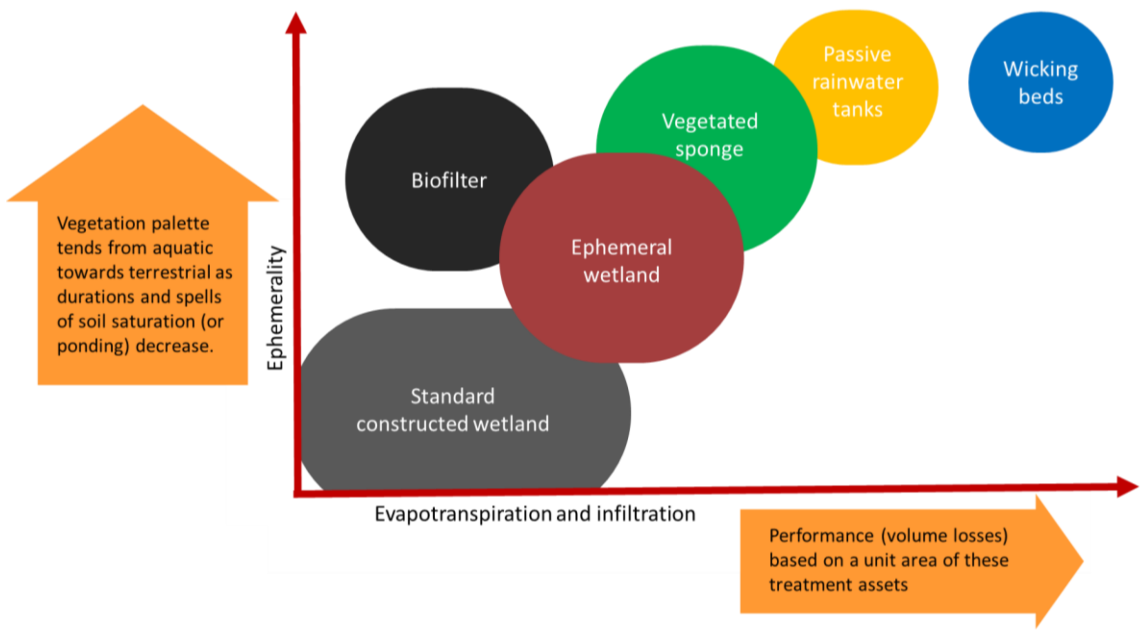
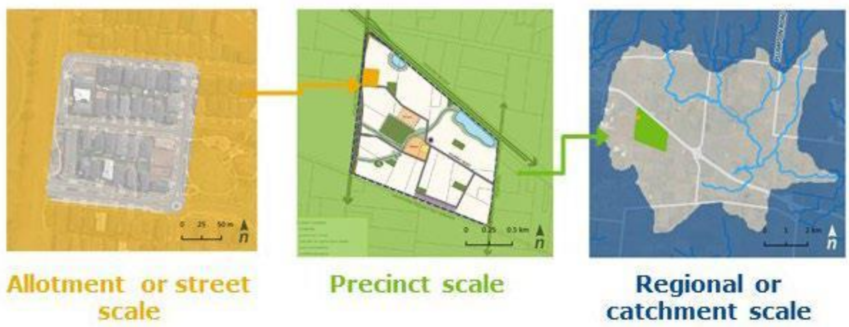


Figure 5 Spectrum of potential asset types and levels of ephemerality or water permanence

This document provides guidance on potential viable design approaches for emerging assets including **vegetated sponges,** constructed **ephemeral stormwater wetlands, wicking beds, passively watered street trees, permeable paving and passive irrigation rainwater tanks**. These draw on natural ephemeral wetland conditions, biofilter design approaches and existing case studies to propose a potential basis and indicative design ranges for the new assets.

Appropriate scale and context



The proposed new asset types can be developed at various scales across the catchment, from lot and street to precinct and regional or catchment scales. Depending on the asset type and context, they will be managed privately, by local councils, or by Melbourne Water.

The assets will take different forms depending on context. For example, a vegetated sponge may consist of:

- A garden area with in-situ soils or a dedicated raingarden area at lot scale receiving flows from a down-spout or a passive irrigation rainwater tank,
- A vegetated sponge within a park or open space receiving water from a daylighted drain;
- A larger vegetated sponge located adjacent to the floodplain and waterway corridor diverting water from a drain outfall to disconnect upstream directly connected impervious areas.

The new asset types must be designed with understanding of the site context and constructed in general accordance with existing practices and guidelines established by Melbourne Water and other relevant asset owners and managers, with adaptation to suit the asset type where necessary with these adaptations outlined in this document.

In certain, exceptional circumstances, ephemeral stormwater wetlands or in-situ soil vegetated sponges may be located within a natural floodplain or waterway corridor to restore a degraded floodplain area. In these cases, it is essential that the following principles are considered and followed:

- Technically feasible upstream opportunities have already been exhausted. WSUD approaches should first be embedded within the development layout, to minimise imperviousness and address stormwater management at source and along the flow paths. WSUD assets within the floodplain proposed as the first or only design response will not be accepted.
- Only considered for floodplains and waterway corridors that are already impacted and degraded and where the assets provide an enhancement to the degraded environment, such that there is a clear net increase in overall environmental values and biodiversity.
- Ensures the protection of any existing and potential ecological values of the floodplain, waterway corridor and surrounding habitats and no existing values are removed or adversely impacted.
- No adverse impact on local or regional flood behaviour, flood storage, flood levels, flow paths, the community, key waterway values (as described in the HWS) and other values.
- WSUD measures should not be at risk of being washed away, destroyed or impacted by sediment or debris up to the 1% AEP flood event.
- Asset type is the best design approach for the site taking into account ecosystem health, stormwater management, liveability, and consistency with regional and precinct plans.
- For vegetated sponges, the design uses in-situ soil-based design rather than filter media where practical to minimise disturbance (e.g. earthworks) within the waterway corridor or floodplain.

Ephemeral stormwater wetlands

What are ephemeral stormwater wetlands?

Ephemeral stormwater wetlands intermittently hold water for extended periods (days to months) and have limited or sometimes no permanent surface ponding (they usually still have permanent pools of water). They can be designed and constructed to function like standard stormwater wetlands [9], in that they are densely planted, allowing for filtering and treatment of stormwater runoff prior to discharge into downstream waterways or infiltration into the underlying soils. However, the wetting and drying regime for ephemeral stormwater wetlands is very different with ephemeral areas of the wetland experiencing significant periods of both wetting and drying.

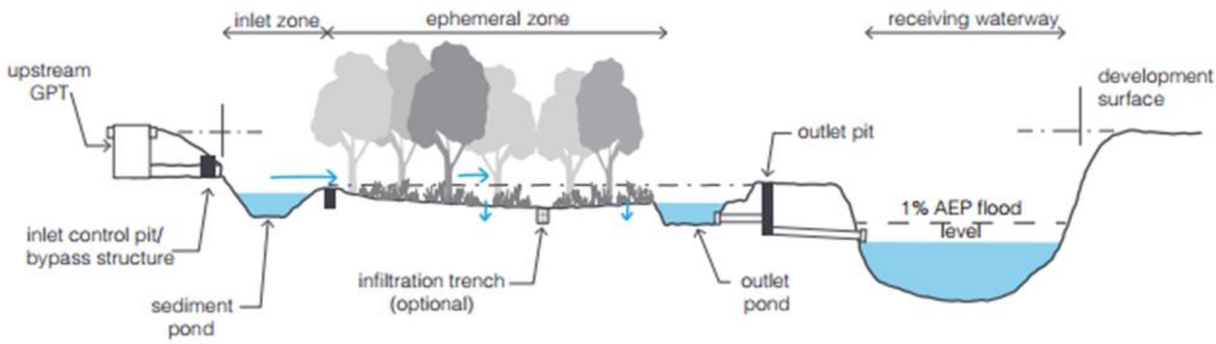
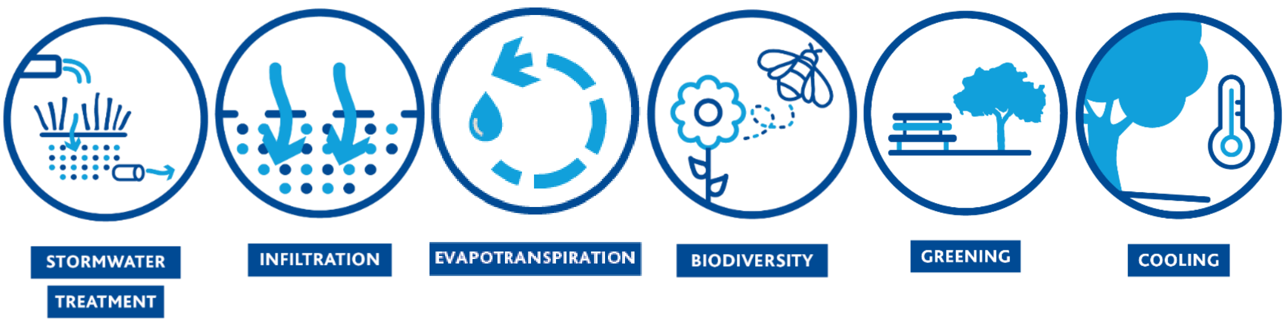


Figure 6: Ephemeral stormwater wetland concept section

Benefits



How do they differ from standard stormwater wetlands?

Standard stormwater wetlands are a well-known and tested approach for water quality treatment. Constructed ephemeral stormwater wetlands are an alternative or potentially approach that can provide a different range of

[9] https://www.melbournewater.com.au/building-and-works/developer-guides-and-resources/standards-and-specifications/constructed-wetlands

benefits, including greater stormwater volume reductions, baseflow recharge, biodiversity and other benefits as outlined below. They usually require a greater footprint than a standard constructed wetland to achieve similar treatment outcomes.

A key difference is the drier and more variable wetting and drying regime. Most or all of the ephemeral stormwater wetland macrophyte zone will usually be allowed to draw down completely (rather than the usual 150-350 mm marsh zone water depths) with permanent water remaining only in limited deep pools (or none at all). The ephemeral zone may have no surface ponding for significant periods of time. Selection, design and establishment of planting can be more challenging due to this variability and potential for extended periods of both wet and dry conditions.

Designing ephemeral stormwater wetlands

Key principles

The general design principles of standard stormwater wetlands outlined in Melbourne Water's *Wetland Design Manual*[10] may be used as a starting point when designing an ephemeral stormwater wetland. Specifically, sections relating to general maintenance, sediment control and drainage structures can be adopted for ephemeral stormwater wetlands.

- **Pre-treatment:** Urban stormwater runoff requires pre-treatment for sediment and gross pollutants prior to discharge into the ephemeral stormwater wetland. A sediment trap such as a sediment pond is essential. Additional pre-treatment solutions such as a gross pollutant trap should also be used to capture litter.
- **Flow pathways:** Ephemeral stormwater wetlands rely on temporarily detaining incoming flows to enable infiltration and evaporation to occur. Careful design of the inlet, outlet and bypass is needed to control the wetting and drying regime.
- **Planting:** Planting is essential for the function of ephemeral wetlands. The planting design should be informed by an ecologist.
- **Wetting and drying regime and plants:** The wetting and drying regime will depend on several factors, including climate, the size of the incoming catchment, wetland surface area, in-situ site soil infiltration rates, and the overflow weir design. The *design team will need an ecologist* competent in choosing a suitable plant community and species to support a healthy and biodiverse ephemeral stormwater wetland. Designers should undertake inundation frequency and spells analysis to help understand the wetting and drying regime and select suitable vegetation. This may be done using

[10] https://www.melbournewater.com.au/building-and-works/developer-guides-and-resources/standards-and-specifications/constructed-wetlands

MUSIC, the supporting *Wetland Analysis Tool*[11] or spreadsheets as described in the *MUSIC Guideline*, noting that different plants and corresponding heights will usually be needed.

- **Infiltration:** Adequate subsurface infiltration is required to ensure that the ephemeral stormwater wetland can dry out and satisfy infiltration objectives of the Healthy Waterways Strategy.
- **Protect groundwater:** Healthy vegetation is needed to ensure stormwater is effectively pre-treated before infiltrating into groundwater and to retain soil structure and permeability.
- **Vegetation selection:** Ephemeral stormwater wetland vegetation must be tolerant over a range of hydrologic conditions from wet to dry regimes.
- **Erosion prevention:** A velocity check should be completed to mitigate erosion issues throughout the ephemeral stormwater wetland.
- **Site grading:** Where a flat surface is not possible, a shallow grade can be applied to the ephemeral zone to help integrate the asset into an existing site. However, a hydraulic assessment must be completed to ensure that velocity and shear stress are within appropriate thresholds.
- **Wetland grading:** The wetland ephemeral zones should be nearly flat but have a slight and even and shallow grade into either permanent pools or the wetland outlet. A draw-down of up to 300 mm below the ephemeral areas and the use of internal drainage such as French drains can be used to ensure water flows towards any deep pools and the outlet. This is to avoid creating isolated pools of standing water that may support mosquito breeding. If the overall wetland needs to be on grade to integrate into the existing landscape, a hydraulic assessment must be completed to ensure that velocity and shear stress are within appropriate thresholds.
- **Asset management**: An asset management approach to design shall be adopted, including assessment of potential failure modes, maintenance and access requirements.

Challenges

- **Plant establishment:** The critical challenge with ephemeral stormwater wetlands is the establishment of plants. Unlike standard stormwater wetlands, where macrophytes experience a more consistent wetting regime, the ephemeral stormwater wetland plants undergo periods of drying and wetting dependent on local climate. A temporary increase in the frequency and retention of inundation during dry periods, to keep the plants damp, but not inundated, is recommended during their establishment phase (1 to 2 years) to help sustain high value native vegetation. This can be achieved via modification of the outlet, a temporary diversion of stormwater flows or other water sources if appropriate, such as groundwater. As for constructed

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[11] https://musicauditor.com.au/

wetlands, protection from excessive bird grazing may also be needed during establishment.

- **Underlying soil infiltration:** A detailed geotechnical investigation is required to determine the infiltration rates of the underlying soil as accurately as possible. Further guidance is provided on geotechnical testing in the MUSIC Guidelines – Chapter 6. Low infiltration rates may allow water to be held in the ephemeral stormwater wetland for too long and drown plants. Higher infiltration rates than expected may draw down the ephemeral stormwater wetland quickly and result in long dry periods that can also put the plants at risk. They may also present a greater risk for groundwater if water flows through too quickly to allow time for treatment within the wetland and root zone. The design should consider sensitivity to different infiltration rates as well as annual and seasonal climate variations.
- **Mosquito breeding:** Limit short-term ponding to prevent mosquito breeding habitat. For example, using shaping of the base, slight grading and/or an infiltration trench through the low point of the ephemeral zone, to promote free draining to outlet and deep pools.

Design features

- **Sediment pond:** to capture sediment and gross pollutants running off developed catchments prior to discharging into the ephemeral stormwater wetland.
- **Inlet connection:** Design appropriate inflow and bypass capacity to achieve performance objectives, comply with relevant guidance for standard stormwater wetlands in Melbourne Water's *Wetland Design Manual* and achieve a desirable wetting and drying regime.
- **Permanent pools:** can be part of the design of ephemeral stormwater wetlands to achieve an appropriate inundation frequency. However, a minimum of 80% of the ephemeral stormwater wetland should be comprised of an ephemeral macrophyte zone.
- **Outlet pit:** should be sized to cater for minor storm events.
- **Ephemeral zone:** the ephemeral zone is analogous to the macrophyte zone in a standard stormwater wetland and should be densely vegetated with Melbourne Water approved planting to remove nutrients from stormwater and support biodiversity.
- **Flow pathway:** A low flow pathway may be used to ensure low flows reach deep pools within the ephemeral stormwater wetland.

Starting points for design

A summary of indicative design parameters is provided in Table 2. This is not intended to be prescriptive but set out a basis for establishing a viable design.

Table 2: Indicative design parameters for ephemeral stormwater wetlands (modelled with wetland node)

Parameter	Value	Guidance
Proportion of deep pools (%)	Required: Up to 20% of ephemeral stormwater wetland area	No more than half of the deep pool areas should be at the ephemeral stormwater wetland inlet to ensure frequent events reach the ephemeral areas.
Extended detention depth (m)	Required: Up to 0.35	As per standard stormwater wetland.
Exfiltration rate (mm/hr)	Recommended: 0.18 to 100	An exfiltration rate suitable for the underlying soils should be adopted and must be set using the guidance provided in the *MUSIC Guideline*.
Notional detention time (hrs)	Required: 72	The outlet orifice should be sized to allow a detention time of 72 hours.
Inundation frequency (%)	Recommended: Inundated (water levels >0) for 40% - 60% of the time and dry for the remainder. Water levels not exceeding 100 mm above NWL for spells greater than 60 days. Water levels not exceeding 50% plant height for more than 20% of time. Water levels not >400 mm below NWL for spells greater than 30 days*	An inundation frequency analysis and assessment of planting is to be completed using the *Wetland Analysis Tool*. Plant selection should consider wetting and drying patterns and spells and may benefit from sensitivity analysis using a range of infiltration rates. *For more than one spell in 10 years. Note this could potentially be addressed through provision for supplemental watering.
Velocities (m/s)	Required: Less than 0.5 m/s for 1% AEP storm event	Refer to Melbourne Water's *Wetland Design Manual* Part A2: Deemed to Comply Criteria for further detail. Variations may be justified through a shear analysis. Note that the biofilm stripping criteria does not apply.

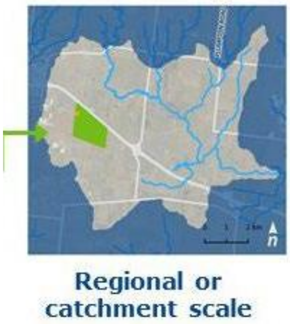
The stormwater treatment provided within an ephemeral stormwater wetland may be included as contributing towards meeting stormwater pollutant load reduction objectives. However, all infiltrated loads must be counted as reaching a receiving water and included in the outflow loads for comparing with best practice pollutant load reduction objectives (i.e. redirected to the receiving node in MUSIC). Furthermore, consideration should be given to the potential for pollutants to be infiltrated and ensuring adequate treatment both upstream of and within the ephemeral stormwater wetland occurs to protect groundwater receiving waters from potential contamination.

Further guidance on approaches to modelling and geotechnical investigations to support infiltration are provided in the MUSIC Guideline - Chapter 6.

Both evapotranspired and infiltrated flows from the ephemeral stormwater wetland may be counted as contributing towards meeting corresponding flow volume objectives. This is conditional on infiltrated flows being likely to reach the waterway with highly attenuated 'low flow' patterns. Consideration should be given to the likely infiltration, recharge and baseflow pathways for infiltrated flows.

Implementation

Appropriate scale and context



Ephemeral stormwater wetlands are best suited as a regional/catchment scale asset.

An ephemeral stormwater wetland may be used in combination with upstream stormwater treatment measures or be located downstream of a standard stormwater wetland to reduce stormwater volume through evapotranspiration and maintain baseflows via infiltration.

Ephemeral stormwater wetlands should not be designed at the expense of existing environmental values and must not be located within intact floodplains or waterway corridors that should be preserved. Instead, catchment managers and planners should seek opportunities at degraded sites where these assets can be integrated into rehabilitation projects.

Alternative designs and scales

At smaller scales, designers may prefer assets such as vegetated sponges, which can function similarly to an ephemeral stormwater wetland.

Things to avoid

Ephemeral stormwater wetlands shine when they can provide benefits to the local environment such as groundwater recharge and the rehabilitation of floodplains, while still providing water quality treatment. Other treatment assets should be considered if these benefits are not likely to be realised within the local context, as the additional challenges faced in establishing and maintaining the plant life of ephemeral stormwater wetlands may outweigh the benefits they provide.

Ephemeral stormwater wetlands should not be located where:

- Their implementation may adversely impact on key waterway values (as described in the HWS) or other values.
- Land and water contamination are identified as a significant risk.
- Salinity risks and the likelihood of infiltration increasing saline groundwater levels within an unconfined aquifer in proximity to the surface or buildings has been identified.
- Under-lying soils are highly dispersive soils that are at risk of erosion when exposed to water and infiltration rates and volumes will be significantly higher than natural conditions.
- Infiltration is likely to put built infrastructure at risk.
- The principles outlined in *Appropriate scale and context* cannot be achieved.

Operation and maintenance

New or unique maintenance

The operation and maintenance of ephemeral stormwater wetlands is similar to that of standard stormwater wetlands, and they can be maintained following the same operations and maintenance procedures. Ephemeral stormwater wetlands have more variable water levels with events and seasons. Establishing and sustaining plants within an ephemeral stormwater wetland may be more difficult than standard stormwater wetlands where water levels tend to vary more consistently within expected ranges. Differences or new maintenance may include:

- More active management of planting may be necessary to maintain healthy and extensive plant cover and manage weeds.
- Pro-actively managing water levels within desired ranges could be beneficial. This may involve adjusting flow rates or weir levels seasonally, directing additional low flows into an ephemeral stormwater wetland during a prolonged dry period or opening relief outlets to draw down water to avoid sustained high water levels, particularly during plant establishment.
- Ephemeral stormwater wetlands can potentially be more easily accessed during dry periods without the need for water entry. This will depend on design and climate conditions. Maintenance should be planned and scheduled during dry periods and seasons.

Civil elements

- Sediment pond

- Inlet
- Outlet
- Overflow

These may include drainage structures such as pits, pipes, penstocks, and weirs.

Landscape elements

- Wetland macrophyte planting
- Batter planting

Resourcing

- Similar to standard stormwater wetlands with a higher proportion of work in dry areas (during summer) rather than on-water.
- Upstream gross pollutant traps and sediment ponds should be regularly maintained to minimise unnecessary sediment and litter accumulation in the ephemeral wetland.
- Greater resourcing needed for plant management than standard stormwater wetlands.
- Active management of levels is recommended through either automated or manual adjustment of inlets and outlets.
- Similar equipment will be needed as for standard stormwater wetlands.
- Wetland inspection and maintenance checklists for standard stormwater wetlands may be adopted (for example Melbourne Water, Stormwater Victoria *WSUD Audit Guidelines*[12]) with few changes.
- Plans and details indicating design intent and expected water levels, location and configuration of inlets and outlets and details of the operation of any adjustable inlets and outlets should be provided to maintenance contractors.

Anticipated asset life

The asset life for ephemeral stormwater wetlands is expected to be similar to standard stormwater wetlands and they should be able to operate for at least 20-30 years.

Risks

Plant establishment: The biggest challenge is the establishment of plants within the ephemeral stormwater wetland. The establishment watering regime should be carefully prepared and diligently followed to ensure successful

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12 https://www.clearwatervic.com.au/user-data/resource-files/wsud-audit-guidelines_jun17_final_low-res.pdf

establishment. Once established, there remains a risk of plants dying if they are not suitable for the wetting and drying regime experienced. During design, provision should be made to allow water levels to be more pro-actively managed and allow flexibility. This can allow inflows to be increased or decreased, or water levels to be drawn down. This may consist of manually or automatically adjustable inlet and outlet weirs or valves as well as water level monitoring with alerts. Access to additional sources of water is recommended for the establishment phase and extended dry periods. This can include a temporary diversion of additional stormwater from an upstream drainage structure, recycled water, groundwater or potable water. The capacity to divert high stormwater flows around the ephemeral stormwater wetland during extended wet periods is recommended.

Soil infiltration: Low infiltration soils within the subgrade of the ephemeral stormwater wetland may lead to long detention times where the design is aiming to rely on volume reductions through infiltration. A geotechnical investigation should be completed to factor in realistic infiltration rates within the inundation frequency analysis. Further guidance is provided on geotechnical testing in the MUSIC Guidelines – Chapter 6. A sensitivity analysis of inundation patterns for varying infiltration rates is also recommended. A large ephemeral stormwater wetland overlying more freely draining soils may infiltrate significant volumes of water. This may lead to development of a ‘groundwater bubble’ or perched water table with elevated groundwater conditions. Consideration should be given to likely groundwater interactions, lateral flow paths and flow rates. Elevated groundwater levels may increase pore water pressure which can reduce the strength of soils. The geotechnical risks to any infrastructure in proximity such as buildings or bridge footings as well as any steep slopes down-gradient from the ephemeral stormwater wetland (such as waterway banks) should be assessed where identified.

Fire risk: For assets that may dry out significantly, potential fire risks should be considered. Mitigation options are as above to allow increased or supplemental inflows and water/soil moisture levels to be sustained during dry periods.

Case study – Torhaven Ephemeral Stormwater Wetland

Ipswich City Council

Deebing Heights, Queensland

Project overview

This project involved the design and construction of an integrated water management corridor that considered all aspects of stormwater management from an 8.3 ha portion of Defence Housing Australia's Torhaven development in Queensland, consisting predominantly of low-density residential housing.

The project reinstated a waterway that replicated natural processes but responded to the realities of a developed catchment. Water quality treatment was provided through 4,000 m^2 of ephemeral stormwater wetlands, see Figure 7. This new approach replicated the function of the pre-existing floodplain, responded to the climatic realities of the area and addressed ongoing maintenance challenges typically experienced by local authorities with standard stormwater wetlands. The project has won the 2019 Stormwater Queensland Awards for Excellence in Infrastructure.

Objectives and challenges

- The objectives were to capture, treat and retain frequent stormwater flows to protect the hydrology of the downstream receiving environment.
- The subject site and surrounding catchment fall steeply towards the discharge point which is located within a floodplain. Perching a conventional constructed stormwater wetland within the floodplain would have impacted existing flood storage volumes.
- There was also opportunity to reinstate a functional riparian floodplain corridor, which would enhance amenity and provide opportunity for passive recreation.

Organisations

Defence Housing Australia, E2Designlab, Water Technology, RPS, ACOR

Cost

$1.3 Million estimated stormwater asset cost, total civil cost Torhaven Stage 1 - $10M.

Timeframe

The project started in April 2016. The design team took this project from inception through to construction supervision over a period of around 2 ½ years. Construction was completed in 2019.

Figure 7 Torhaven ephemeral stormwater wetland (E2Designlab)

Design features

- Two **sediment ponds** capture sediment and gross pollutants to address water quality objectives.
- Inlet connection designed to ensure **uniform distribution** of flow throughout the ephemeral stormwater wetland to protect it from erosion risks that arise from steep fall sites.
- Ephemeral stormwater wetland zone shaped using low bunded compartments and a **high flow waterway** to allow periodical inundation from stormwater and flood flows.
- The **ephemeral zone** was planted with ephemeral Melaleuca Forest and groundcover communities, increasing environmental values and rehabilitation of habitat.
- A reinstated constructed waterway provides an **overflow pathway** for the treatment train.

Outcomes

- Delivery of a constructed ephemeral stormwater wetland and waterway that is resilient to the impacts of an urbanising catchment, replicates the functions of an ephemeral waterway and draws on the principles of natural floodplain management.
- Rehabilitated floodplain with enhanced floodplain engagement
- Increased landscape and recreational amenity.
- Improved habitat, biodiversity and riparian connectivity.

- Increased infiltration into underlying soils.
- Pollutant reduction achieved: 84.3 % TSS, 73% TP, 50.1% TN (modelled).

Lessons learnt

- Ephemeral stormwater wetlands can, under certain circumstances, be used within floodplains to provide best practice urban stormwater treatment whilst also enhancing their function.
- A removable weir plate can be left off during construction. Ensure the controllable range extends above and below normal water level.
- Adaptive water level controls were important for enabling plant establishment. Understanding and use of these is often quickly lost after construction so simplicity, reliability and a fail-safe approach is best.
- Allow drainage using a French drain to allow water levels to draw down below ephemeral areas.
- Water level control and adaptive controls are important to support plant establishment

Figure 8 Torhaven ephemeral stormwater wetland (Sally Boer, E2Designlab)

Vegetated sponges

What are vegetated sponges?

Vegetated sponges are vegetated areas that filter and reduce the volume of runoff discharged to waterways. They include dense planting of native sedges, shrubs and trees (such as Melaleuca) into in-situ soils or filter media that can filter stormwater runoff. They are usually set into the ground or may be surrounded by a shallow bund (subject to risk assessment) to create an extended detention depth for temporary water storage, promoting infiltration and evapotranspiration. They can also be designed to contribute towards best practice stormwater treatment objectives with upstream pre-treatment for litter and sediment at a minimum.

Vegetated sponges have many benefits, such as acting as a buffer for flows being directed to waterways to reduce flow magnitude, velocity and duration. This reduces the risk of erosion and preserves conditions for fish and other aquatic plants and animals. Evapotranspiration from vegetated sponges can have a cooling effect on the surrounding area. Infiltration of flows can recharge groundwater and help sustain low flows in waterways during dryer periods.

The effectiveness of vegetated sponges to achieve volume reductions will depend on local geotechnical conditions. Vegetated sponges may be less effective in areas featuring heavy clay soils, where infiltration rates are low, although this can be addressed through use of larger areas and a submerged zone to allow time for infiltration.

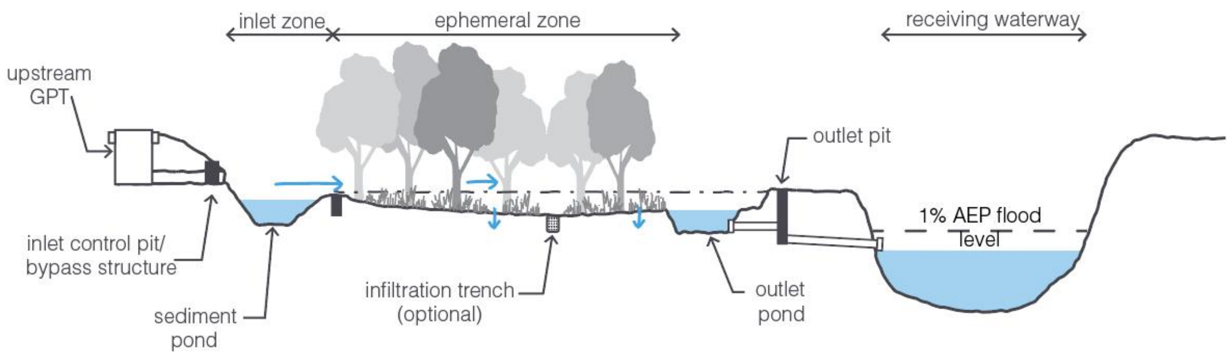


Figure 9: Vegetated sponge concept section

How do they differ from traditional biofilters or raingardens?

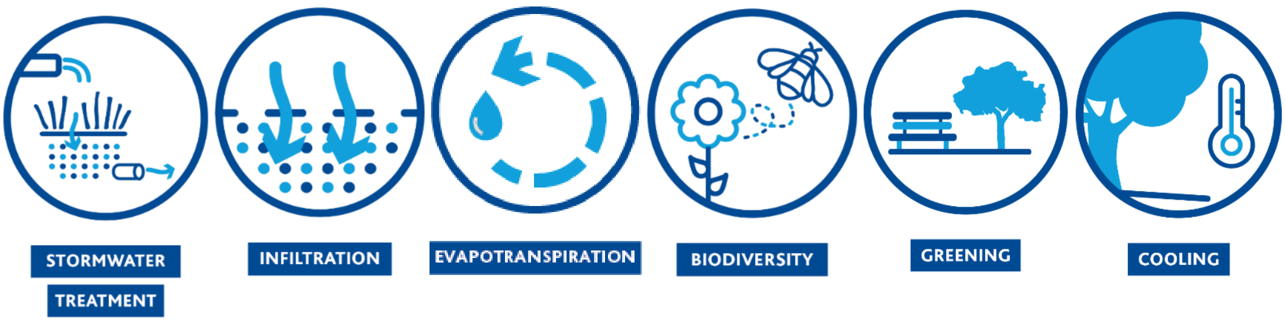
Vegetated sponges are similar to unlined biofilters or raingardens but their primary function is to provide water volume reductions and baseflow recharge, water quality treatment being their secondary function. The configuration for a vegetated sponge may take different forms (for example, with or without a submerged zone) and have different planting responses. They differ from standard stormwater wetlands and ephemeral stormwater wetlands in that water is primarily stored within the soil rather than within an extended detention depth or surface ponding zone.

The most common configuration will include use of an imported filter media. They will usually have underdrainage with an elevated outlet to ensure they do not become over-saturated. A temporary saturated or submerged zone below the underdrain will maximise retention and allow time for infiltration. A vegetated sponge will usually have a larger footprint than stormwater treatment biofilters since their primary purpose is to maximise stormwater volume reduction through evapotranspiration and infiltration processes, which are generally slower processes than filtration treatment.

Vegetated sponges may have filter media with lower hydraulic conductivity and more soil moisture retention than that used in biofilters since they will be more constrained by the infiltration capacity of the underlying soil than the hydraulic conductivity of the media itself.

An alternate design configuration is to use in-situ soils in lieu of filter media. This has the benefit of minimising soil and vegetation disturbance as well as costly earthworks. These will usually have limited underdrainage and no submerged zone (provision of smaller-scale relief under-drainage such as an infiltration trench with an elevated outlet to protect against over-saturation is recommended). The design will depend substantially on the infiltration rates and absorption capacity of the in-situ soils, and evapotranspiration.

Benefits



Designing vegetated sponges

Key principles

- They can be applied at all scales from lot/street to precinct to regional/catchment scale. Similar to biofilters, vegetated sponges should be designed with a low-flow bypass where necessary to avoid persistent inflows over extended time periods (such as baseflows from a large upstream catchment). This is to ensure they have opportunity for appropriate wetting and drying cycles.
- Design and function are essentially that of an unlined biofilter but usually with a significantly larger size relative to catchment to facilitate evapotranspiration and infiltration (indicatively 3-10% of catchment). Liners may be considered on the sides if deemed necessary to protect adjacent infrastructure.
- They should, in most respects, follow the design principles and guidance set out in Biofiltration Systems in Development Services Schemes (Melbourne Water, 2020)13.
- They will most commonly use filter media but may use in-situ soils where soils are suitable (refer to Table 4).
- They will preferably have dense planting of native sedges and shrubs suited to the filter media or in-situ soils. When in proximity to waterways and floodplains, they should be comprised of appropriate alluvial ecosystem communities, including forb, sedge, grass and trees vegetation belonging to the indigenous vegetation communities to support habitat values.
- They should have a relatively flat surface to promote even flow distribution.
- They may be depressed in the landscape or surrounded by low bunds to create an extended detention depth for temporary water storage, infiltration and evaporation.
- An asset management approach to design shall be adopted, including assessment of potential failure modes, maintenance and access requirements.
- They should have a clearly defined edge for maintenance purposes so that planting and filter media/soils within and outside the asset can readily be identified and differentiated.

Challenges

- The volumetric reductions achieved depend significantly on geotechnical conditions, with infiltration usually being the dominant flow path for flows that are retained and not discharged as surface runoff. If the subsurface soils have low infiltration, vegetated sponges will depend more upon evapotranspiration and will achieve lower stormwater volume reductions per unit area of footprint. A detailed geotechnical investigation is required to

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[13] https://www.melbournewater.com.au/media/14586/download

determine the infiltration rates of the underlying soil as accurately as possible. Further guidance is provided on geotechnical testing in the MUSIC Guidelines – Chapter 6.

- Where shallow groundwater levels exist (persistently or seasonally), the waterway water level is close to the base level of the vegetated sponge, or a perched water table is formed, the potential infiltration will be limited to the rate of lateral groundwater flows away from the asset. This will usually be lower than the freely draining vertical infiltration rate applicable for deep groundwater conditions and assumed in MUSIC. Where there is a shallow groundwater table, an infiltration rate reflecting the lateral flow rates and hydraulic head (depth of water above groundwater level) should be adopted.
- A large, vegetated sponge may infiltrate significant volumes of water leading to a 'groundwater bubble' or perched water table with elevated groundwater conditions. Consideration should be given to likely groundwater interactions, lateral flow paths, and flow rates. Elevated groundwater levels may increase pore water pressure and reduce the strength of soils. The geotechnical risks to any infrastructure in proximity, such as buildings, bridge footings or steep slopes down-gradient from the vegetated sponge (such as waterway banks), should be assessed where identified.
- Flow pathways to the waterway for infiltrated flows should be considered. The intent of infiltration is that surface runoff flows that are damaging to the receiving waterway (i.e. flows with high magnitude and frequency) are reduced, flows are attenuated through the landscape, groundwater recharge via surface infiltration will be closer to natural levels, and persistent baseflows or low flow volumes to the waterway are restored. If infiltrated water rapidly returns to the downstream waterway at rates exceeding natural low flows, then it may not be achieving these objectives. If flows are retained within the soils and groundwater and slowly released to the waterway, they can then be considered low flows and the volumes counted as contributing towards the infiltration objective. For vegetated sponges relatively close to the waterway, it may be appropriate to count only the portion of the infiltrated flows discharging at flow rates less than the average daily baseflow rate that the upstream catchment to the vegetated sponge would naturally provide.

Design features

- **Pre-treatment:** The primary function of vegetated sponges is stormwater surface runoff volume reduction. They may also provide a secondary function for stormwater treatment since they are also effective for treating nutrients and dissolved pollutants. At a minimum, upstream treatment for gross pollutants and sediment should be provided.
- **Inlet:** The inlet connection to the sponge should be designed to ensure a uniform distribution of flow throughout the vegetated sponge.
- **Extended detention depth:** Shallow ponding of around 0.1 m is needed at the surface with flat or gentle slopes to promote even flow distribution. This

can be achieved by depressing the asset in the landscape or by creating low bunds around the asset.

- **Submerged zone:** Vegetated sponges should include an unlined temporary submerged zone (for example, via a raised outlet) to increase the storage volume available for infiltration. Liners may be considered on the sides if necessary to protect adjacent infrastructure.
- **Edge:** Vegetated sponges should have clearly defined edges for the infiltration area (whether filter media or in-situ soil) and for the batters. This helps delineate maintenance responsibilities between the asset and the surrounding landscape where different groups may be managing these. It also enables ready identification of the filter media/soil zone, should any future remediation works be needed to address clogging, contamination or other issues.

Starting points for design

A summary of indicative design parameters for vegetated sponges with imported filter media is provided in Table 3 and for vegetated sponges with in-situ soils in Table 4.

Other aspects not covered below should generally be designed in accordance with *Biofiltration systems in Development Services Schemes* (Melbourne Water, 2020).

This includes the design of inlets and outlets, which should aim to ensure that flood flows are conveyed safely and erosion risks are effectively managed through limiting inflow capacity, relative position of inlets and overflows, and inflow distribution. The guidance on upstream litter and coarse sediment removal and design for maintenance should also be adopted.

Table 3 – Indicative design and modelling parameters for vegetated sponges with imported filter media (modelled using bioretention node)

Parameter	Value	Guidance
Extended detention depth (m)	Required: 0.0 to 0.5 Recommended: 0.0 to 0.15	For modelling use a nominal depth of 10-20 mm if design has zero extended detention depth with water overflowing freely). Maximum depth of 500 mm.
Filter depth (m)	Required: 0.3 to 0.6 Recommended: 0.4 to 0.6 or 0.7 to 1.0 with trees*	Depth above underdrain invert. Total filter media depth including submerged zone greater than or equal to 400 mm preferred.
Saturated hydraulic conductivity (mm/hr)	Required: 36 to 300 Recommended: 36 to 100	Broad range to allow raingarden media to be used. Media with greater soil moisture retention (and low nutrients) preferred. For modelling assume lesser of design hydraulic conductivity or 100 mm/hr.
Exfiltration rate (mm/hr)	Recommended: 0.18 to 100	An exfiltration rate suitable for the underlying soils should be adopted and must be set using the guidance provided in the *MUSIC Guideline*.
Underdrain	Recommended: Yes	Include above a submerged zone.
Submerged zone depth (m)	Recommended: 0.3 to 0.5	Include depth of filter media, transition media and drainage below underdrain invert. Sand is preferred over gravel to support capillary rise.

*Avoid placing underdrainage or drainage layer material directly beneath trees

Table 4 – Indicative design and modelling parameters for vegetated sponges with in-situ soil (modelled with bioretention node)

Parameter	Value	Guidance
Extended detention depth (m)	Required: 0.0 to 0.5 Recommended: 0.0 to 0.15	For modelling use a nominal depth of 10-20 mm if design has zero extended detention depth with water overflowing freely). Shallow depth of up to 150 mm preferred. Maximum depth of 500 mm.
Filter depth (m)	Required: 0.3 to 0.6 Recommended: 0.4 to 0.6	Set based on the average effective root depth of the vegetation.
Saturated hydraulic conductivity (mm/hr)	Required: 3.6 to 300 Recommended: 3.6 to 100	A saturated hydraulic conductivity suitable for the surface soils should be adopted and set using the guidance provided in the *MUSIC Guideline*. These are likely to be sandy loam, sandy clay or medium clay in the range 0.36 to 36 millimetres per hour. For modelling assume lesser of design hydraulic conductivity or 100 mm/hr.
Exfiltration rate (mm/hr)	Recommended: 0.18 to 100	An exfiltration rate suitable for the underlying soils should be adopted and set using the guidance provided in the *MUSIC Guideline.*
Underdrain	Recommended: Yes	Usually, only relief under-drainage to protect against over-saturation may be provided.
Submerged zone depth (m)	Recommended: 0	Usually no submerged zone for in-situ soils.

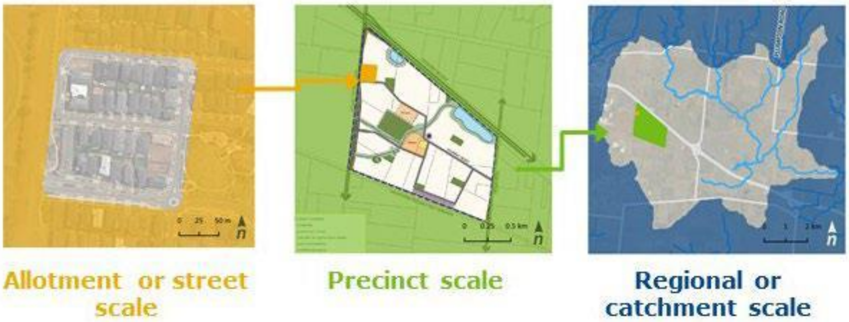
Since exfiltration into the underlying soil is usually the primary flow pathway, a detailed geotechnical investigation is important to determine the infiltration rates of the underlying soil as accurately as possible.

Consideration should be given to the potential for pollutants to be infiltrated and ensure adequate treatment occurs, both upstream of and within the vegetated sponge, to protect groundwater receiving waters from potential contamination.

Further guidance on approaches to modelling and geotechnical investigations to support infiltration are provided in the MUSIC Modelling Guideline.

Implementation

Appropriate scale and context



Vegetated sponges may be located at any scale within urban areas. They may take different forms, such as simple garden areas receiving flows from a down-spout or tank (for example a passive irrigation rainwater tank), within a park or open space, or be located adjacent to the floodplain and waterway corridor.

In certain exceptional circumstances, vegetated sponges may take the form of a 'riparian sponge', located within a natural floodplain or waterway corridor, on the in-situ soils to restore a degraded floodplain area. See further discussion in *Appropriate scale and context*.

Alternative designs and scales

Designs at varying scales include park, streetscape or lot-scale unlined raingardens of increased size with increased soil moisture holding capacity (hydraulic conductivity of 36-100mm/hr) – encourage tree plantings within or adjacent to promote evapotranspiration losses (and minimise potential seepage into surrounding areas, such as road subgrade).

Designs using in-situ soils to minimise soil works and costs, as well as mirror the flow regime of the local environment, are a possible alternative where infiltration rates are reasonable. These are the preferred approach for assets located in, or close to, more sensitive environments, particularly natural floodplains and waterway corridors to minimise earthworks and disturbance.

A vegetated sponge with in-situ soils will usually have a lower hydraulic conductivity and require a significantly larger footprint than a design using imported filter media, although this depends on soil conditions. They are also unlikely to feature a full underdrainage layer or submerged zone as the intent is to minimise earthworks and associated costs and disturbance, although relief underdrainage is still recommended to ensure the upper root zone soils do not become over-saturated.

Vegetated sponges may be depressed in the landscape or surrounded by a bund (subject to risk assessment) to create an extended detention depth for temporary water storage and allow additional time for infiltration and evapotranspiration.

Things to avoid

Biofiltration Systems in Development Services Schemes (Melbourne Water, 2020) provides a general guide of where biofiltration assets may not be appropriate and these are generally also applicable to vegetated sponges.

Some key things to avoid are as follows:

- Under-sizing assets whereby a relatively large catchment flows into a relatively small, vegetated sponge. Effective vegetated sponges would generally not have an area less than 2% of their catchment (ideally 3-10% of catchment).
- Allowing uncontrolled sediment to accumulate on a vegetated sponge as it would risk smothering the vegetation.
- Locating vegetated sponges where:
    - Their implementation may adversely impact on key waterway values (as described in the HWS) or other values.
    - They can't drain freely or are at risk of being 'too wet' to support a regularly wetting and drying root zone and healthy plants.
    - Land and water contamination are identified as a significant risk.
    - Shallow groundwater levels exist, as the potential infiltration will be limited to the rate of lateral groundwater flows away from the asset. As a guide, known seasonal or permanent groundwater levels within 1 m of the base level may constrain infiltration potential.
    - Salinity risks and the likelihood of infiltration increasing saline groundwater levels within an unconfined aquifer in proximity to the surface or buildings have been identified.
    - Concentrated infiltration into highly dispersive soils, at risk of erosion when exposed to water. Refer to guidance on geotechnical testing provided in the MUSIC Guidelines – Chapter 5.
    - Infiltration at the location may put infrastructure at risk.
    - There is a lack of identifiable pathways for infiltrated flows to waterways or deep groundwater. These may include lateral flow through groundwater downslope towards waterways that is not impeded by surrounding buildings and/or adequate adjacent planted areas that allow for evapotranspiration.
    - Their implementation may adversely impact the function or ecology of a waterway or floodplain.
    - The principles outlined above in *Appropriate scale and context* cannot be achieved.

Operation and maintenance

The operation and maintenance of vegetated sponges is mostly similar to biofilter/raingarden assets with a focus on maintaining healthy plants and infiltration capacity.

Civil elements

- Inlet pits and pipes
- Outlet and overflow pits, pipes and weirs
- Maintenance access

Landscape elements

- Vegetated sponge surface
- Batters

New or unique maintenance

Vegetated sponges may have lower saturated hydraulic conductivity than raingarden assets. This needs to be considered when infiltration rates are tested.

It is recommended to test the saturated hydraulic conductivity of the media or surface soils using laboratory or, ideally, field tests upon commissioning to establish a baseline for expected performance. Future testing may then identify if significant changes occur due to sediment accumulation or other clogging processes.

It is recognised that performance of vegetation sponges is usually driven by the infiltration rates into underlying soils rather than the infiltration capacity of the sponge itself. Where in-situ soils are proposed to be used, infiltration tests of in-situ soils should be undertaken for these at depth to determine the range of expected infiltration rates.

Vegetated sponges may be planted with trees along with other plants. These may be managed similarly to other trees in parks. Some research into raingarden assets (Hoyland Street in Brisbane) indicates the level of effort required for weeding may be reduced for assets including trees. Plant species may be chosen based on the following considerations:

- indigenous species for relevant Ecological Vegetation Classes (EVCs)[14] in the area with similar conditions (particularly wetting and drying conditions), such as swamp forest

[14] https://www.environment.vic.gov.au/biodiversity/bioregions-and-evc-benchmarks

- plants tolerant to a range of wet and dry conditions, taking into account expected conditions for the vegetated sponge (which is usually wetter than surrounding terrestrial areas, though filter media may also dry out more quickly)
- plants with strong growth
- plants that establish deep and extensive root systems
- plants that will be complementary and mutually supporting.

The plant species used for standard biofilters such as those outlined in the *Biofiltration Systems in Development Services Schemes* (Melbourne Water, 2020) may be adopted as an initial guide. Reference may then be made to suitable indigenous plant communities, such as swamp forest or melaleuca swamp.

Resourcing

- Resourcing similar to biofilters or raingardens should be anticipated.
- A brief inspection of litter, sediment accumulation and plant condition is recommended every 3 months or following major storm events, with a more thorough inspection annually or bi-annually.
- Upstream gross pollutant traps and sediment ponds should be regularly maintained to minimise unnecessary sediment and litter accumulation in the vegetated sponge. Significant assets (large and/or high profile) may be inspected and maintained more frequently.
- Vegetated sponges will usually be larger relative to their catchment than other raingarden assets with lower flow and sediment loading rates. For this reason, they may require less maintenance relative to their area to manage litter and sediment. As for a bioretention or wetland, they will usually have upstream litter and sediment control with a gross pollutant trap and/or sediment pond.

Anticipated asset life

With effective pre-treatment for litter and sediment, vegetated sponges should be able to operate for at least 20-30 years.

Risks

Blockage: Blockage of inlets and outlets is a risk that can result in diversion of flows, respectively leading to excessive drying out or ponding of an assetThese should be checked regularly, and any debris or sediment accumulation cleared.

Sediment accumulation and clogging: Sediment accumulation on the surface of the vegetated sponge may result in clogging and reduced surface infiltration rates. This may, in turn, result in surface ponding for extended periods and loss of plants that cannot tolerate long periods of inundation. Gradual accumulation of sediment lifting the surface level and compromising storage volumes is also a risk even if infiltration rates remain acceptable, and therefore sediment inflows should be minimised. Observable warning signs include visible sediment accumulation, wet patches, puddles or ponding more than 24 hours after rainfall, and presence of inundation tolerant weeds.

Weeds: Planting to achieve dense coverage and shading as quickly as possible to minimise weed establishment. Quickly replant any bare patches to minimise opportunity for weed establishment. Monitor plant health to identify potential plant stress due to excessive wetting or drying, sickness or pests.

Over-saturation: All WSUD assets including vegetated sponge areas receive more water than standard garden beds. Vegetated sponges with in-situ soils may be at increased risk of water-logging or ponding during extended wet periods. This is best managed through provision of under-drainage with an outlet elevated above the base. Where in-situ soils are used, this does not need to be extensive across the surface area but can be achieved through the use of relief under-drainage, such as a drainage trench along the down-slope side of the asset with an outlet elevated above the base.

Excessive drying: Vegetated sponges with filter media are larger than typical biofilters so receive lower flow loading rates (flow volume per area). At the same time, imported (sandy) filter media may retain less soil moisture than other soils. This may be assessed by considering soil moisture curves and spells and can be mitigated through using filter media with higher soil moisture retention capacity. As for all other landscaping and assets, consideration may be given to opportunities for supplemental watering during prolonged dry periods (for example, more than 4 weeks without rainfall). This may be through designed irrigation or including them on the asset register to receive trucked water along with trees.-

Case study – Wicks Reserve Vegetated Sponge Bio-infiltration System (adapted from Knox City Council, 2012)

The Basin, Victoria

Overview

The Wicks Reserve Bio-infiltration basin is an innovative vegetated sponge system that aims to protect Dobsons Creek, a waterway of high ecological significance, from the degrading impacts of urbanisation. The system combines bio-filtration, infiltration and harvesting of stormwater, and contributes to restoring both the water quality and flow regime of the creek back towards its natural 'pre-development' state.

The system is located within Wicks Reserve – situated only 200 m away from Dobsons Creek – in the Knox municipality area. Wicks reserve is a site of high biological significance due to (1) the presence of depleted and vulnerable Ecological Vegetation Classes (e.g. Wet Heathland, Swampy Woodland and Grassy Forest), (2) a large, breeding population of the Swordgrass Brown butterfly and (3) excellent birdlife.

The system intercepts stormwater flows from two pipes draining the 11.5ha impervious urbanised catchment to the South of Wicks Reserve. Whilst part of the stormwater is lost through evapotranspiration, most filters through the vegetated filtration media into the base of the system – a 300 mm layer of scoria. This base layer facilitates infiltration into the surrounding soil and creates a large storage area for the treated stormwater (1.5 ML). This water can be pumped out of the system and used to supply a 23 kL tank, which provides filtered water for toilet flushing and to irrigate the surrounding forested area.

The project was an initiative driven by Knox's Water Sensitive Urban Design (WSUD) and Stormwater Management Strategy and is part of the Dobsons Creek catchment disconnection project. It won the Stormwater Victoria Excellence in Infrastructure Award in 2011.

Objectives

- Restore the hydrology of the creek back towards its natural 'pre-development' state (increased baseflows and reduced frequency, rates and volumes of runoff).
- Reduce the concentrations and loads of sediment, nutrients, heavy metals and toxicants entering the creek.

- Provide access to water for irrigation of the surrounding forest and toilet flushing through a novel stormwater harvesting system, using the large storage volume available within the base of the infiltration system.
- Raise community awareness.

Challenges

Sealing an unforeseen leak in the drainage system after planting of the sponge was completed caused significant sediment runoff into the sponge, affecting plant growth and reducing infiltration rates.

Figure 10 Vegetated sponge at Wicks Reserve (Knox City Council, 2012)

Organisations

Knox City Council, Monash University, The University of Melbourne, Contek Constructions, Melbourne Water

Cost

$745,000 Total, including $585,000 co-funding from Melbourne Water

Timeframe

Planning commenced in 2009. The design and tender were undertaken in 2010 and construction in 2011.

Design features

- A stormwater infiltration and harvesting system comprising a **gross pollutant trap**, a **sediment basin**, a constructed **vegetated sponge** bio-infiltration basin with filter media and underdrainage, and a **water tank** for storing filtered water to be used for toilet flushing and irrigation.
- An undulating basin surface area provides opportunities for different plant species to thrive within different parts of the system (Figure 11).
- Boardwalks, paths, seating and interpretive signage provide opportunities for community recreation and education.

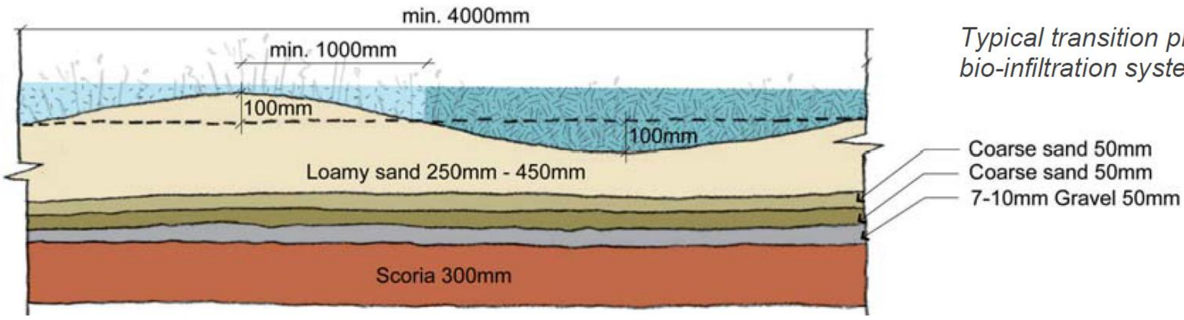


Figure 11 Typical cross section of Wicks Reserve system, showing its undulating surface design (Knox City Council, 2012)

Outcomes

- Monitoring of the Wicks Reserve system shows that, on average, 95% of runoff is filtered through the basin, with only 5% bypassed without treatment. Some 31% of inflow is infiltrated, while around 4% is directly evapotranspired from the basin surface. Flow peaks are reduced on average by 81%, while concentrations of TSS, TP and TN are reduced by 93, 84 and 73%, respectively. Importantly, the system returned an overall flow regime which is closer to natural than the original state, albeit still with significant peak flows. The infiltration flows were important in restoring the low flows closer to the reference condition.
- The harvested stormwater is used to irrigate adjacent forested areas and therefore contributes to the ecological health of the reserve.
- The undulating surface of the bio-infiltration basin provided opportunities for different plant species to thrive within different parts of the system resulting in a more diverse plant mix. A local ecologist provided specialist advice on the plant species mix, which contains vegetation representative of the Ecological Vegetation Classes of the area.
- The project team encouraged community awareness and engagement at different stages throughout the project:

  - A community consultation process was developed at the concept phase of the project.
  - The construction contractor provided information during construction to visitors to the site.
  - An opening BBQ allowed over 60 members of the community to celebrate the completion of the project.
  - Interpretive signage was installed on-site after completion of the project.

- The new design of the raingarden has enhanced the public realm within Wicks Reserve, improving access with an all-weather surface for walking (boardwalk) and public seating area.
- The project also brought about a positive social outcome. More people use the reserve to enjoy the ambience of the 'wetland' and walk around the board walk, increasing the passive surveillance within the reserve.

Lessons learnt

- Several different areas of council participated in the design of the system, which fostered innovation and greatly improved the quality of the design. Maintenance staff were involved from the onset and provided input into the design. This helped inform maintenance costs and the ongoing maintenance requirements of the system. Furthermore, the biodiversity section suggested the idea of designing the undulating surface, allowing a larger diversity of plants to be incorporated into the design.
- The use of 'unit rates' for the estimation of construction and maintenance costs during the design and planning phase greatly facilitated project planning and tracking of funding allocations.
- Fairly intensive vegetation maintenance was required for the first year of operation. The maintenance team now has a checklist of activities to carry out every 6 weeks.
- Planting has established well and Wicks Reserve has not required supplemental watering.
- The success of this project has paved the way for other initiatives to achieve similar outcomes. Two such examples are Knox's road re-construction projects (Raingardens for helping your creek) and Melbourne Water and South East Water's household tank give-away scheme (Tanks for helping your creek) to reduce the volumes of stormwater directly entering creeks.
- Vegetated sponge systems such as the Wicks Reserve basin can mitigate the impacts of urban runoff on streams and shift the urban water balance towards natural conditions. However, monitoring of the Wicks Reserve system shows that complete flow regime restoration requires catchment-scale action involving a combination of measures that reduce overall runoff volume, primarily through stormwater harvesting.

Wicking beds

What are wicking beds?

A wicking bed is a vegetated system (turf open space or vegetated garden bed) that has a reservoir of water or wicking layer at the base from which water is drawn upwards like a wick to the topsoil layer above. The wicking bed uses the natural process of soil capillary rise, driven by evapotranspiration, to irrigate the active root zone. As the vegetation removes 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. The depth and composition of the wicking layer is governed by capillary rise distance and storage volume. Wicking beds are scalable and most likely to be used in combination with sports fields but may also be used for passive recreational lawns or garden beds.

When full, the wicking layer overflows to prevent saturation of the topsoil layer. This also provides for a well-draining vegetated surface layer appropriate for sporting fields. When it rains, the wicking storage zone is topped up with excess rainwater that infiltrates down through the wicking bed as well as water flowing in from other sources. Other possible sources of water can include rainwater from nearby rooftops, treated stormwater from nearby urban catchments or car parks and recycled water.

Wicking lawns on sports fields provide a stronger and more resilient turf surface due to the subsurface water source encouraging the turf to develop deeper roots. This facilitates quicker wear recovery and increases the usability of the space after heavy rainfall events. Wicking beds improve environmental ground factors such as soil moisture and ground hardness to reduce injury risk from falls.

Healthy and well-watered turf has been found to increase CO_2 capture and reduce surface temperatures on hot days. Unirrigated turf and synthetic surfaces can have a surface temperature almost as hot as road pavement on a hot day. In contrast, wicking turf areas that are reliably watered can present a significant urban cooling benefit and improve microclimate.

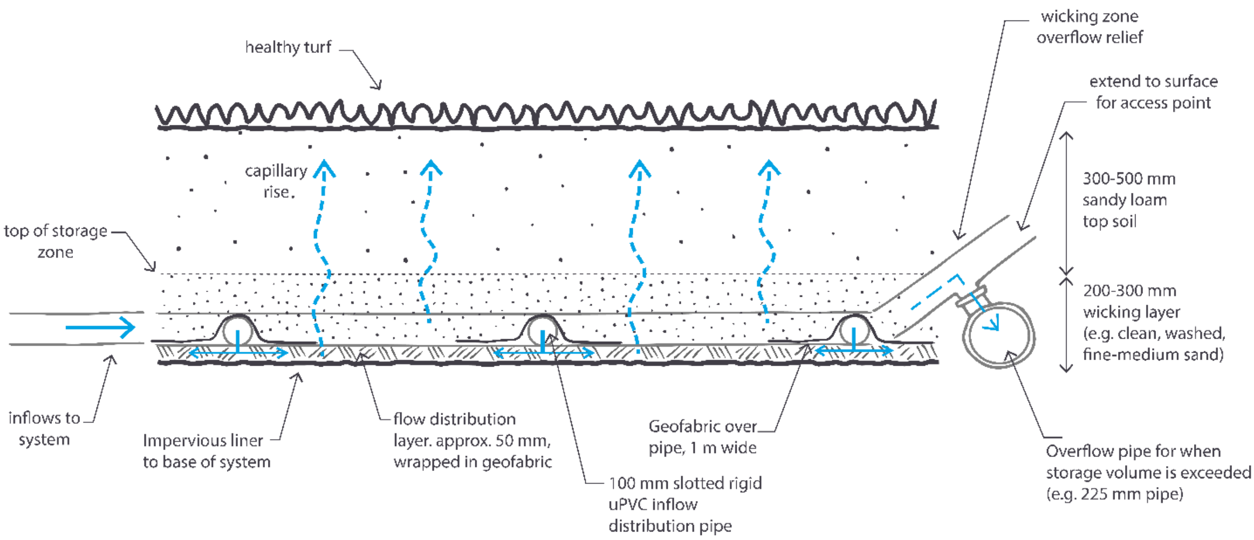


Figure 12 Typical cross-section through a turf wicking bed

Benefits

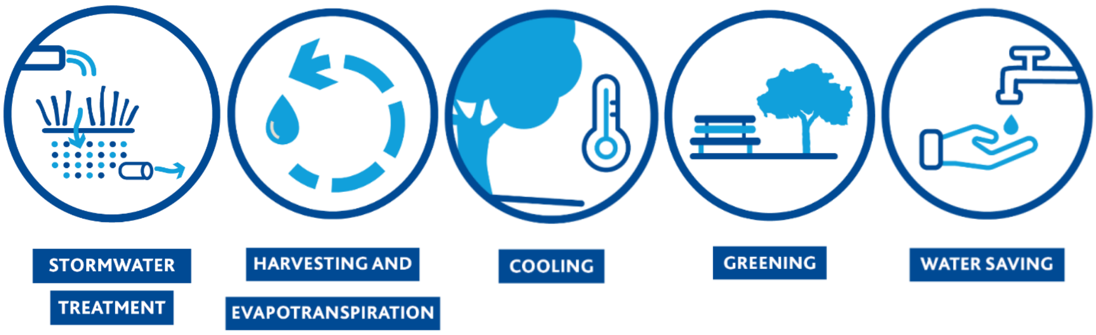


Figure 13 Benefits of wicking beds

How do they differ from traditional raingardens?

Unlike raingardens which receive water above ground, wicking beds are fed water directly into their underground reservoir. The above ground vegetation draws moisture from this reservoir via capillary rise. This provides the opportunity to co-locate these beds underneath sports fields.

It is essential that any stormwater directed to a wicking storage is effectively pre-treated to remove any sediments. This may include a gross pollutant trap, sediment pond or forebay and must include an absolute filtration barrier to sediment, such as a raingarden or permeable pavement.

Designing wicking beds

Key principles

- Wicking beds are generally suitable for sites where quality open space is desired for aesthetics and/or functionality such as sports fields. As such, the area is often determined by landscape and open space design processes rather than achieving stormwater treatment or volume reduction outcomes.

- When designing wicking beds, consideration needs to be given to the wicking zone storage volume, the catchment size and the water demand of the turf or other vegetation used.
- As a general guiding principle for wicking bed sizing, the contributing catchment area should be a minimum 2 times the surface area of the lawn (and preferably 3-10 times) to achieve a reliable source of irrigation (that is >70% reliability) although sizing and reliability depends upon intended use, climate conditions and availability of backup water supplies (in which case yield is more important than reliability).
- Effective subsurface flow distribution is required. Adequate wicking zone overflow capacity is also required to ensure turf does not become waterlogged.
- It is important that frequent events runoff reaches the storage zone to ensure it is working optimally. Flows greater than the 1EY storm event should bypass the wicking system to avoid oversizing of flow distribution networks.
- Irrigation demand of wicking lawns is determined by climate conditions, plant species and surface area.
- An asset management approach to design shall be adopted, including assessment of potential failure modes, maintenance and access requirements.

Challenges

- Water balance modelling of a wicking bed system is dependent on variables such as porosity, hydraulic conductivity, and potential evapotranspiration factor. These variables are difficult to accurately estimate at a strategy or concept stage.
- Water quality modelling in MUSIC is also difficult to accurately analyse. Designers can use two approaches (one using a bioretention node, a second using a rainwater tank node with the evapotranspiration rates set as the tank demand) to create an upper and lower bound for water quality modelling results but there is no way to confidently estimate these at present due to a lack of field monitoring and targeted configuration of a treatment model specifically for wicking beds.
- An excess of stormwater volumes draining towards the wicking bed can lead to erosion and flooding issues if the overflow pit is not properly configured.

Design features

- **Pre-treatment:** Urban stormwater runoff requires pre-treatment for gross pollutants and all sediment (that is 80% TSS) prior to discharge to the wicking bed.

- **Inlet**: The inlet connection to the wicking bed
- **Subsurface flow distribution**: A subsurface flow distribution layer should be provided with slotted pipes and gravel or drainage cells to ensure appropriate distribution of stormwater volumes throughout the wicking bed.
- **Wicking layer**: The depth and media porosity of the wicking layer or underground reservoir will determine the volume of water that can be stored.
- **Overflow outlet**: An adequate wicking layer overflow structure is required to ensure the turf does not become waterlogged.
- **Impermeable layer**: An impermeable layer may be required to retain water in the wicking layer.

Starting points for design

There are two main approaches to designing a wicking bed: the bioretention approach and the rainwater tank approach. The modelling of these approaches is further explained in the *MUSIC Guideline*.

The cross-section detail shown in Figure 12**Error! Reference source not found.** and supporting guidance in Table 5 provide an example of a known effective design that can be adapted to suit the project context and objectives.

Table 5 Indicative design and modelling parameters for wicking beds (modelled using bioretention node)

Parameter	Value	Guidance
Rainwater tank approach		
Catchment area	Upstream catchment area	The direct rainfall on the surface does not need to be modelled in a rainwater tank model, because this rainfall is factored into the demand calculation of the tank.
Tank volume (kL)	User defined	$Storage\ volume = (surface\ area) \times (depth\ of\ wicking\ layer) \times (porosity\ )$
Overflow pipe diameter (mm)	User defined	Set to the overflow pipe outlet size of the wicking system.
Annual demand	User defined	Annual demand using PET distribution. The potential irrigation demand for a lawn is determined by several factors including: • Climatic conditions - temperature, humidity, wind, sunshine. • Crop factor – volume of water required for a specific species to grow. This can vary through a season and different growth phases of a plant. • Surface area – larger wicking lawns will have a higher demand. Irrigation demands may be estimated using standard textbook methods[15], an appropriate crop factor for the planting and assuming a high irrigation efficiency. An example demand is shown below considering the minimum factors: $Demand = PET \times crop\ factor \times irrigation\ efficiency -\ rainfall$

[15] For example: Connellan, G., 2013, Water use efficiency for irrigated turf and landscape

Parameter	Value	Guidance
Bioretention approach		
Catchment area	External upstream catchment area plus wicking bed surface area	To improve the accuracy of soil moisture and evapotranspiration modelling in MUSIC, the surface area of the wicking bed should be modelled as an additional catchment area with 100% imperviousness representing direct rainfall on the surface.
Surface area of wicking bed	User defined	Set to the surface area of the wicking system's landscape. This area will determine the irrigation demand and the storage volume available.
PET Factor (water demand)	User defined	The potential irrigation demand for a lawn is determined by several factors including: • Climatic conditions - temperature, humidity, wind, sunshine • Crop factor – volume of water required for a specific species to grow. This can vary through a season and different growth phases of a plant. • Surface area –larger wicking lawns will have a higher demand. Irrigation demands may be estimated using standard textbook methods[16], an appropriate crop factor for the planting and assuming a high irrigation efficiency. An example demand is shown below considering the minimum factors: $\boldsymbol{Demand = PET \times crop\ factor \times irrigation\ efficiency - rainfall}$
Extended detention depth (m)	Recommended: 0.3 to 0.5	The extended detention will function similarly to the storage zone of the wicking system, so the depth should be calculated based on the storage zone of the wicking system. $EDD = (wicking\ layer\ depth) \times (porosity\ of\ wicking\ media)$

[16] For example: Connellan, G., 2013, Water use efficiency for irrigated turf and landscape

Parameter	**Value**	**Guidance**
Filter depth (m)	Recommended: 0.3 to 0.5	Depth of the sandy loam topsoil (typically 300-500mm).
Saturated hydraulic conductivity (mm/hr)	Required: 36 to 100	As per design if <100 mm/hr or 100 mm/hr for loamy sand top-soil or filter media.
Exfiltration rate (mm/hr)	Recommended: 0	Usually no exfiltration allowed.
Underdrain	Required: Yes	
Wicking layer media	N/A	The wicking layer media choice (for example sand, scoria) will influence the maximum wicking layer depth and porosity. Storage volume (relates to both wicking layer depth and porosity).
Wicking layer (Submerged zone) depth (m)	Recommended: Nominally 0.3 to 0.5	The maximum depth of the storage zone is determined by the capillary rise or wicking ability of the media while a minimum depth is required to incorporate a flow distribution network.

Parameter	Value	Guidance
Wicking layer storage volume (m^3)	Varies	The storage zone or aquifer for the wicking lawn extends under the full surface area of the system, such that all turf/landscape can have equal access to the soil moisture stores. The depth of the storage zone (wicking layer) and the porosity of the wicking media will determine the volume of water that can be stored. $\boldsymbol{Storage\ volume}\ (\boldsymbol{m^3}) = (\boldsymbol{surface\ area}, \boldsymbol{m^2}) \times (\boldsymbol{depth\ of\ wicking\ layer}, \boldsymbol{m}) \times (\boldsymbol{porosity\ of\ wicking\ media})$ If the storage zone of the wicking system contains several layers of varying porosity, a weighted average of porosity should be adopted. Note, this is only applicable if modelling the wicking bed using a rainwater tank node.
Wicking layer porosity (-)	Recommended: 0.35-0.95	The porosity will depend on the chosen wicking media. Sand and most natural materials will have a relatively low porosity of 0.35, whereas wicking storage cells can have a porosity of up to 0.95.

Implementation

Appropriate scale and context

Wicking beds are suitable at various scales, including lot/street and precinct levels, from home garden beds or lawn areas, to streetscapes with passively watered trees and raingardens with wicking zones, as well as public gardens, parks, large-scale sporting fields.

Wicking beds may be used for either active or passive recreational areas including sports fields, lawns and gardens.

Wicking beds are best suited for new sites where the subsurface works can be undertaken on the proposed space. Due to the subsurface works required, retrofitting wicking beds can be a costly exercise.

They are particularly suitable for high-end sports fields, where subsurface drainage is typically already needed. These are also applications where irrigation costs can be expensive, and so wicking systems can significantly save on operating costs long-term. One of the best opportunities to pursue wicking beds is when the irrigation and drainage for a sports field need to be reconstructed, as the wicking bed can then become a marginal extension of the planned project.

Alternative designs and scales

As a potential alternate design configuration, the impermeable layer may be omitted and infiltration to underlying soils allowed if underlying infiltration rates are low and maintaining irrigation is not critical (such as passive rather than active recreational areas).

More information on other designs and scales can be found in *Designing for a cool city: Guidelines for passively irrigated landscapes*[17].

Things to avoid

To prevent sediment from entering the sub-surface wicking storage, it is essential have effective pre-treatment, such as a raingarden or permeable pavement at the stormwater entry point.

Operation and maintenance

The operation and maintenance of wicking beds is similar to biofilter assets with a focus on maintaining healthy plants and infiltration capacity. The entry point for stormwater requires greater attention and care while the common issues of water-borne litter and sediment accumulation across the broader surface are not likely to be present.

New or unique maintenance

- The inlet zone (commonly a biofilter or permeable paving) may have high loading rates for litter and sediment and therefore require frequent

[17] https://watersensitivecities.org.au/content/new-passive-irrigation-guidelines-to-cool-our-cities/

cleaning. It is important the inlet is not blocked as this may restrict flows reaching the wicking storage and plants.

- Upstream gross pollutant traps and sediment ponds should be regularly maintained to minimise unnecessary sediment and litter accumulation in the inlet zone.
- The surface may be maintained similar to a typical sporting field, passive recreational area or garden.
- Care should be taken not to penetrate through the root zone and allow soil materials to enter the wicking storage during any excavation works of the surface.

Civil elements

- Upstream pre-treatment for litter and sediment (for example gross pollutant trap, sediment pond or forebay and biofilter/raingarden or permeable paving)
- Inlet pits and pipes
- Subsurface flow distribution layer
- Subsurface overflow drainage
- Engineered filter/growing media
- Wicking (submerged zone) storage
- Outlet or overflow pit

Landscape elements

- Vegetated surface

Resourcing

- Resourcing effort similar to biofilters should be anticipated. More frequent attention to the pre-treatment and inlet filtering surface should be expected while the broader wicking asset will likely need much more minimal maintenance.
- Ideally a brief inspection focusing on the inlet zone every 3 months or following major storm events is recommended, with a more thorough inspection annually or bi-annually. Significant assets may be inspected and maintained more frequently.
- Lawn mowing may be undertaken as per standard requirements for a sports field or recreational grassed surface as appropriate.
- Where a permeable pavement is used as an inlet filtering surface to preclude entry of sediment, this may need to be cleaned through vacuuming and/or pressure washing at regular intervals. This depends on the design hydraulic loadings. Inspections every 3 months and annual cleaning is recommended as an initial starting point with refinement based on experience.

Anticipated asset life

With effective pre-treatment for litter and sediment, wicking beds have an expected life of least 20-30 years.

Constructed systems to date are only about 8 years old so there is limited experience to draw upon.

Risks

Blockage: Blockage or sediment clogging of the inlet filtering surface (biofilter, permeable pavement or other filtering surface) is a risk that could result in diversion of flows away from the asset. If this occurs for a prolonged period, it may lead to excessive drying and loss of plant cover. Inlets should be checked regularly, and any debris or sediment accumulation cleared. As for all WSUD assets, monitoring of water levels or soil-moisture levels within an asset would be beneficial to provide an early warning of potential issues.

Plant health and establishment: There are similar risks and management requirements as for other lawn, gardens and biofilter/raingarden assets.

Compaction: Car parking, public events such as markets involving temporary infrastructure and trafficking over with heavy machinery should be avoided to minimise risk of compaction and loss of infiltration capacity.

Case study – Gladstone East Shores Parkland

Gladstone, Queensland

Overview

The Gladstone East Shores Parkland is a world-class recreational hub for the City of Gladstone, located on the foreshore of Auckland Inlet. Due to the high evaporation rates, an innovative application of 'wicking bed' technology was used to store harvested stormwater runoff under the turf surface for passive irrigation of the two high use open lawn areas. The wicking beds were implemented alongside biofilter and lineal stormwater wetlands to treat stormwater runoff. Eight years after construction, the turf wicking beds continue to provide a sustainable, reliable irrigation source for the passive recreation space, helping treat stormwater runoff, increase the quality and resilience of the turf, and reducing the volume of stormwater runoff entering the Auckland Inlet.

As a testament to the success of Stage 1A of East Shores Parkland, the project received The Planning Institute of Australia “Great Place” Award at the state and national level.

Objectives and challenges

- Provide a world-class resilient parkland in a drying climate.
- Protect the Auckland inlet from stormwater pollution.
- Reduce reliance on potable water supplies.

Organisations

Gladstone Ports Corporation, E2Designlab, Urbis

Cost

Total project cost $40 million, $170-200/m^2 for the turf open space with wicking zone (this unit rate includes bulk earthworks, impervious liner, flow distribution and drainage system, sand wicking layer, topsoil, and turf).

Timeframe

Detailed design started in 2012. Constructed in 2014.

Figure 14: Aerial image of Gladstone East Shore Parkland. The greener, more even turf visible in the lower half of the photo is grass irrigated via a wicking bed.

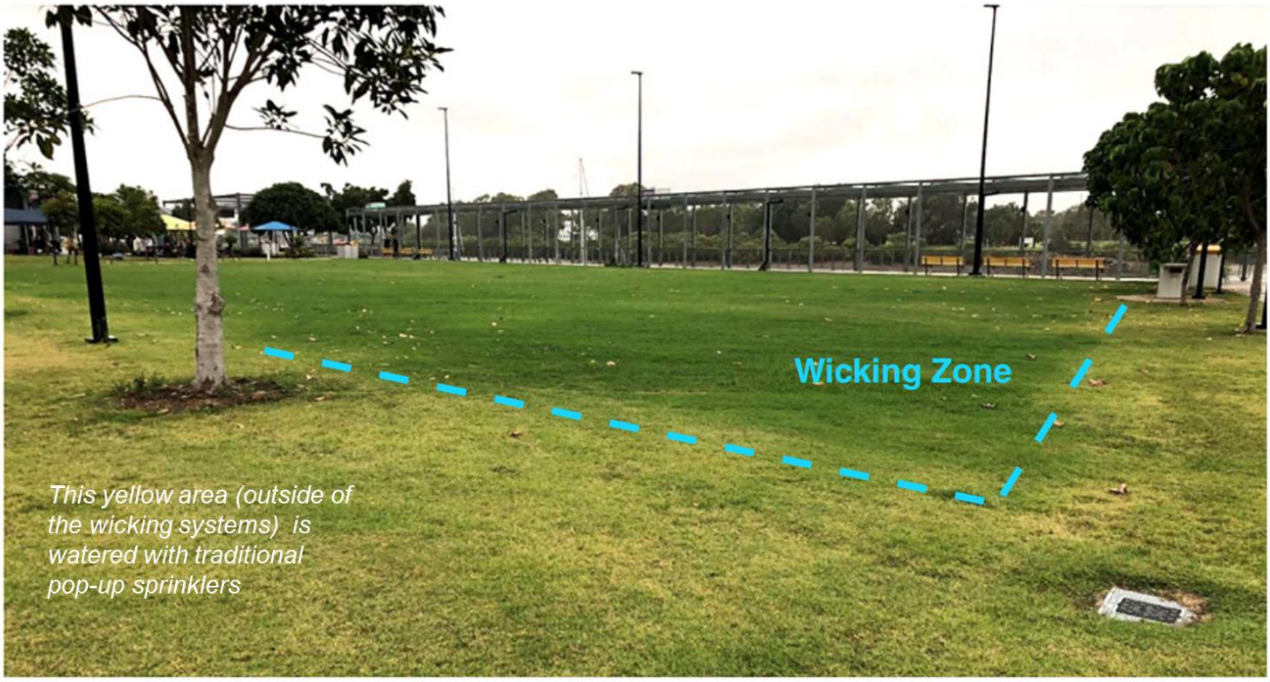


Figure 15 Gladstone East Shores wicking system

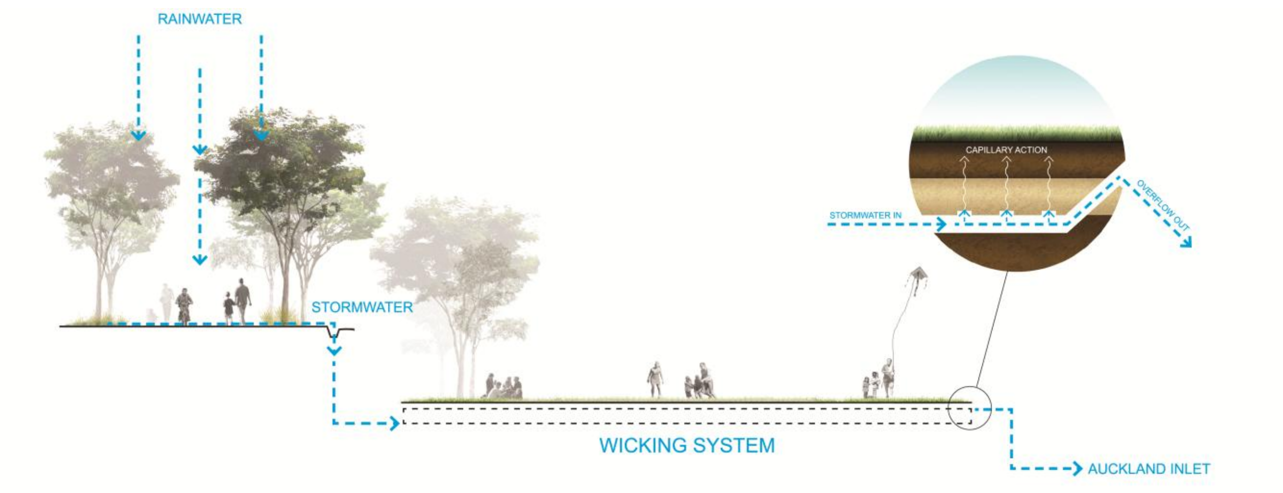


Figure 16 Gladstone East Shores wicking system schematic

Design features

- Water was percolated through a 300 mm deep washed fine sand layer, creating a **wicking zone reservoir**.
- In the event of subsurface overflow, an **overflow pipe** was set at the top of the storage zone to discharge excess volumes to Auckland inlet and avoid excessive saturation of the root zone.
- **Wicking zone media and topsoil:** growing media layer, sand layer, geotextile liner and waterproofing layer.
- Permeable pavement and biofilters were used for **pre-treatment** of stormwater to remove litter and sediment.
- **Distribution layer:** To ensure even distribution of the flows through the wicking layer.

Outcomes and benefits

- Efficient irrigation using stormwater from beneath the soil, meaning no surface losses that would normally occur with traditional spray irrigation methods
- Reduction in potable water demand – at least 70% of the fields' irrigation demand provided by passive irrigation with stormwater
- Reduction in operational energy costs for irrigation pump operation
- Reduction of stormwater runoff and pollutant loads entering Auckland inlet (modelled results for the combination of all implemented WSUD assets: 90.2% TSS, 78.9% TP, 57.4% TN)
- Anecdotally, reduced fertiliser use, less wear and tear of turf, and higher aesthetic quality of turf due to even growth and colour.

Learnings for future application

- Wicking-bed technology is a viable solution for achieving healthy turf growth, reduced sports injuries and integrated water management benefits.
- Poor soils, shallow rock and the need for fill on the site provided the opportunity to recreate the soil profile in a new and functional way.
- Stormwater quality outcomes can be achieved by using stormwater as a resource and don’t necessarily need to be achieved through traditional stormwater treatment devices.

Passive irrigation rainwater tanks

What are passive irrigation rainwater tanks?

A passive irrigation rainwater tank is a traditional rainwater tank that releases water very slowly via a garden hose or drip irrigation into a nearby garden or lawn area. This area can be regarded as a 'vegetated sponge' asset as described in this document. The slow rate of irrigation allows the water to be absorbed into the passively irrigated area, allowing time for evapotranspiration and infiltration and avoiding saturating the area excessively. The consistent and predictable draw-down of the tank ensures that there is available storage volume for the next rainfall event. In this way, incorporating passive irrigation for all or part of a storage tank's capacity can help meet stormwater flow volume objectives for harvesting/evapotranspiration and infiltration as well as flood mitigation.

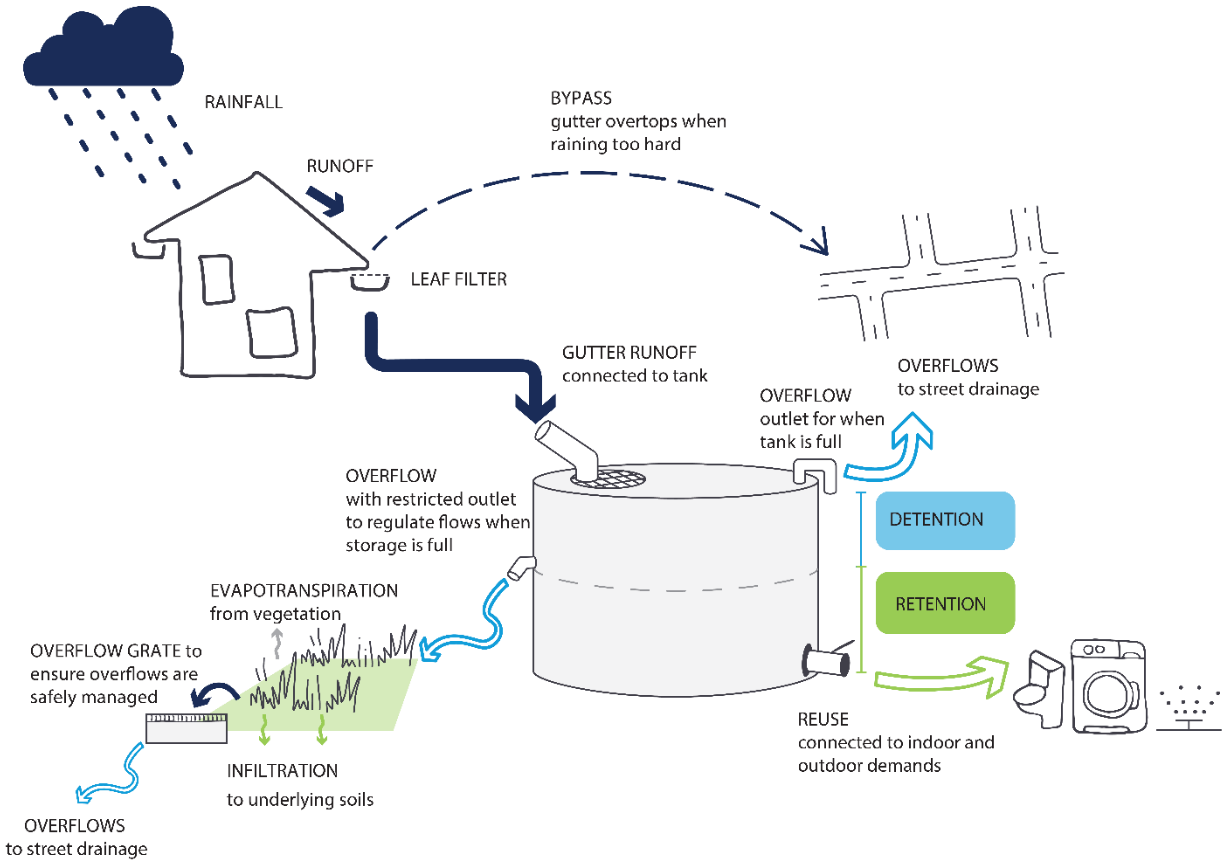


Figure 17: Passive irrigation rainwater tank schematic

Figure 18 Left, a rainwater tank connected to a garage roof for passive irrigation of raised garden beds. Middle, a rainwater tank connected for passive irrigation to adjacent garden bed and trees. Right, a tank with mid-level diversion for passive irrigation

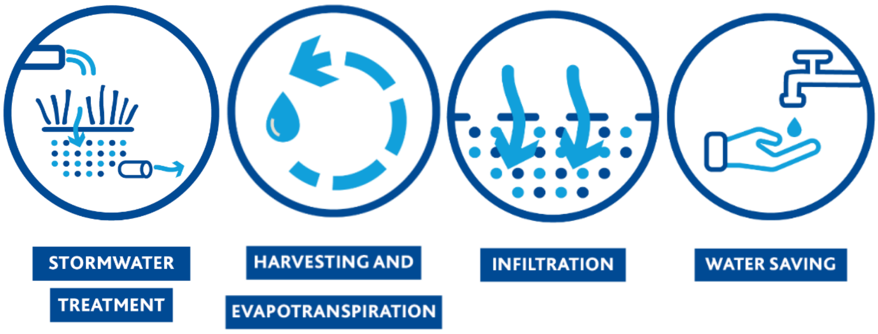
How do they differ from traditional rainwater tanks?

Passive irrigation rainwater tanks are very similar to traditional rainwater tanks. They still feature pipe connections to non-potable water demands and the same overflow function. The main difference between the two is the 'slow release' function of the passive irrigation rainwater tank where water is allowed to continuously drain at a limited rate from the tank to irrigate the garden and infiltrate into underlying soils.

The passive irrigation component of the rainwater tank can come in different configurations such as:

- An independent tank capturing rainwater solely for passive irrigation of garden and lawn areas. A pipe at the bottom of the tank gradually drains all of the available storage volume of the tank.
- A pipe near the top of a standard rainwater tank that drains excess captured rainwater above a defined capture storage.
- A separate, smaller tank that takes overflow from a primary rainwater tank.

Benefits



Designing passive irrigation rainwater tanks

Key principles

- The total demand from the rainwater tank will be the sum of the selected household non-potable water demands (if applicable) and the irrigation demand of the lawn or garden to which the tank is directed.
- The passive irrigation may be released from the main rainwater tank storage, from an upper portion or a separate or independent tank.
- Vegetated sponges receiving discharges should be able to absorb, evapotranspire or infiltrate most of the inflow volume without being saturated excessively. As a simple guide, this can typically be achieved by directing not more volume of water to the asset than the difference between evapotranspiration and rainfall for the garden or lawn (vegetated sponge) area. This estimate does not account for seasonal variations and the fact that overflows should be anticipated in wetter months and accommodated within the design. For a more precise estimate, an irrigation demand for the vegetated sponge taking into account the vegetation type, soils and other factors could be undertaken.
- An overflow pit or pathway connected to the street drainage system must be provided for the passively irrigated garden or lawn area to mitigate any risk of flooding.
- An asset management approach to design shall be adopted, including assessment of potential failure modes, maintenance and access requirements.

Challenges

- The volume of water drained from the rainwater tank must be managed to avoid causing erosion or flood impacts on adjacent properties.
- As rainwater tanks are typically located in private lots, maintenance and reliability of these assets can be uncertain. Tanks are sometimes disconnected or not maintained correctly, removing all benefits of the assets. There is a further risk for passive irrigation rainwater tanks that the

passively irrigated garden or lawn area may be compromised or modified. Ideally this should be clearly identified as an asset with relevant plans and where appropriate, signage.

Design features

- **Tank size:** The rainwater tank should be sized to achieve desired objectives including internal reuse, passive irrigation, reduction of stormwater flow volumes for waterway protection and potentially also flood mitigation.
- **Inlet screen:** An inlet screen is used to screen gross pollutants and coarse sediment prior to reuse.
- **Passive irrigation pipe:** The flow rate of this slow release outlet pipe should be limited to ensure appropriate flow volumes and rates are draining to the vegetated sponge area to avoid excessive saturation or flooding. In practice, a garden hose of a standard size will commonly be used for small-scale assets.
- **Passively irrigated vegetated sponge area (lawn or garden) area:** The vegetated sponge that the tank drains to is an essential part of the system as this is where water is absorbed into the soil and allowed to evapotranspire or infiltrate.
- **Overflow:** An overflow pit or pathway that connects excess flows to the drainage system needs to be provided to ensure that the area is drained quickly following high rainfall events that may otherwise result in flooding.

Implementation

Appropriate scale and context

Allotment or street scale

Passive irrigation rainwater tanks are typically implemented at the lot scale although they could also be implemented at other scales where there is sufficient roof catchment and area to irrigate.

Passive irrigation rainwater tanks are most suitable when there is a planted area with a moderate to high water demand suited for passive irrigation. Users may be more likely to maintain a rainwater tank supplying a vegetable garden or lawn that provides them with direct use rather than other assets such as a raingarden or sub-surface asset.

While the intention is for these systems to be passive, valves can potentially be installed to allow the user control over the irrigation function of the tanks. This can provide additional water for internal household uses if required or mitigate issues arising from excess irrigation of the lawn during winter.

Alternative designs and scales

The passive irrigation configuration of this asset can take many forms: leaking pipe at the bottom, additional overflow pipe or a separate rainwater tank.

Things to avoid

Locating passively irrigated lawn or garden where:

- land and water contamination are identified as a significant risk
- groundwater is within 1 m of base level of the passively irrigated lawn or garden area
- salinity risks and the likelihood of infiltration increasing saline groundwater levels within an unconfined aquifer in proximity to the surface or buildings has been identified
- surrounding or down-slope soils are sodic or dispersive soils, hence at risk of erosion when exposed to water
- infiltration is likely to pose a significant risk to adjacent built infrastructure, for example where it is in close proximity to underground infrastructure or building foundations. Indicatively an offset distance of 1-5 m may be needed depending on context, infrastructure and soil conditions.
- high pedestrian traffic is likely to occur when wet

Operation and maintenance

New or unique maintenance

The operation and maintenance of passive irrigation rainwater tanks is mostly similar to rainwater tanks. The main difference is considering the passively irrigated garden or lawn area (vegetated sponge) and its capacity to absorb the additional flows supplied from the tank and its catchment.

Most maintenance for this area will be the same as a typical garden or lawn.

The following additional considerations apply:

- The garden or lawn area may be wetter than other areas and may be more susceptible to damage and compaction when wet.
- The passive irrigation from the tank will usually occur automatically immediately following rain events. If the garden or lawn area becomes excessively wet, it may be necessary to limit flows, particularly during winter or wet periods. This can potentially be achieved by shutting off passive irrigation flows or redirecting flows to drainage infrastructure (recognising these actions compromise the intended function of the system and should be restored to standard operation as soon as possible).
- Depending on configuration, these assets may not require any pump or electrical infrastructure. This means they can be more readily maintained by a home-owner since the most common maintenance will be cleaning the rain-head and inlet screen.

Civil elements

- Roof gutter and downpipes
- Rain-head (screen on downpipe)
- Inlet screen on tank
- Rainwater tank
- Tank base
- Outlet and irrigation pipes
- Overflow pit for irrigated lawn or garden area

Landscape elements

- Passively irrigated vegetated sponge area (garden or lawn)

Resourcing

- The rain-head and inlet screen should be inspected every three months or after major storm events (and ideally immediately prior to expected large storm events).
- Most maintenance may be undertaken by a home-owner using gloves and a ladder. Care should always be taken when working at heights.
- If the passively irrigated garden or lawn area is persistently wet, advice may need to be sought from a specialist or WSUD practitioner to inspect and advise on the best way to improve operation of the asset to balance the functional design intent with the home-owners right to enjoyment of their property and practical use of the garden or lawn area.

Anticipated asset life

The expected asset life is the same as for rainwater tanks and is typically 20 or more years (less or equal than 10 years for pumps and controllers).

Risks

Blockages: Inlet screens on rainwater tanks can be blocked by debris and sediment, especially if there are overhanging trees over the roof. These require regular attention to prevent blockage which can prevent water reaching the tank and garden or lawn area.

Infrastructure damage: The irrigation pipes may consist of conventional irrigation or sub-surface slotted or 'aggie' pipes. These may be damaged by digging. Clearly communicating their location to landowners by providing a plan and description of the system may aid in communication and minimising risks.

Excessive saturation: There is potential for the passively irrigated garden or lawn to become excessively or undesirably wet following a large storm event or long wet period. The vegetation may be damaged through pedestrian or other traffic when wet and the soil compacted. Use of the area may need to be reduced following wet periods. Another risk is that the home-owner may seek to disable the outflows and direct them to drainage if the lawn or garden area is persistently or undesirably wet due to faulty design, construction or other issues. In most cases the system will be designed to require no homeowner intervention and be 'tamper-proof'. If a valve is provided, passive irrigation may be switched off when the garden or lawn area is wet after a large rainfall event and opened 2-3 days following rainfall. It is important that it is re-opened to ensure the asset continues to function.

Case study – Dobsons Creek Rainwater Tanks

Overview

"Tanks for helping our Creek" was an initiative started up by Knox City Council and Melbourne Water in 2010, to improve Dobsons Creek, the waterway within Council area with high ecological value. The objectives of the initiative were to restore catchment hydrology to pre-development levels, reduce runoff to the creek, and improve ecological values. These objectives were achieved by implementing stormwater disconnection measures on public and private land such as passive irrigation rainwater tanks, and other WSUD measures such as an end of line biofilter and streetscape WSUD retrofits.

Objectives and challenges

- Improve the health of Dobsons Creek by disconnecting impervious surfaces to restore pre-development catchment hydrology
- Involve the community in stormwater management
- Retrofitting WSUD in a developed catchment

Organisations

Melbourne Water, Knox City Council, South East Water, the University of Melbourne, CRC for Water Sensitive Cities

Cost

Contribution of $5 million by Melbourne Water (including research and monitoring costs).

Timeframe

The Knox Stormwater Strategy and project conception was developed in 2009-2010. The Wicks Reserve Bio-infiltration system (a vegetated sponge) was constructed in 2011. The tank solutions were delivered to 150 residential properties between 2012 and 2014. An additional 33 properties received tanks and streetscape assets were constructed in 2015. The project is under evaluation since 2016 (CRC for Water Sensitive Cities, 2018).

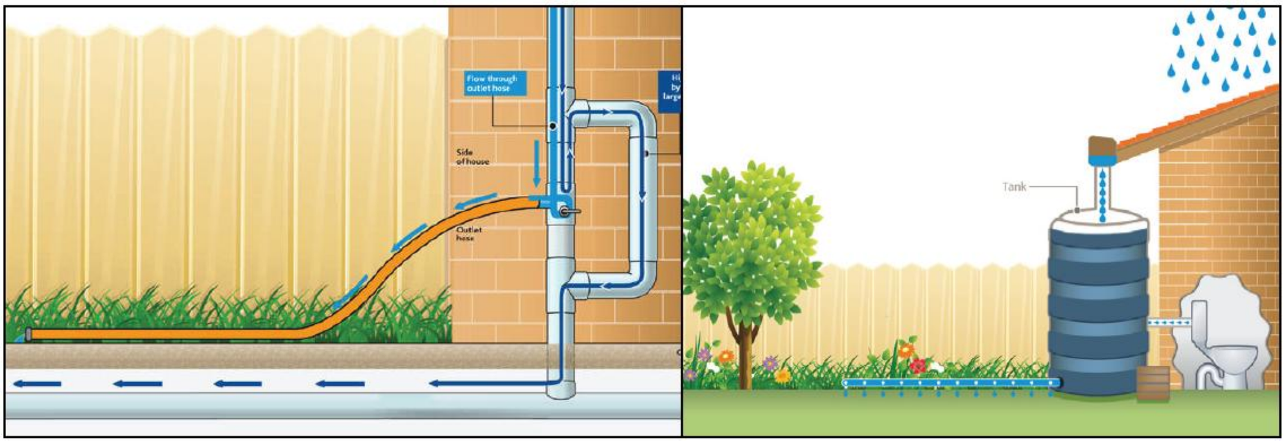


Figure 19 A downspout diversion and a passive irrigation rainwater tank

Design features

- One to three 4.5 kL **rainwater tanks** were retrofitted onto 180 dwellings. They were connected to the toilet and/or laundry and featured a dripper hose which constantly dispersed water into adjacent garden/lawn to draw the tanks down to reduce stormwater volumes discharged to the waterway.
- A 1,900 m^2 bio-infiltration asset (a **vegetated sponge**) at Wicks Reserve serviced a 11.5 ha catchment and WSUD treatment trains were also retrofitted into streetscapes.

Outcomes

- Installation of 338 rainwater tanks, 449 toilet and/or laundry connections, 554 downpipe connections and 264 downpipe diversions.
- A 30% reduction in household potable water use was achieved.
- At a catchment scale, there was an 80% reduction in the magnitude of flows (includes both on-site and catchment scale responses).
- Modelled pollutant load reductions: 98% TSS, 89% TP and 77% TN.

Lessons learnt

- There was benefit in using technologies previously tested in research (in this case, earlier implementation of Little Stringybark Creek passive irrigation rainwater tanks).
- Importance of trust between agencies and community to deliver successful assets on private property.
- Challenges included working with steep slopes and around other services as well as managing potential greywater runoff.
- Passively irrigated rainwater tanks are practical and viable to implement at the lot scale.

Passively watered trees

What are passively watered trees?

Trees can be passively watered with stormwater, particularly those integrated into streetscapes or paved areas. Stormwater runoff from these surfaces is directed towards the tree, where it temporarily ponds and infiltrates into a permeable zone around its base. The water is absorbed into the root zone, providing an opportunity for treatment and for the tree to uptake water, which is later returned to the atmosphere through evapotranspiration. Any excess water then infiltrates into the subsoil through a filter media installed beneath the paving.

Key elements of passively watered trees are described below and shown in Figure 20.

1. The area over which water can infiltrate from the surface pond into the filter media.
2. The area over which water exfiltrates from the filter media to the underlying soil.
3. The tree canopy area or vegetated surface area over which evapotranspiration can occur.
4. The effective filter media volume which is calculated as the filter area multiplied by filter media depth.
5. The effective volume of extended detention storage (calculated as extended detention depth multiplied by surface area).

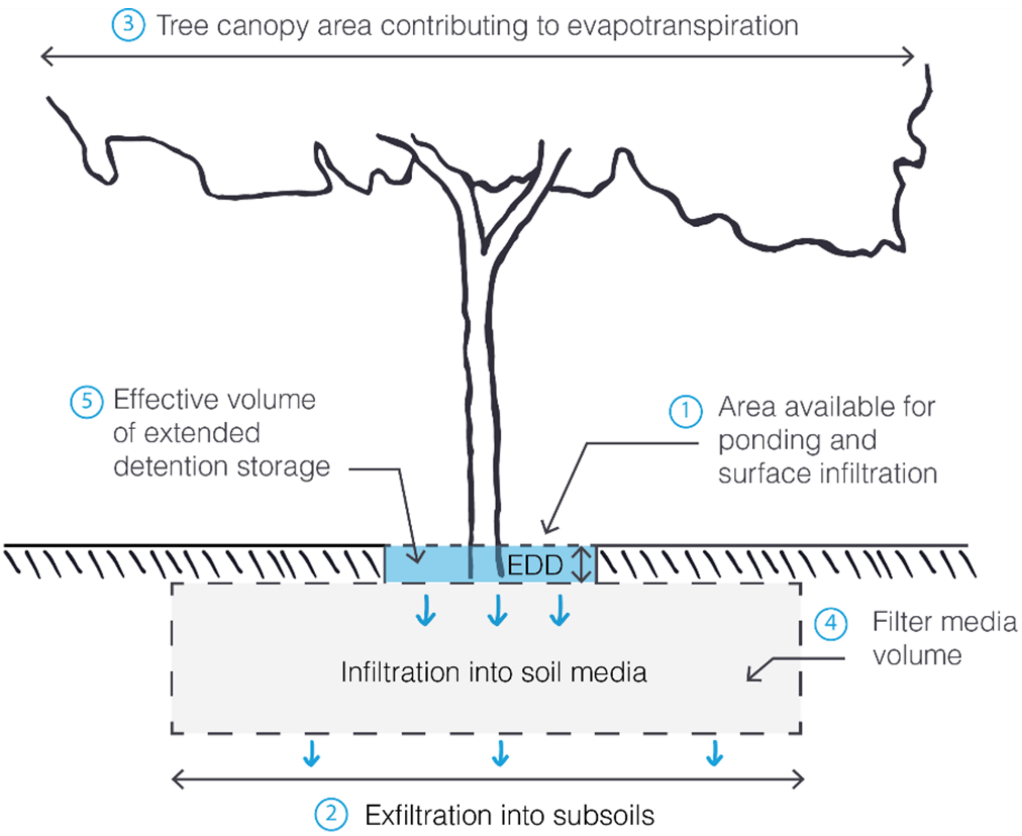


Figure 20 Passively watered tree schematic

Benefits

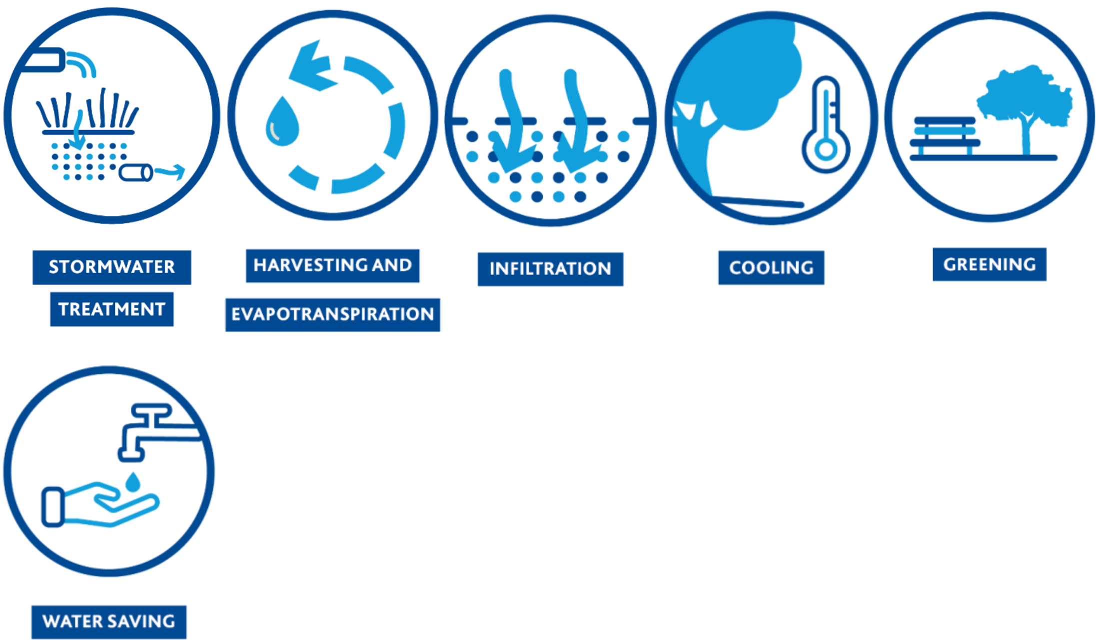


Figure 21 Benefits of passively watered trees

Designing passively watered trees

Key principles

- Trees with low or moderate potential water use are not generally recommended for passive irrigation in Melbourne as they may be at greater risk of over-saturation.
- It is recommended to consult with Council for suitable tree species within streetscapes. These should consider local climate, context as well as capacity to cope with both extended wet and dry conditions. Specific guidance is not provided here due to the wide variation in preferences between Councils.
- A passively watered tree may be planted with either raingarden filter media or a suitable tree planting media.
- It is essential any alternate planting media is low in organics and nutrients and is structurally stable.
- It is recommended that relief underdrainage is installed with an invert level at least 300 millimetres and preferably 500 millimetres below surface to ensure an aerobic upper root zone is maintained to protect trees from over-saturation. Where this is not possible, potential over-saturation of the tree prior to maturity should be assessed by modelling with a smaller canopy area and reviewing the filter media saturation profile and wet spells.
- A submerged zone of at least 200 millimetres below the under-drainage is recommended. Refer to local guidance as this may vary by municipality due to climate differences.

Starting points for design

Passively watered trees can be considered a variant of bioretention for modelling purposes. Approaches for modelling this asset are further explained in the *MUSIC Guideline*.

A summary of indicative design parameters for passively watered trees is provided in Table 6.

Table 6 Indicative design and modelling parameters for passively watered trees (modelled using bioretention node)

Parameter	Value	Guidance
Low flow bypass (m^3/s)	0 or design bypass flow rate	Should be set to appropriate value if lower flows will bypass the tree pit. For example, if the kerb cut-out sits higher than the

Parameter	Value	Guidance
		base of the kerb resulting in some water bypassing. Otherwise set to 0.
High flow bypass (m^3/s)	Inlet capacity or 100 if no restriction	Set model input value to inlet capacity where limited (most common). This is important for kerb cuts and inlets. Otherwise, where not restricted, set to arbitrary high number and treatable flow rates are determined by the extended detention depth and corresponding surface storage volume.
Extended detention depth (m)	Required: 0.01 to 0.5 Recommended: 0.1 to 0.3	Typical range. This should be based on ensuring the correct volume of surface water storage.
Filter depth (m)	Required: 0.3 to 0.6 Recommended: 0.4 to 0.6 or 0.7 to 1.0 with trees*	Filter depth is the depth of filter media or tree pit soil above underdrain invert. Total filter media depth including submerged zone greater than or equal to 400 mm with at least 700 mm recommended for trees.
Saturated hydraulic conductivity (mm/hr)	Required: 30 to 300 Recommended: Tree pit soils: 30 mm/hr Bioretention filter media: 100 mm/hr	Assume lesser of design hydraulic conductivity or 100 mm/hr for modelling. Tree pit soils design range: 30-50 mm/hour Bioretention filter media design range: 100-300 mm/hour (100-200 mm/hour preferred) Media with greater soil moisture retention preferred.
PET scaling factor	High water use tree: 1.8 Low water use tree: 1.5	This influences the evapotranspiration rate. This base factor should be revised by multiplying it by canopy area / filter area

Parameter	Value	Guidance
Exfiltration rate (mm/hr)	Recommended: 0.18 to 100	An exfiltration rate suitable for the underlying soils should be adopted and must be set using the guidance provided in *Infiltration into surrounding soils (exfiltration rate)* in the *MUSIC Guideline***Error! Reference source not found.**. If groundwater risks are identified, refer to the guidance in that section on sensitivity testing of the input parameters
Underdrain	Recommended: Yes	Include above a submerged zone
Submerged zone depth (m)	Recommended: 0.3 to 0.5	Include depth of filter media, transition media and drainage below underdrain invert Sand is preferred over gravel to support capillary rise.
Total nitrogen (mg/kg)	800	Design total nitrogen concentration <=800 mg/kg recommended. Media with low nutrients preferred.
Orthophosphate content (mg/kg)	Required: >=30 Recommended: >=50	Design orthophosphate content <=50 mg/kg recommended. Media with low nutrients preferred. May be lowered if total phosphorus is limiting pollutant. Evidence that filter media meets this specification must be provided at construction.

Alternative designs and scales

More information on different designs and scales can be found in *Designing for a cool city: Guidelines for passively irrigated landscapes*[18].

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[18] https://watersensitivecities.org.au/content/new-passive-irrigation-guidelines-to-cool-our-cities/

Permeable or porous paving

What is permeable paving?

Permeable paving allows runoff to drain through or between a paved surface and infiltrate the underlying media. It can provide some degree of stormwater treatment but more importantly increases the pervious area of the developed catchment that can infiltrate into the soil. An example of a typical permeable pavement cross-section is shown in Figure 22. Permeable paving is considered a type of unvegetated filter and may be modelled using the media filtration node.

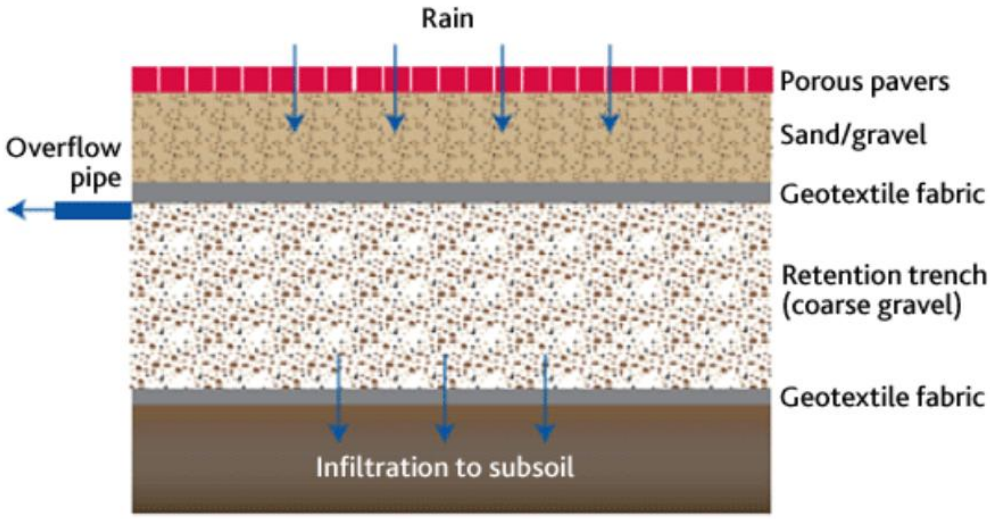

Figure 22 A typical permeable paving cross section

Benefits

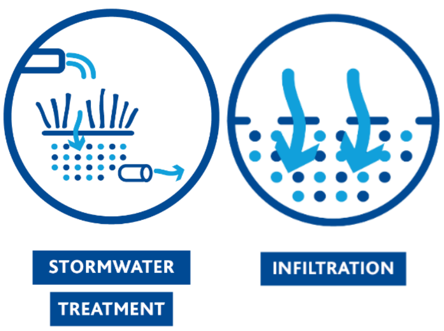

Figure 23 Benefits of permeable paving

Designing permeable paving

Starting points for design

Permeable paving can be considered a media filtration asset. Approaches for modelling this asset is further explained in the *MUSIC Guideline*.

A summary of indicative design parameters for permeable paving is provided in Table 7.

Table 7 Indicative design and modelling parameters for permeable paving using the media filtration node

Parameter	Value	Guidance
Extended detention depth (m)	Design recommended: 0.0 Model recommended: Nominal 0.01-0.02	Assumes zero extended detention depth with water overflowing freely from the permeable pavement. May be set higher if there is a specific design intent to allow frequent ponding above the paving.
Exfiltration rate (mm/hr)	Required: 0 to 100	The exfiltration rate applies to the underlying soil (not the filter media) and must be set using the guidance provided in *Infiltration into surrounding soils (exfiltration rate)* in the *MUSIC Guideline***Error! Reference source not found.**. Designs including infiltration must consider site suitability as well as constraints for infiltration such as reactive clay soils, bedrock, groundwater, slope, soil contamination and nearby infrastructure.
Surface area (m^2)	User defined	The total surface area of the permeable pavement. This includes both pavers and permeable openings for permeable interlocking pavers or similar.
Filter area (m^2)	User defined	For permeable interlocking pavers or similar with openings to allow infiltration, the opening area of the permeable pavement (not the total surface area) should be set as the filter area. This must be estimated based on the product specifications.

Parameter	Value	Guidance
Filter depth (m)	User defined	Set the filter depth to represent the depth of the treatment zone, nominally the depth of permeable pavement and underlying sand and gravel supporting layers including the base course.
Filter median particle diameter (mm)	Recommended: 1 to 5	Set to median particle size, such as 2 millimetres (a range of 1 to 5 millimetres depending on design is acceptable).
Saturated hydraulic conductivity (mm/hr)	Required: 100 to 200	Range recommended to realistically represent long term conditions allowing for clogging of the pavement surface over time with periodic maintenance. Permeable pavement specifications often detail high infiltration rates, commonly thousands of millimetres per hour, however these can be expected to decline exponentially over time.
Depth below underdrain pipe (% of filter depth)	User defined	Set to zero per cent if no submerged zone below underdrainage. Set to an appropriate percentage where a submerged or storage zone below underdrainage is provided to encourage additional infiltration.

Further guidance on approaches to modelling and geotechnical investigations to support infiltration are provided in the MUSIC Guideline – Chapter 6.

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Document History

Date	Reviewed/ Actioned By	Version	Action
January 2025	Senior Stormwater Technical Advisor	1	For industry review
December 2025	E2DesignLab	2	Final Draft prepared to include industry feedback
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