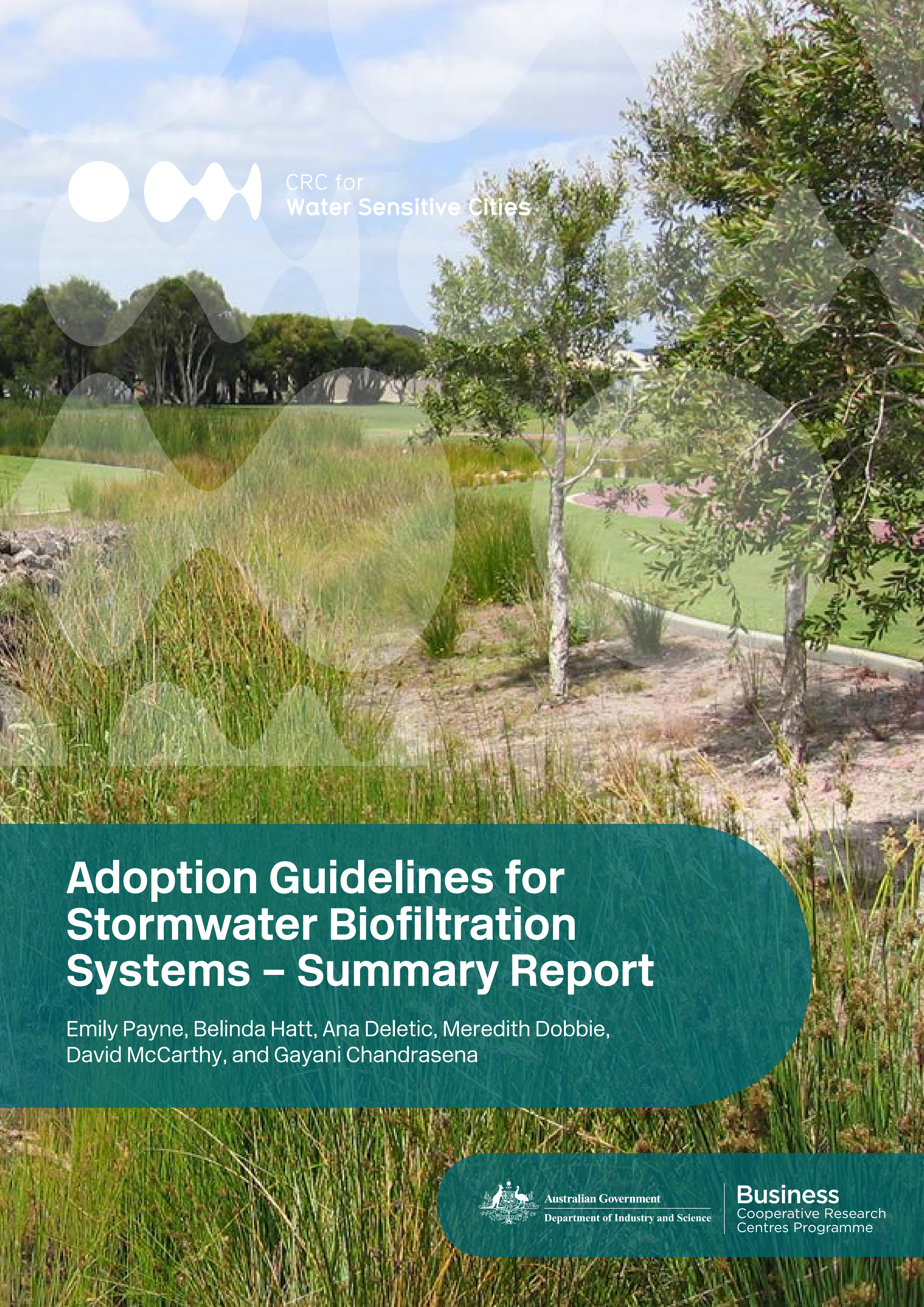

CRC for
Water Sensitive Cities

Adoption Guidelines for Stormwater Biofiltration Systems – Summary Report

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Australian Government
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Adoption Guidelines for Stormwater Biofiltration Systems – Summary Report
Cities as Water Supply Catchments – Sustainable Technologies (Project C1.1)
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Disclaimer

Introduction

What is stormwater biofiltration?

Compared with undeveloped or natural catchments, stormwater runoff from urban areas tends to have substantially larger peak flows, volumes and pollutant loads. The poor water quality and altered hydrology are both highly detrimental to the health of receiving waters (e.g. streams, estuaries, bays).

Water biofiltration is the process of improving water quality by filtering water through biologically influenced media (Figure 1). Stormwater biofiltration systems (also known as biofilters, bioretention systems and raingardens) are just one facet of a range of accepted Water Sensitive Urban Design (WSUD) elements. They are a low energy treatment technology with the potential to provide both water quality and quantity benefits.

A typical biofilter consists of a vegetated swale or basin overlaying layers of porous media. Stormwater is diverted from a kerb or pipe into the biofilter, where it flows through dense vegetation and temporarily ponds on the surface, before slowly filtering down through the filter media (Figure 1). Depending on design, treated flows are either infiltrated to underlying soils, or collected in the underdrain system for conveyance to downstream waterways or storages for subsequent re-use.

The technology can be applied to various catchment sizes and landscape settings (Figure 2), from street trees and private backyards to street-scale applications and car parks, up to larger regional stormwater treatment systems, including those in public parks and forested reserves. Further, biofilter design can be tailored to optimise performance for local conditions and specific treatment objectives.

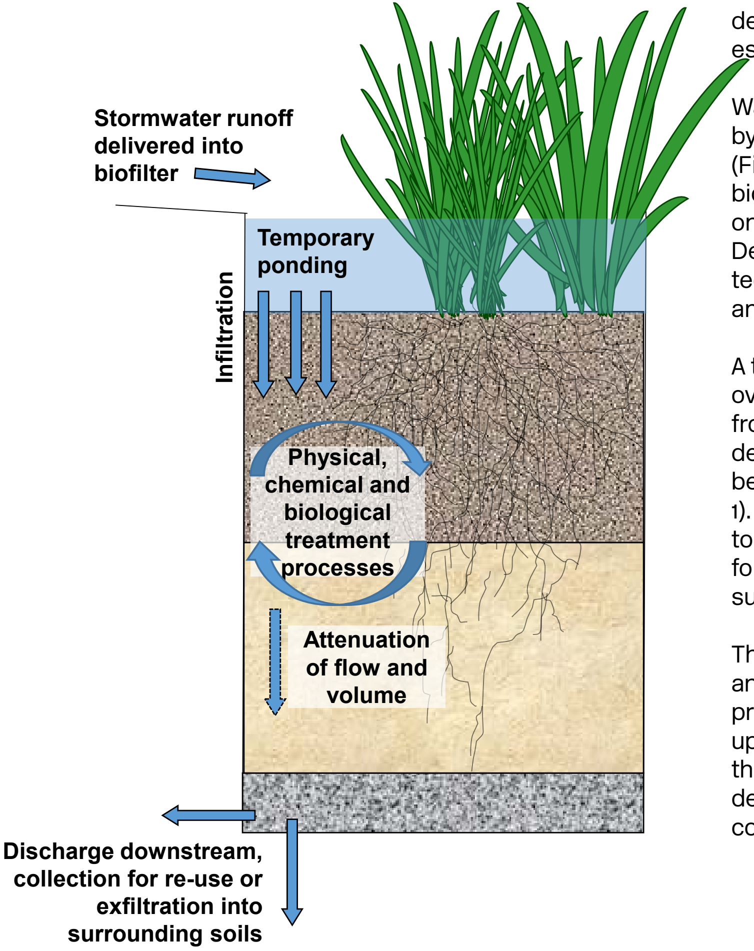

Figure 1. Key principles of stormwater biofiltration

Who are the guidelines for?

The Adoption Guidelines for Stormwater Biofiltration Systems (“Biofilter Adoption Guidelines v2”, CRC for Water Sensitive Cities, 2015) provide information on stormwater biofilter performance, the business case for its adoption, technical design guidance and key issues for constructing, monitoring and maintaining systems. They have been developed based upon the latest biofiltration research and in collaboration with industry partners, to address the key needs of practitioners working with stormwater biofilters.

The guidelines are intended for use by planners, engineers, landscape architects, developers, constructors and all other parties involved in urban design. The first version of the guidelines, commonly known as the “FAWB[1] Guidelines”, has been revised and updated to incorporate recent research work and improved practical experience. This document provides a brief summary of the key design, construction and maintenance issues outlined in the Biofilter Adoption Guidelines v2 (CRCWSC, 2015).

Figure 2. Diverse applications and designs of stormwater biofilters

What’s new in version 2 of the Guidelines?

- The business case for biofiltration
- Updated guidance on vegetation selection, media specifications and stormwater harvesting
- Updated design configuration guidance – inclusion of a raised outlet
- Guidance for landscape design and community acceptance – designing biofilters that look attractive
- Tips for designing systems for successful long-term operation, and low maintenance
- Tips to address challenging site conditions
- Illustrations and summaries of biofilter functions, key maintenance issues and important construction checks
- Summary of biofilter performance and key processes

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[1] *Facility for Advancing Water Biofiltration, Monash University*

Why choose stormwater biofiltration?

Stormwater biofiltration is one technology within a suite of options available in Water Sensitive Urban Design (WSUD). Along with other WSUD technologies, the benefits of stormwater biofilters are numerous and wide-ranging:

- Improved water quality and restoration of a hydrological regime closer to pre-development conditions in downstream waterways. This leads to reduced erosion and scour, and improved waterway health.
- Concentration of pollutants at a centralised point, providing containment, treatment and facilitating appropriate disposal or re-use.
- Provision of a green space that enhances aesthetics and amenity, cools the urban microclimate and benefits human health.
- Self-watering and self-fertilising systems (except during prolonged dry periods when supplementary watering is required).
- Provision of low-energy, small scale, flexible in application and design, localised water treatment solutions.
- If stormwater harvesting is adopted, provision of an alternative and local water supply (e.g. for watering sports fields).
- Can provide benefits to amenity and aesthetics by providing shelter, shade or screening.
- Enhances urban biodiversity and habitat.
- Additional resultant benefits include increased use and enjoyment of downstream aquatic environments (including commercial and tourism activities), increased property values and avoided costs of waterway restoration works, traditional stormwater drainage infrastructure and conventional landscaping and maintenance.

Many of these benefits are difficult to quantify in a cost-benefit analysis. However, multiple studies have demonstrated that the benefits of WSUD commonly exceed the costs of implementation. This is the case, even when only limited benefits are quantified. Detailed information can be found in Chapter 2 of the Biofilter Adoption Guidelines v2 (CRC for Water Sensitive Cities, 2015). In summary, some of the strongest economic arguments for stormwater biofiltration, or more broadly, any water-sensitive technologies for the urban environment are:

- The amenity value of streetscape raingardens in Sydney is realised in residential house prices, increasing property values by around 6% ($54,000 AUD) for houses within 50 m and 4% ($36,000 AUD) up to 100 m away. This demonstrates that the community values raingardens highly, and a typical raingarden installation at a street intersection can generate around $1.5 million increase in residential value (Polyakov, 2015).
- A business case analysis of WSUD technology found the benefits do surpass the costs, despite the fact that only select benefits could be quantified. Even on a standalone basis, the value of nitrogen reduction was predicted to exceed the project lifecycle cost. Increased property values were estimated at approximately 90% of the capital costs of WSUD; and the saved cost of waterway restoration works equates to approximately 70% of the project life cycle cost (Water by Design, 2010).
- From a waterway protection and restoration perspective, WSUD technologies cost less to implement than the economic cost of traditional stormwater drainage (i.e., taking into account the avoided costs of restoration works, etc.; Vietz et al., 2014).
- A reduction in nitrogen load in stormwater runoff is currently valued at $6,645/kg nitrogen in Victoria, on the basis of past stormwater treatment works (Melbourne Water website, 2015).
- The cost of effective maintenance for WSUD systems is outweighed by the value gained by higher performance and prolonged lifespan (Browne et al., 2013).

Despite these benefits, it is recognised that capital costs can be relatively high for some biofilters, such as those in retrofit settings or in tight urban spaces where innovative design or construction methods are required.

Key functions and components

A wide range of chemical, biological and physical processes act to retain or transform incoming stormwater pollutants. The plants, filter media and microbial community all play important roles in pollutant processing, as stormwater enters the biofilter and infiltrates through the media.

All biofilters operate using the same basic principles. However, designs are flexible and it is important to adapt configurations to meet the specified performance objectives and local site conditions. Biofilters comprise a number of basic, essential elements (Figure 3) – hydraulic controls (inflow, overflow or bypass capacity, a ponding/detention zone and raised outlet), vegetation and the layers of filter media. Additional design components may or may not be included, depending upon the objectives, opportunities or constraints presented by the site or its catchment (Figure 4). The functional role of each biofilter component is summarised in Table 1.

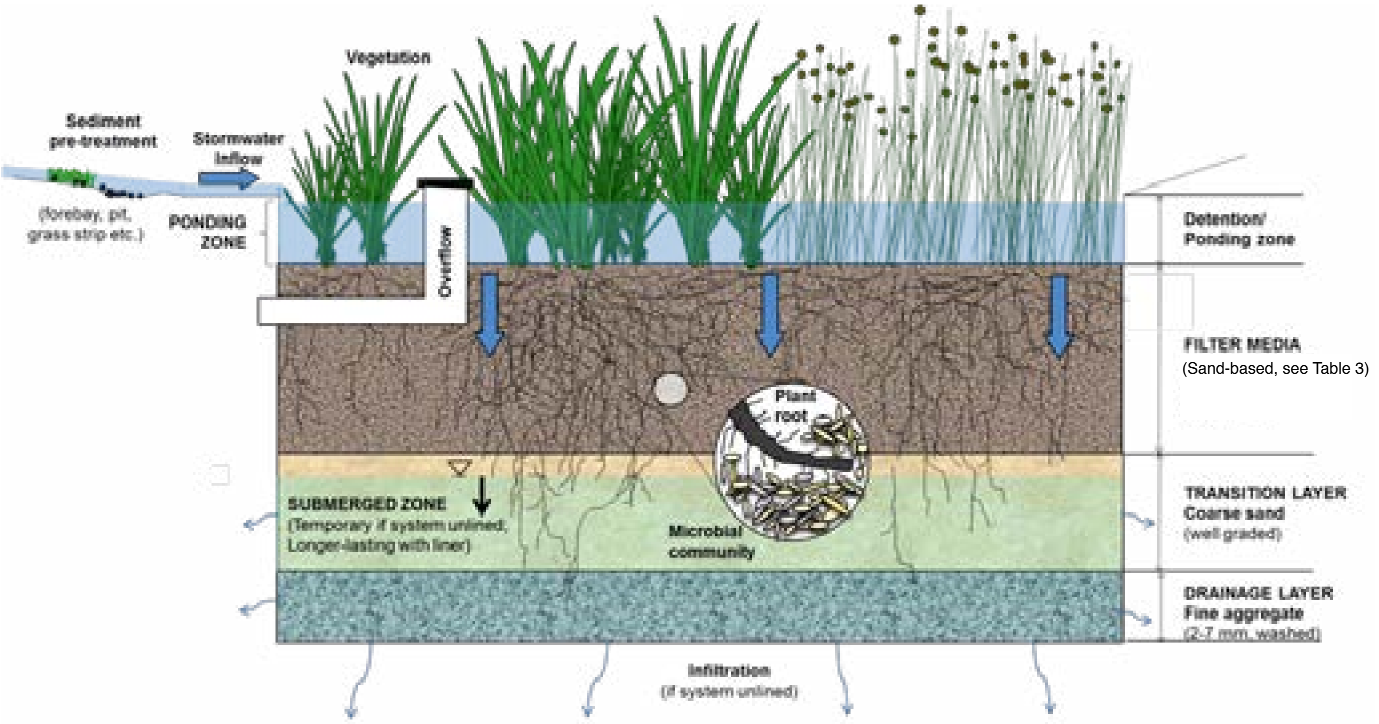


Figure 3. Essential components for stormwater biofilters (note configurations will vary)

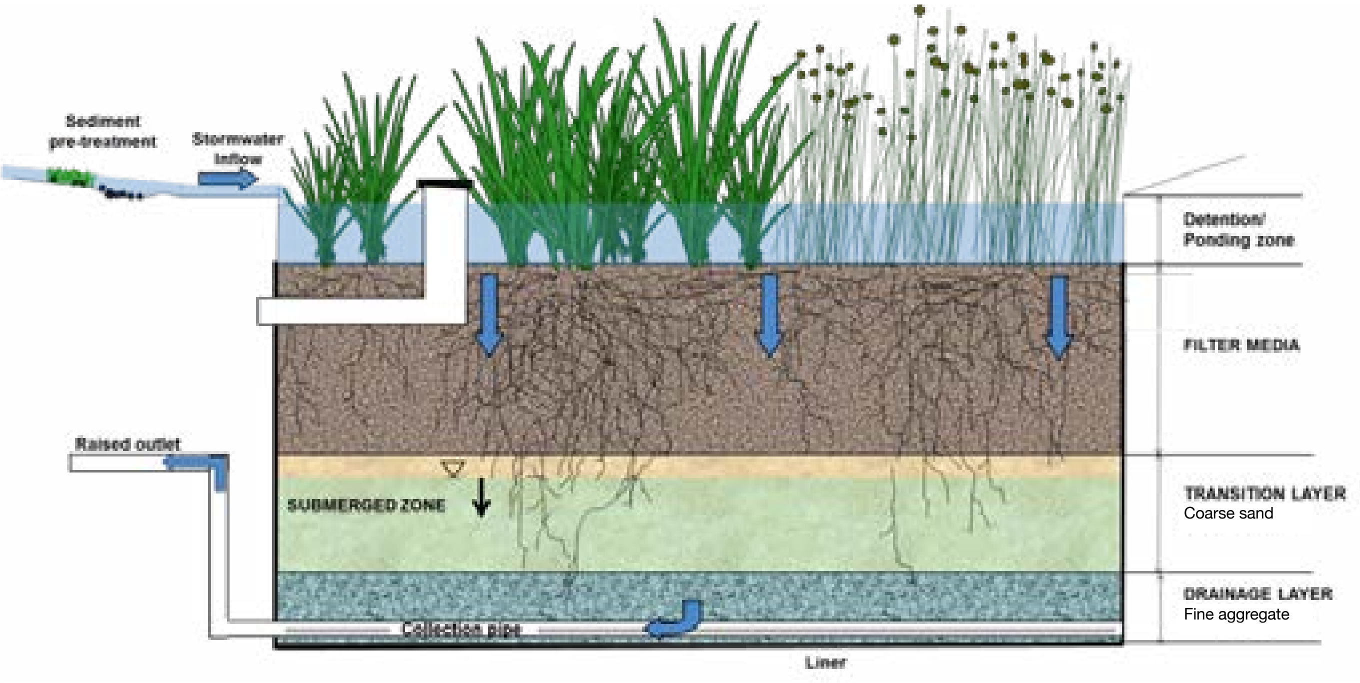


Figure 4. Typical biofilter configuration recommended for dense urban areas and/or where prolonged dry spells are experienced

Table 1. Key components of stormwater biofilters and their functional roles

Essential components and function	**Key information can be found within Biofilter Adoption Guidelines v2 (CRCWSC, 2015), Section…**	
Inflow	Delivers stormwater into biofilter	3.6.3
Overflow	Allows high flows to bypass to avoid damage to system	3.6.3
Ponding	(or detention zone) Increases treatment capacity by allowing stormwater to pond before infiltration	3.6.2
Vegetation	Serves multiple roles in water treatment via uptake, transformation to organic forms, carbon provision to microbes, transpiration reducing stormwater volume, stabilising media surface, helping to maintaining infiltration rates, provides cooling to surrounding environment, amenity and aesthetics. The microbial community associated with plant roots facilitates uptake, decomposition and transformation of stormwater pollutants and plant litter.	3.6.5
Filter media	Provides physical filtration of particulates, physiochemical pollutant removal processes such as adsorption, fixation, precipitation, supports vegetation growth and the infiltration of stormwater attenuates and reduces the magnitude of the outflow hydrograph (providing stream health benefits)	3.6.4
Transition layer	Coarse sand. Provides a bridging layer to prevent migration of fine particles from the upper filter media to the gravel drainage layer	3.6.4
Drainage layer	Gravel. Allows the system to drain, either into a collection pipe and outflow point or infiltration into surrounding soils, also provides higher porosity to temporarily store stormwater within the pore space	3.6.4
Unlined	Allows infiltration into surrounding soils, either for the entire or only part of the system	3.6.3
Pre-treatment	Collects coarse sediment and litter, helping to protect the biofilter itself from premature clogging and blockages, and facilitating maintenance. Recommended for all systems except those whose impervious catchment is <2ha in size without identifiable sediment sources, or systems only receiving roof runoff (Water by Design, 2014).	3.6.3
Additional components (depending upon treatment objectives and site conditions)		
Collection pipe	Underdrain formed with slotted pipe and used to drain and collect effluent from the system. May not be needed for small systems or those with only exfiltration and no outflow pipe.	3.6.3
Raised outlet; creates temporary submerged zone	Strongly recommended, providing multiple benefits for water treatment and plant survival. Allows ponding in the lower portion of the biofilter, increasing moisture availability for plants and providing larger retention capacity for the temporary storage of stormwater. If the system is unlined, the raised outlet promotes exfiltration and creates a temporary submerged zone. Alternatively, if combined with an impermeable liner, it provides a longer-lasting submerged zone which benefits nitrogen removal via denitrification.	3.6.3
Submerged zone (or Saturated zone)	Created using a raised outlet, but may be temporary (if system unlined) or longer-lasting (if lined). Serves multiple roles: i.) provides a water supply to support plant and microbial survival across dry periods; ii.) benefits nitrogen removal, particularly following dry periods; iii.) provides anaerobic conditions for denitrification; iv.) provides prolonged retention for a volume of stormwater – which allows longer processing time.	3.6.3
Liner; creates long-lasting submerged zone	Prevents infiltration and may fully or only partially line the system	3.6.3
Carbon source	(wood chips) Mixed throughout the submerged zone when a liner is present. As the carbon source decomposes, it provides electrons to drive denitrification	3.6.4

Technical Considerations in Design

The design process

One of the greatest benefits of biofiltration is the adaptability and flexibility of the technology. Successful biofiltration systems are designed to meet various objectives, applications or site conditions. Design tips for different objectives are provided in Table 2. Key design decisions, which are influenced by site conditions and applications, are illustrated in a flowchart in Figure 5.

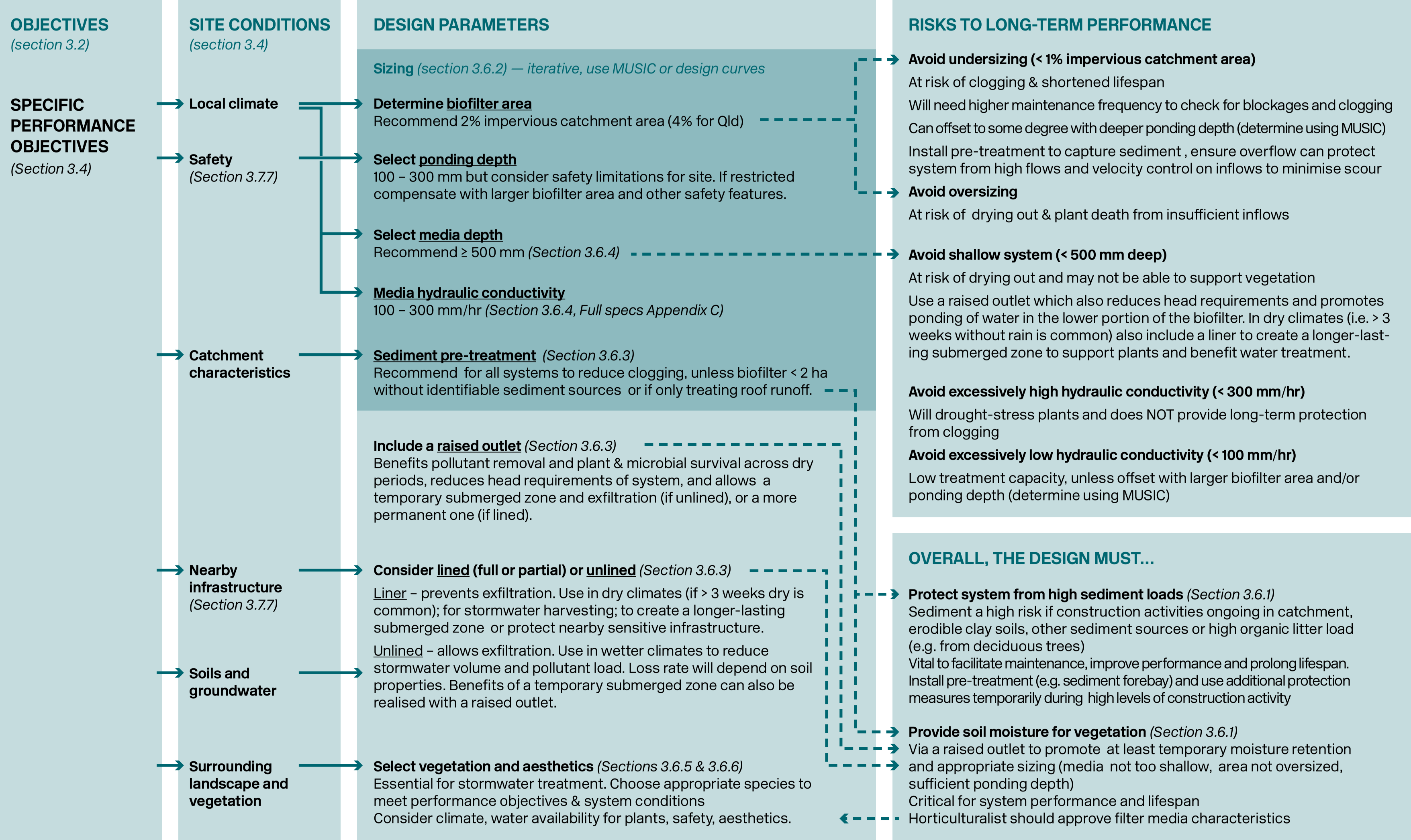
Table 2. Stormwater biofiltration design tips to meet different performance objectives

Waterways Protection	
Nutrients	• Plants are essential: therefore plant densely, include a diversity of species, and select at least 50% of species with characteristics for effective removal (particularly for nitrogen – see below for further guidance). • Minimise nitrogen & phosphorus content in filter media to avoid leaching. • Include a raised outlet and liner to create a submerged zone, particularly in dry climates (>3 weeks dry is common) and if nitrogen removal is a key objective. • Minimise desiccation by watering across dry periods and using species that cover or shade the surface. • To enhance phosphorus retention, select media rich in iron- or aluminium-oxides.
Sediment	• Primarily captured in surface layer. Remove by scraping once treatment is compromised by clogging. • Protect biofilter from high sediment loads from catchment (e.g. during construction) using temporary or permanent measures (e.g. pre-treatment). • Size the system appropriately to avoid a shortened lifespan from clogging; area – 2% of impervious catchment (Melbourne climate) or 4% (Brisbane) and sufficient ponding depth.
Heavy metals	• High fraction bound to sediment (see above). • Organic matter binds metals, but note high content compromises nutrient removal and infiltration. • Iron removal optimal with a larger biofilter area (≥4%) and use of effective species (e.g. *Carex appressa*).
Organic micro-pollutants	• For example: hydrocarbons, pesticides, herbicides, polyaromatic hydrocabons (PAHs), phthalates and phenols. • Similarly as for heavy metals, organic matter assists removal but content must not be excessive. • Prolonged drying benefits removal.
Pathogens	• Use known effective plant species (e.g. *Leptospermum continentale, Melaleuca incana, Carex appressa*). • Include a raised outlet and liner to create a submerged zone which provides prolonged retention for die-off and adsorption to occur. • Some drying is beneficial, but beyond 2 weeks drying performance is adversely affected. Successive inflow events (back-to-back) also lead to poor treatment. • Top-up the level of the submerged zone during prolonged dry periods. • (Subject to further testing), consider use of a novel antimicrobial media (heat-treated copper-coated Zeolite) to enhance pathogen removal (see Biofilter Guidelines).
Flow management	• Objectives may include reduction in volume, peak flow and frequency of flows. • Maximise biofilter treatment capacity via increased area, media depth or hydraulic conductivity of media (but within recommended range). • Consider including a submerged zone to retain a proportion of runoff. • Promote infiltration if conditions are suitable (e.g. unlined, partially lined or bioinfiltration design). • Maximise evapotranspiration loss by maximising the biofilter area and using a dense planting.

Cont.

Table 2 Cont.

Stormwater harvesting	
Pathogen, sediment, heavy metals and organic micro-pollutants may be key objectives (see Appendix D of the Biofilter Adoption Guidelines v2 (CRCWSC, 2015)). Nutrient removal may not be important if re-use for irrigation purposes.	
Maximise pathogen removal & yield	• Design to co-optimise for yield and to meet ecosystem protection objectives – generally line the system but balance with stormwater storage and demand patterns to achieve desired discharge reduction. • Use good species for pathogen removal. • Use media types that are effective for removal of pathogens (see Appendix D, but note that the use of this new, novel antimicrobial media requires care, as field testing is yet to be completed).
Additional	
Biodiversity	• Use a diverse mixture of local native species.
Microclimate	• Include trees to provide shading and cooling via evapotranspiration. • Locate in urban zones lacking green spaces e.g. streets and car parks.
Amenity, aesthetics & community engagement	• Use species and landscaping that manifest compatibility with local surroundings (see below for further guidance). • Include a raised outlet to retain more moisture to support green and lush plant growth. • Engage with the community and communicate the function of the system through design (e.g. signage), and encourage the public to view and walk alongside the biofilter. • As far as practicable, keep the biofilter tidy, well-tended and green – design for low-level maintenance.
Habitat	• Use flowering species to promote birds and insects, and native plants from nearby habitat patches.



OBJECTIVES *(section 3.2)*

SPECIFIC PERFORMANCE OBJECTIVES *(Section 3.4)*

SITE CONDITIONS *(section 3.4)*

Local climate

Safety *(Section 3.7.7)*

Catchment characteristics

Nearby infrastructure *(Section 3.7.7)*

Soils and groundwater

Surrounding landscape and vegetation

DESIGN PARAMETERS

Sizing *(section 3.6.2) — iterative, use MUSIC or design curves*

Determine biofilter area
Recommend 2% impervious catchment area (4% for Qld)

Select ponding depth
100 – 300 mm but consider safety limitations for site. If restricted compensate with larger biofilter area and other safety features.

Select media depth
Recommend ≥ 500 mm *(Section 3.6.4)*

Media hydraulic conductivity
100 – 300 mm/hr *(Section 3.6.4, Full specs Appendix C)*

Sediment pre-treatment *(Section 3.6.3)*
Recommend for all systems to reduce clogging, unless biofilter < 2 ha without identifiable sediment sources or if only treating roof runoff.

Include a raised outlet *(Section 3.6.3)*
Benefits pollutant removal and plant & microbial survival across dry periods, reduces head requirements of system, and allows a temporary submerged zone and exfiltration (if unlined), or a more permanent one (if lined).

Consider lined (full or partial) or unlined *(Section 3.6.3)*

Liner – prevents exfiltration. Use in dry climates (if > 3 weeks dry is common); for stormwater harvesting; to create a longer-lasting submerged zone or protect nearby sensitive infrastructure.

Unlined – allows exfiltration. Use in wetter climates to reduce stormwater volume and pollutant load. Loss rate will depend on soil properties. Benefits of a temporary submerged zone can also be realised with a raised outlet.

Select vegetation and aesthetics *(Sections 3.6.5 & 3.6.6)*
Essential for stormwater treatment. Choose appropriate species to meet performance objectives & system conditions
Consider climate, water availability for plants, safety, aesthetics.

RISKS TO LONG-TERM PERFORMANCE

Avoid undersizing (< 1% impervious catchment area)

At risk of clogging & shortened lifespan

Will need higher maintenance frequency to check for blockages and clogging

Can offset to some degree with deeper ponding depth (determine using MUSIC)

Install pre-treatment to capture sediment , ensure overflow can protect system from high flows and velocity control on inflows to minimise scour

Avoid oversizing

At risk of drying out & plant death from insufficient inflows

Avoid shallow system (< 500 mm deep)

At risk of drying out and may not be able to support vegetation

Use a raised outlet which also reduces head requirements and promotes ponding of water in the lower portion of the biofilter. In dry climates (i.e. > 3 weeks without rain is common) also include a liner to create a longer-lasting submerged zone to support plants and benefit water treatment.

Avoid excessively high hydraulic conductivity (< 300 mm/hr)

Will drought-stress plants and does NOT provide long-term protection from clogging

Avoid excessively low hydraulic conductivity (< 100 mm/hr)

Low treatment capacity, unless offset with larger biofilter area and/or ponding depth (determine using MUSIC)

OVERALL, THE DESIGN MUST…

Protect system from high sediment loads *(Section 3.6.1)*
Sediment a high risk if construction activities ongoing in catchment, erodible clay soils, other sediment sources or high organic litter load (e.g. from deciduous trees)
Vital to facilitate maintenance, improve performance and prolong lifespan.
Install pre-treatment (e.g. sediment forebay) and use additional protection measures temporarily during high levels of construction activity

Provide soil moisture for vegetation *(Section 3.6.1)*
Via a raised outlet to promote at least temporary moisture retention and appropriate sizing (media not too shallow, area not oversized, sufficient ponding depth)
Critical for system performance and lifespan
Horticulturalist should approve filter media characteristics

Figure 5 Key design decisions and tips to adapt to site conditions and performance requirements. Note: section references refer to the relevant sections of the Biofilter Adoption Guidelines v2 (CRCWSC, 2015)

Key design aspects

Media selection

The filter media is central to biofilter functioning and careful selection is essential. Media must be sourced that does not leach nutrients and has sufficient hydraulic conductivity, but which also supports plant growth, provides filtration capacity for fine sediment and has a stable particle size distribution. Incorrect media specification is a common problem in poorly functioning or failed systems experiencing problems such as nutrient leaching or plant death. In addition, geofabrics should never be used between media layers. The full specifications for biofilter media are described in the Guidelines for Filter Media in Biofiltration Systems (Appendix C of the Biofilter Adoption Guidelines v2 (CRCWSC, 2015)), but key requirements are outlined in Table 3.

Table 3. Essential and recommended media requirements

	Property	Specification to be met	Why is this important to biofilter function?
Filter Media (top layer/ growing media)			
ESSENTIAL SPECIFICATIONS	**Material**	Either an engineered material – a **washed, well-graded sand** – or naturally occurring sand, possibly a mixture	Media must be sand-based (and not a loam) to ensure adequate hydraulic conductivity, low nutrient content and structural stability
	Hydraulic conductivity	**100 – 300 mm/hr** (higher in tropical regions but must be capable of supporting plant growth). Determine using ASTM F1815-11 method	Provides adequate capacity to treat a higher proportion of incoming stormwater Testing method best represents field conditions
	Clay & silt content	**< 3% (w/w)**	Above this threshold hydraulic conductivity is substantially reduced. Too many very fine particles also reduce structural stability leading to migration and leaching
	Grading of particles	**Smooth grading** – all particle size classes should be represented across sieve sizes from the 0.05mm to the 3.4mm sieve (as per ASTM F1632-03(2010)	Provides a stable media, avoiding structural collapse from downwards migration of fine particles
	Nutrient content	**Low nutrient content** Total Nitrogen **(TN) < 1000 mg/kg** Available phosphate (Colwell) **< 80 mg/kg**	Prevents leaching of nutrients from the media
	Organic matter content	**≤ 5%** to support vegetation	Although some organic matter helps to retain moisture for vegetation and can benefit pollutant removal, higher levels will lead to nutrient leaching
	pH	**5.5 – 7.5** – as specified for 'natural soils and soil blends' in AS4419 – 2003 (pH 1:5 in water)	To support healthy vegetation over the long-term – without which the biofilter cannot function effectively
	Electrical conductivity	**< 1.2 dS/m** – as specified for 'natural soils and soil blends' in AS4419 – 2003	
	Horticultural suitability	Assessment by horticulturalist – **media must be capable of supporting healthy vegetation**. Note that additional nutrients are delivered with incoming stormwater	

Cont.

Table 3 Cont.

	Property	Specification to be met	Why is this important to biofilter function?
GUIDANCE	**Particle size distribution (PSD)**	Note that it is most critical for plant survival to ensure that the fine fractions are included (% w/w) Retained **Clay & silt** **< 3%** **(< 0.05 mm)** **Very fine sand** **5-30%** **(0.05-0.15mm)** Fine sand 10-30% (0.15-0.25 mm) Medium sand 40-60% (0.25-0.5 mm) Coarse sand < 25% (0.5-1.0 mm) Very coarse sand 0-10% (1.0-2.0mm) Fine gravel < 3% (2.0-3.4 mm)	Of secondary importance compared with hydraulic conductivity and grading of particles, but provides a starting point for selecting appropriate material with adequate water-holding capacity to support vegetation. **Filter media do not need to comply with this particle size distribution to be suitable for use in biofilters**
	Depth	400-600 mm or deeper	To provide sufficient depth to support vegetation Shallow systems are at risk of excessive drying
	Once-off nutrient amelioration	Added manually to top 100 mm **once only** Particularly important for engineered media	To facilitate plant establishment, but in the longer term incoming stormwater provides nutrients
	Submerged zone	Strongly recommended, particularly if entirely engineered media is used, filter media has a relatively high hydraulic conductivity or a shallow depth	To provide water retention to support plants through dry periods, and greater pollutant removal
Transition sand (middle layer)			
ESSENTIAL SPECIFICATIONS	**Material**	**Clean well-graded sand e.g. A2 Filter sand**	Prevents the filter media washing downwards into the drainage layer
	Hydraulic conductivity	**Must be higher than the hydraulic conductivity of the overlying filter media**	To allow the system to drain and function as intended
	Fine particle content	**< 2%**	To prevent leaching of fine particles
	Particle size distribution	Bridging criteria – the smallest 15% of sand particles must bridge with the largest 15% of filter media particles (Water by Design, 2009) (VicRoads, 2004): **D_{15} (transition layer) ≤ 5 x D_{85} (filter media)** *where: D_{15} (transition layer) is the 15th percentile particle size in the transition layer material (i.e.,15% of the sand is smaller than D_{15} mm), and D_{85} (filter media) is the 85th percentile particle size in the filter media* The best way to compare this is by plotting the particle size distributions for the two materials on the same soil grading graphs and extracting the relevant diameters (Water by Design, 2009)	To avoid migration of the filter media downwards into the transition layer
		Bridging criteria **only in designs where transition layer is omitted** (Water by Design, 2009; VicRoads, 2004): D_{15} (drainage layer) ≤ 5 x D_{85} (filter media) D_{15} (drainage layer) = 5 to 20 x D_{15} (filter media) D_{50} (drainage layer < 25 x D_{50} (filter media) D_{60} (drainage layer) < 20 x D_{10} (drainage layer)	To avoid migration of the filter media into the drainage layer only in the case where a transition layer is not possible.
G.	**Depth**	≥ 100 mm	(as per above purpose)

Table 3 Cont.

	Property	Specification to be met	Why is this important to biofilter function?
Drainage layer (base)			
ESSENTIAL SPECIFICATIONS	**Material**	**Clean, fine aggregate - 2-7 mm washed screenings (not scoria)**	To collect and convey treated stormwater, protect and house the underdrain (if present), or provide a storage reserve as part of a submerged zone, or prior to exfiltration (in unlined systems).
	Hydraulic conductivity	**Must be higher than the hydraulic conductivity of the overlying transition layer**	To allow the system to drain and function as intended
	Particle size distribution	Bridging criteria D_{15} (drainage layer) $\leq 5 \times D_{85}$ (transition media) *where: D_{15} (drainage layer) - 15th percentile particle size in the drainage layer material (i.e., 15% of the aggregate is smaller than D_{15} mm), and D_{85} (transition layer) - 85th percentile particle size in the transition layer material*	To avoid migration of the transition layer into the drainage layer
	Perforations in underdrain	Perforations must be small enough relative to the drainage layer material Check: **D_{85} (drainage layer) > diameter underdrain pipe perforation**	To prevent the drainage layer material from entering and clogging the underdrainage pipe (if present)
G.	**Depth**	Minimum 50 mm cover over underdrainage pipe (if present)	To protect the underdrain from clogging

Vegetation selection

Plants are an essential component of functioning biofilters. However, biofilter performance differs between plant species, particularly for nitrogen removal and species tolerance of hydrological conditions. To optimise stormwater treatment, the following is recommended:

- Species must be capable of survival in the biofilter environment (sandy substrate, prolonged drying and intermittent inundation).
- Use a diversity of species and various plant types (grasses, sedges, rushes, trees).
- Consider root characteristics as good indicators of performance, while above-ground appearance generally provides a poor guide.
- Include at least 50% of species either known to be effective performers (see Table 4 and Figure 6), or species with desirable traits for effective removal of the target pollutants. The following plant traits are particularly critical for nitrogen removal:
    - ¬ Extensive and fine root systems, which maximise uptake capacity, provide contact with the stormwater and support a large microbial community. This requires high total root length, root surface area, root mass, root:shoot ratio and proportion of fine roots. A high total plant biomass can accompany such an extensive root system.
    - ¬ Relatively rapid growth but ability to survive and conserve water across dry periods.
    - ¬ Avoid the use of nitrogen-fixing species.
- Plant densely (8-12 plants/m^2 for understorey species, <1 plant/m^2 for shrubs and trees) and carefully establish seedlings to develop an effective and low-maintenance biofilter in the long-term.

Selection of additional species for the biofilter (but comprising < 50% of plants) can consider other objectives, such as increasing the aesthetics and amenity of the local environment, providing diversity and habitat, microclimate benefits or meeting safety requirements. Further guidance is provided in the Biofilter Adoption Guidelines v2 (CRCWSC, 2015) (see Section 3.6.5) and 'Vegetation guidelines for stormwater biofilters in the South West of Western Australia' (Monash Water for Liveability, 2014).

Table 4. List of known plant species tested for their performance in stormwater biofilters (Chandrasena et al., 2014; Feng et al., 2012; Le Coustumer et al., 2012; Oversby, 2014; Read et al., 2008)

Objective	Effective	Medium or Mixed performance with different conditions	Poorer performers
Nitrogen removal	· *Baumea juncea* · *Baumea rubiginosa* · *Carex appressa* · *Carex tereticaulis* · *Ficinia nodosa* · *Goodenia ovata* · *Juncus amabilis* · *Juncus flavidus* · *Juncus pallidus* · *Juncus subsecundus* · *Melaleuca ericifolia* · *Melaleuca incana* · *Melaleuca lateritia*	**Medium** · *Poa labillardieri* · *Poa sieberiana* · *Sporobolus virginicus* **Effective in wet/ poorer in dry** · *Allocasurina littoralis* · *Cyperus gymnocaulos* · *Juncus kraussii* · *Leptospermum continentale* **Effective in dry/poorer in wet** · *Poa poiformis*	· *Acacia suaveolens* · *Astartea scoparia* · *Austrodanthonia caespitosa* · *Banksia marginata* · *Dianella revoluta* · *Dianella tasmanica* · *Gahnia trifida* · *Gahnia sieberiana* · *Hakea laurina* · *Hypocalymma angustifolium* · *Leucophyta brownii* · *Lomandra longifolia* · *Microlaena stipoides* · *Pomaderris paniculosa* · *Rytidosperma caespitosum*
Pathogen removal	· *Carex appressa* · *Leptospermum continentale* · *Melaleuca incana* · Palmetto® buffalo		· *Dianella tasmanica* · *Poa labillardieri* · *Sporobolus virginicus*
Infiltration capacity	· *Melaleuca incana* · *Melaleuca ericifolia*		
Iron removal	· *Carex appressa*		

Carex appressa

Melaleuca incana

Juncus kraussii

Carex tereticaulis

Juncus pallidus

Figure 6. Examples of effective species for nitrogen removal in stormwater biofilters

Designing biofilters that look attractive – aesthetics and community appreciation

Biofilters form part of local streetscapes and neighbourhoods, and successful integration into the urban landscape requires community support. This is achieved by designing biofilters that look good. Landscape design tips are outlined below and illustrated in Figure 7a-c, while full details can be found in Section 3.6.6 and Appendix F of the Biofilter Adoption Guidelines v2 (CRCWSC, 2015):

- Conduct a site visit and note the: i.) neighbourhood character (e.g. dense inner urban, leafy suburban, or semi-urban with fringing natural bushland); ii.) land use; iii.) architecture; iv.) existing landscaping; v.) planting style (formal or informal); and vi.) species selection (native, exotic or mixed).
- Design to reflect the context of each individual site; an appealing design for one environment might not suit another.
- Consider long-term appearance and form as plants grow.
- Use colours (e.g. various tones of green foliage, flowers or structural materials for edges, barriers, bridges or seating), textures (small-leaved plants for fine texture/ large-leaved plants for coarse, or materials such as concrete, stone, iron or timber) and patterns (formal geometric, random or curvilinear) to create visual interest.
- Use native and/or exotic species depending upon context.
- Include some complexity (e.g. canopy and understorey layers, or different plant heights) but the design should be orderly and tidy.
- Include trees as features (if possible), but avoid deciduous species.
- Include seasonal variety with various flowering plants.
- Consider public accessibility and signage to indicate function.
- Include a raised outlet to allow ponding in the lower portion of the biofilter (temporary if unlined but longer-lasting with a liner) to support healthy, lush, beautiful green plants.

Figure 7a. Incorporation of flowering plants in the raingarden provides colour and seasonal variation

Figure 7b. Even in the absence of flowers, interest is created by a mix of shades and tones of green foliage, of different texture. Source: M. Dobbie

Figure 7c. Different materials for paving, edging, inlet zones and other structures provide contrast and interest

Figure 8. Context is critical. In this bushy outer suburban setting (above), four different raingarden designs are not equally successful aesthetically. The bottom right-hand option with abundant flowering exotic plants does not relate well to the immediate setting or the nearby gardens. Source: M. Dobbie; photo manipulation: H. Smillie.

Figure 9. Different plant layouts for a specific site create quite different aesthetic effects. Left: random; centre, geometric; right, curvilinear. Source M. Dobbie; photo manipulation: H. Smillie.

Designing for stormwater harvesting

Biofilters are used not only for waterway protection, but also for the collection and treatment of stormwater runoff for re-use (e.g. for irrigation of gardens, public spaces or sports fields, or domestic non-potable uses such as toilet flushing). For these applications, the removal of pathogens is of primary concern, although removal of heavy metals and organic micro-pollutants are also of particular importance (nutrient removal is not critical if used for irrigation). The system must comply with any local guidelines, policies or legislation for stormwater harvesting and designs should typically consider the following (please see Section 3.6.7 of the Biofilter Adoption Guidelines v2 (CRCWSC, 2015) for further details):

- Line the system to maximise yield and create a longer-lasting submerged zone (see below). At the same time, co-optimise to meet ecosystem protection objectives (e.g. reduced flow volume, frequency and flow peaks towards pre-development hydrology). This can be achieved through design and operation, such balancing storage and demand requirements for the treated water to achieve the desired flow reduction.
- Include plant species shown to be effective for pathogen removal with extensive root systems such as *Carex appressa*, *Leptospermum continentale* and *Melaleuca incana*.
- Some degree of drying benefits pathogen removal, but dry periods > 2 weeks reduce performance significantly. Include a raised outlet to retain moisture within a submerged zone (recommend 450 – 500 mm, but see Section 3.6.7 of the Biofilter Adoption Guidelines v2 (CRCWSC, 2015) for further details) and to provide prolonged retention capacity for pathogen removal. If possible, top-up the submerged zone water levels as required during long dry periods (> 3 weeks).
- Consider use of novel antimicrobial media, such as a surface layer of heat-treated and copper-coated Zeolite (Li et al., 2014a; Li et al., 2014b), but adopt with caution as field-testing has yet to be completed (see Appendix D of the Biofilter Adoption Guidelines v2 (CRCWSC, 2015)).
- Biofilters can effectively reduce many metal concentrations below those of irrigation water quality, and often also meet drinking water standards (Zinger, 2012). Most metals are removed in the surface layer of media. However, if drinking water standards are applicable, effective iron removal may require the biofilter to be sized to at least 4% of its catchment and additional treatment for aluminium may also be required (Feng et al., 2012). Metal accumulation, particularly for zinc, requires additional monitoring in catchments with current or past industrial activity.
- Biofilters can also effectively remove a wide range of organic micro-pollutants including hydrocarbons, oils and phthalates. However, currently herbicides and chloroform are less effectively removed (Zhang et al., 2014).

Key design tips

- Carefully tailor designs to meet specific performance objectives and suit local site conditions, including climate, geology, topography and groundwater.
- Ensure the system is sized appropriately (biofilter area, ponding depth). This is vital for volumetric treatment capacity, the rate of sediment and pollutant accumulation (and therefore lifespan) and the moisture regime to support plant and microbial communities. Avoid excessive oversizing (inflows may be insufficient to sustain vegetation) and undersizing (reduced treatment capacity, lifespan and higher maintenance demands).
- Carefully select the filter media in accordance with specifications – in particular, low clay and silt content is essential for effective infiltration and low nutrient content minimises leaching, whilst also providing a suitable growing medium for plant growth.
- Include a raised outlet to support healthy plant growth, benefit pollutant removal (particularly for nitrogen and pathogens) and promote infiltration (in unlined systems; suitable in wetter climates) or provide a longer-lasting submerged zone (if lined; recommended in dry climates where > 3 weeks dry is common).
- Design effective system hydraulics to ensure an even distribution of flows across the entire surface, the desired ponding depth and safe bypass of high flow events.
- Select plant species and planting layout to meet treatment objectives, aesthetic, safety and microclimate considerations (See Plant Selection Fact Sheet in Appendix A of the Biofilter Adoption Guidelines v2 (CRCWSC, 2015)). Include a diversity of plant species and, if appropriate, consider inclusion of trees as a canopy layer.
- Plant densely to enhance pollutant removal - particularly for nitrogen - facilitate maintenance by minimising weed intrusion and help maintain infiltration capacity.

Practical Implementation

Construction and establishment tips

- Protect the system from sediment when construction activities are occurring within the catchment, as well as during biofilter construction itself.

- Installing sediment pre-treatment is highly recommended for all systems, unless the latter have a very small catchment and no sediment sources, or the biofilter treats only roof runoff (Water by Design, 2014).

- Conduct quality checks throughout construction and landscaping works to ensure that the design intent is represented. Critical checks include the flow hydraulics (invert level of inlet/s, invert level of the outlet and overflow structures, ponding depth and slope of the biofilter surface), filter media (material, layering, depths, potential contamination with site soils, minimal compaction and avoidance of mulch) and vegetation (plant density, seedling size and establishment). Common problems include incorrect surface gradients for streetscape systems (sloping towards the kerb) and inadequate or no ponding capacity (if the system is overfilled with media or invert levels are wrong).

- Establishment of healthy plant coverage across the biofilter is vital for effective function. The period of seedling establishment and early growth is a vulnerable time and long-term success can hinge on its management. Plant death or stunted growth will compromise long-term hydraulic and pollutant removal. A common problem is to 'plant and forget', but careful and timely management during establishment will avoid increased replanting and maintenance costs, e.g. repair of erosion.

- Further details are provided in Section 4.2 of the Biofilter Adoption Guidelines v2 (CRCWSC, 2015).

Sediment management: high risk of sediment washing into biofilter during construction in catchment

No step down into biofilter: flow cannot easily enter

Level of overflow designed or constructed too low, overfilling with media or uneven biofilter surface: these reduce ponding & flow distribution, allowing flows to bypass

Figure 10. Common sediment and hydraulic problems in biofilters

Monitoring and maintenance tips

Gather background information and undertake qualitative (e.g. check plant health and condition of media surface and flow structures) and preliminary quantitative monitoring (i.e. hydraulic conductivity and media testing for metals accumulation) for every system. If more extensive quantitative monitoring is to be conducted, clearly define the objectives, carefully plan an appropriate sampling plan and incorporate requirements into design.

For effective planning within an organisation: i.) train maintenance contractors in biofilter function; ii.) develop an inventory of assets and record monitoring and maintenance activities; iii.) clearly differentiate maintenance from more significant rectification or reset works; iv.) allow sufficient budget, including for additional maintenance during establishment; and v.) develop a maintenance plan and provide on-site information to maintenance crews, including individual system characteristics.

Do not use mulch (rock or organic) as this can clog outlets, prevent spread of vegetation and hinder sediment removal.

Establish a dense and healthy cover of vegetation for treatment efficiency, erosion protection, self-mulching, and less long-term maintenance or remediation.

Ensure sufficient soil moisture is available – soil moisture should not drop below the vegetation wilting point (~0.1 % (v/v)). Systems that are too shallow, sandy or small are particularly vulnerable to drying out.

Include species known to help maintain hydraulic conductivity – vegetation helps to counteract the cumulative effects of clogging. Some species, including *Melaleuca ericifolia*, have demonstrated greater potential to do this than others.

Design pits, pipes and culverts to facilitate inspection – pit lids should not be difficult to manage, nor require heavy lifting by maintenance personnel, and pipes should be designed to facilitate inspection and cleaning.

Provide safe and easy maintenance access with minimum need for traffic management – when locating and designing the system.

Further details are provided in Section 4.3 and 4.4 of the Biofilter Adoption Guidelines v2 (CRCWSC, 2015).

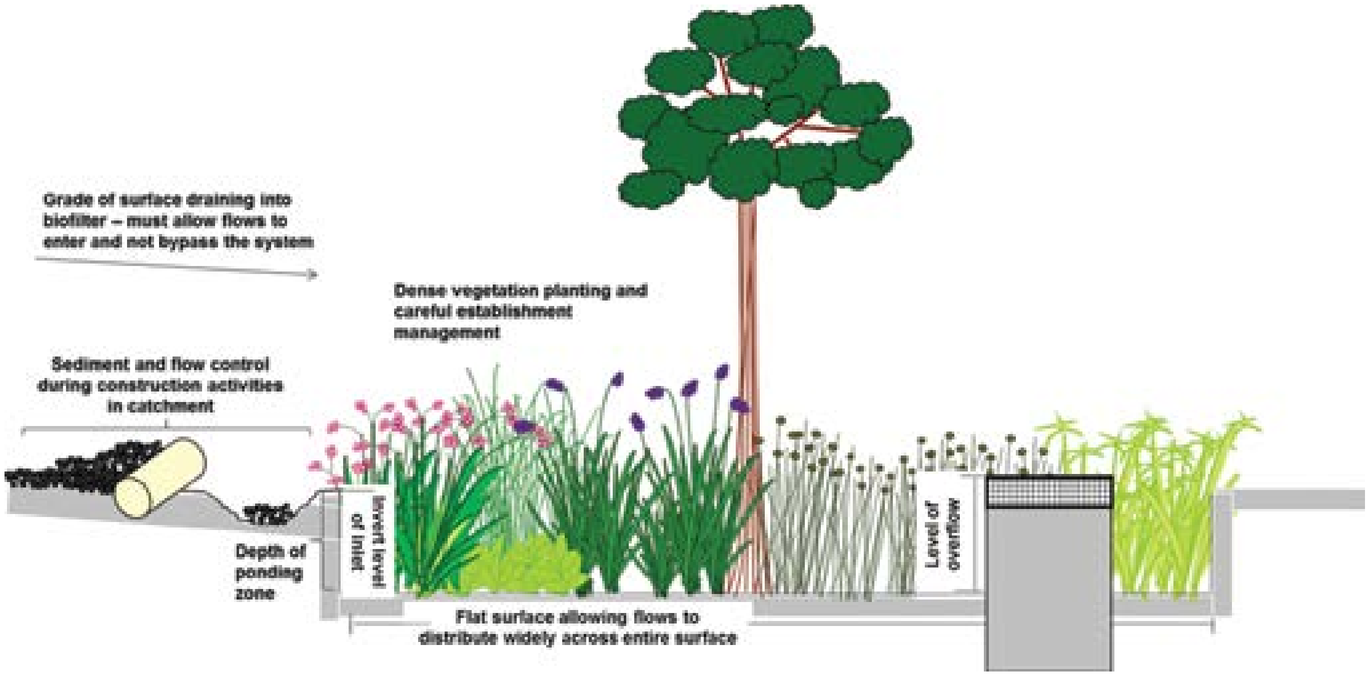


Figure 11. Common problems and critical quality control checks, during and following construction

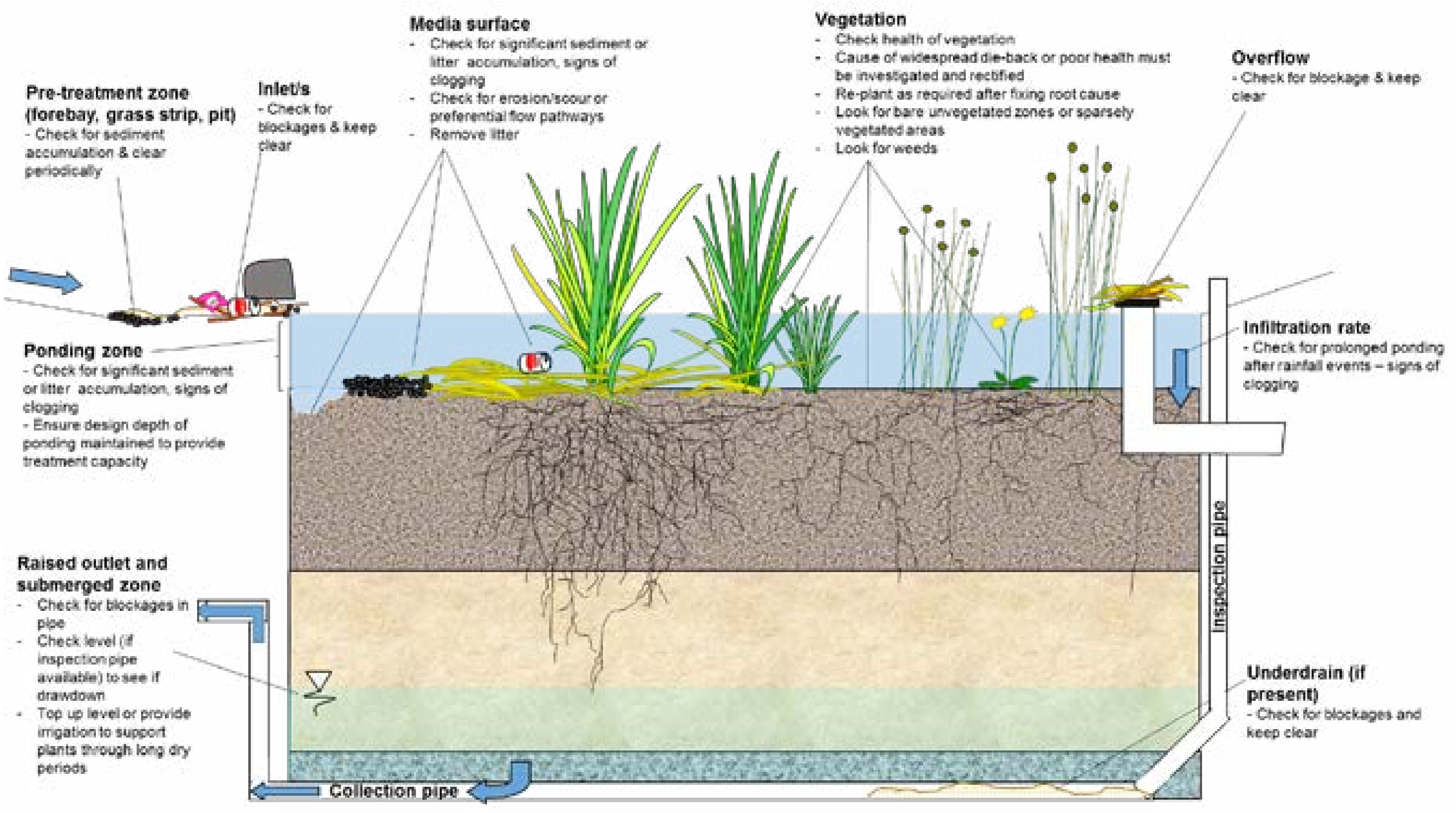


Figure 12. Critical checks and tasks for a monitoring and maintenance program

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Notes

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