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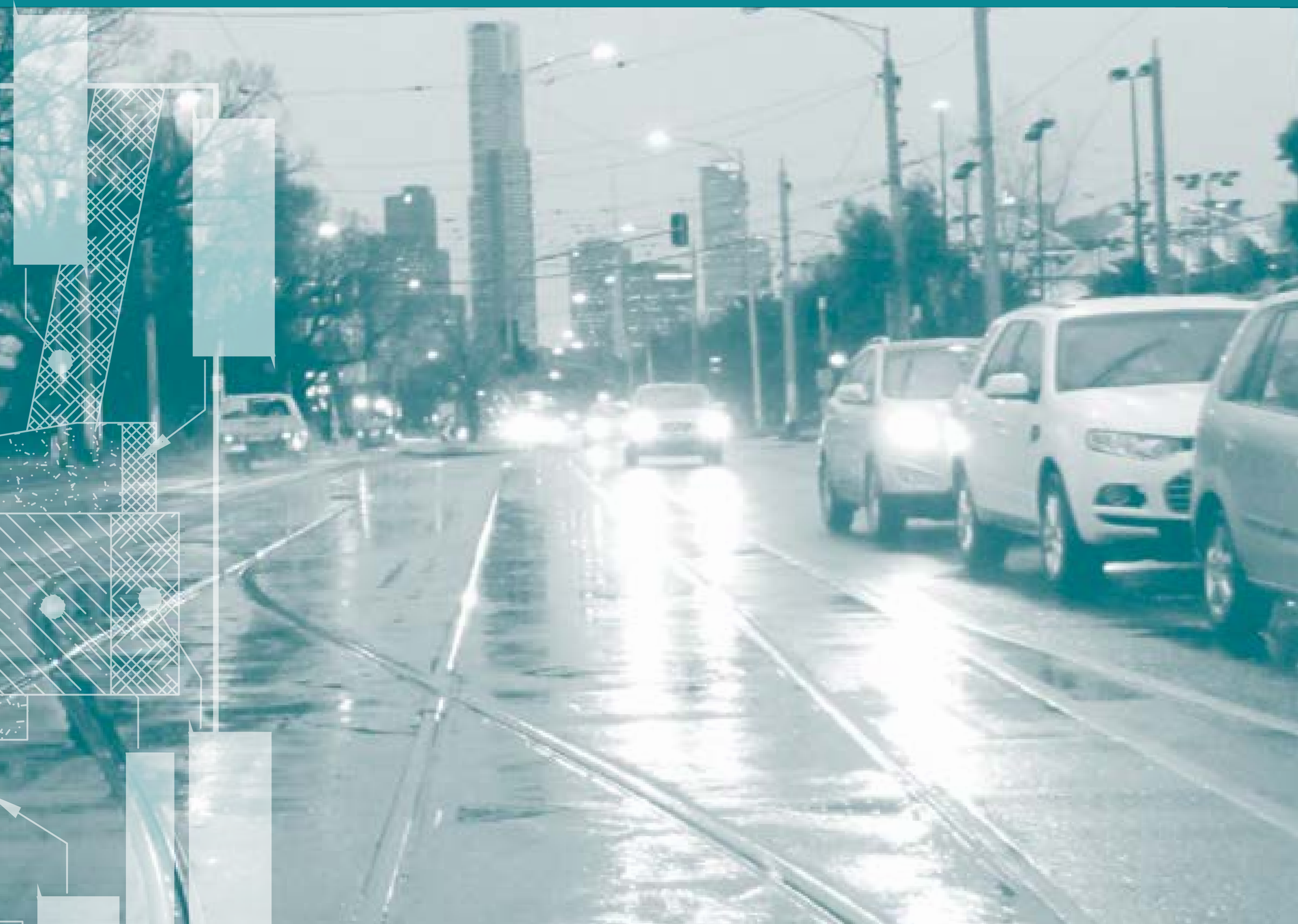
Chapter 3: Technical Considerations



3.1 Introduction

This chapter of the Adoption Guidelines focuses on technical considerations for biofiltration systems. **The purpose of this chapter is to supplement rather than replace existing design guidelines for biofiltration systems, as these often contain specific local requirements.** It is also important to note the **intention of this document is to act as a reference**, with readers encouraged to go directly to specific sections of interest.

The chapter begins with a brief discussion of considerations in the conceptual design stage, including guidance for setting performance targets and linking management objectives to design, key steps in bio filter design that are often overlooked. The early sections of the chapter also include a summary of biofilter components, their function and internal processes. Four fundamental design configurations are then presented in Section 3.5. This is followed by a discussion of the key design aspects; sizing, hydraulics, media, vegetation, aesthetics, harvesting and additional considerations (Section 3.6).

3.2 Setting management objectives

3.2.1 Performance targets for biofiltration

Identifying appropriate performance targets for each biofilter is essential to ensure that the design is tailored to meet the specific needs of the local environment, and to allow efficiency to be measured. The expected performance of stormwater biofilters for water quality is outlined in Section 2.4, while this section discusses suitable objectives to meet legislated or ecological requirements.

A number of states, territories, regions and municipalities stipulate or suggest performance targets for WSUD, which often include biofiltration systems. These targets should in all cases take precedence when planning for stormwater biofiltration. However, in the absence of local targets, the primary performance objective should be to **maintain or restore runoff volumes and frequency to pre-development levels**. For example, in Melbourne, the objective approximately translates to maintaining discharges from the stormwater pollutant treatment train for the 1.5-year ARI at pre-development levels (Melbourne Water, 2008). In South-East Queensland, the 1-year ARI for pre-development and post-development peak discharges are matched in order to satisfy this requirement for maintaining the geomorphic integrity of the receiving streams.

Should the pre-development runoff objective not be achieved, then load reduction targets, such as those in Chapter 7 of *Australian Runoff Quality* (Wong, 2006), are recommended alternatives, particularly for protection of lentic waterways such as lakes, estuaries and bays. In South-East Queensland, guidelines have been provided to meet such targets as well as to minimise the impact of small, frequent rainfall events on aquatic ecosystems: the first 10mm of runoff from impervious surfaces up to 40% of the site and 15mm of runoff for higher levels of imperviousness shall be treated within 24 hours of the runoff event (see Appendix 2 in (Gaskell, 2008). Note, however, that these are not alternatives. Rather, they exist in addition to the predevelopment runoff objective. In western Sydney, the first 15 mm of runoff is required to be treated for a 24-hour to 48-hour period on development sites less than five hectares in area (UPRCT, 2004). For the ACT, 14 mm of runoff shall be retained for at least 24 hours (up to 72 hours) in order to treat the 3-month ARI event (PLA, 2008).

Pollutant load reduction objectives are provided in the majority of Australian states and territories, the most rigorous for private development sites being in South-East Queensland, where 80% of total suspended solids, 60% of total phosphorus, and 45% of total nitrogen on the site shall be retained by the stormwater treatment train (see Appendix 2 in (Gaskell, 2008)).

3.3 How does a biofilter work?

3.3.1 Components of a biofilter

All biofilters operate using the same basic principles and some features are essential and common to all biofilters (Figure 6). Configurations are flexible though, and some characteristics will be tailored, allowing each system to be adapted for optimised performance. Additional design components may or may not be included (Figure 7), depending upon performance objectives and the opportunities or constraints presented by the site or its catchment. Each component contributes to system functioning (summarised below in Table 9). It is important that each key element is designed, constructed or maintained to serve its intended function, to ensure success of the system.

Whilst the complexity of biofilter components varies (e.g. inlets may comprise a simple break in the kerb or more complicated piped delivery), all systems require the following **essential components:**

1. **Hydraulic controls:** These are structures that control both the inflow rate and the volume of stormwater into the plant/filter media zones of the biofilter. They incorporate the following:

    a. Inflow zone – controls the inflow rates into the system;

    b. Overflow or bypass capacity – controls the volume of water that is treated, allowing high flows to exit or bypass the system; and

    c. Ponding/detention depth on top of the media – controls the volume of water that is detained for treatment (and thus determines the frequency of bypass).

2. **Vegetation:** Plants are crucial for both removal of nutrients and maintenance of hydraulic conductivity (K_s). Plant roots also harbour the majority of the microbial community (in the zone surrounding the root; the rhizosphere), which are also essential for pollutant removal and transformation processes. Plants also contribute to the reduction of outflow volumes via evapotranspiration, which can additionally help the local microclimate. Vegetation should therefore be carefully specified according to the system objectives as well as the local climate.

3. **Filter media:** The purpose of the filter media is to both remove pollutants (through physical and chemical processes), as well as to support the plants and microbial community that are responsible for biological treatment. The filter media also reduces peak flows and outflow volumes by detaining and retaining runoff. The different media layers are designed to facilitate pollutant removal and allow the system to drain. The filter media generally has three layers:

    a. Soil/sand-based media, where most treatment occurs;

    b. Transition layer, which serves to prevent washout of filter media; and,

    c. Drainage layer – collects treated water at the bottom of the filter and conveys it to the drainage pipes;

4. **Raised outlet (creates a temporary submerged zone):** This provides benefits irrespective of whether the system is unlined or lined. The raised outlet allows water to pond in the lower layers of the biofilter, creating a submerged zone which provides moisture to plants (vital across extended dry periods), prolonged retention and superior pollutant removal (particularly for nitrogen). If connected to a conventional stormwater drainage system, a reduced drop in head is required to achieve a given biofilter depth. If the system is unlined a raised outlet promotes exfiltration to surrounding soils, and if combined with a liner it will create a longer-lasting submerged zone.

Optional components, which should be adapted to suit the treatment objectives or site conditions include:

1. **Liner (creates a longer-lasting submerged zone in conjunction with a raised outlet)**: This will prevent exfiltration into surrounding soils, which is desirable to collect treated water for re-use in stormwater harvesting schemes, if sensitive structures nearby require protection (refer to *Australian Runoff Quality* (Wong, 2006) for allowable offset distances), or if interaction with shallow groundwater is not desirable. With a raised outlet, a liner provides a more durable submerged zone, which is essential and strongly recommended in dry climates (where > 3 weeks dry periods are common). Without this moisture retention, desiccation can lead to plant death and significantly reduced water treatment.

2. **Carbon source (e.g. wood chips):** Recommended when a liner and submerged zone are present to provide electrons to drive denitrification, particularly in early biofilter life before plant roots establish at depth (as roots also release carbon that can be utilised by microbes). It is mixed throughout the media comprising the submerged zone (i.e. the sand transition and drainage layers).

3. **Outflow controls:** These dictate how treated water leaves the system, which may be through exfiltration into the surrounding soils (if the system is unlined or partly unlined) and/or direct outflow through a drainage pipe. If outflows are collected for an outflow pipe a slotted pipe may be included as an underdrain to help flow conveyance out of the system.

How these components are specified and arranged depends on the objectives of the system as well the site conditions (as discussed in Sections 3.3 and 3.4.1).

The next section outlines possible system configurations, while details on how each component is designed are presented in Section 3.6.

Table 9. Key components of stormwater biofilters and their functional roles

Essential components and function	**Key information can be found within Biofilter Adoption Guidelines (CRC for Water Sensitive Cities, 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 between pores	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, nor for 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

Cont.

Table 9. Continued

Essential components and function	Key information can be found within Biofilter Adoption Guidelines (CRC for Water Sensitive Cities, 2015), Section...	
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 N 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

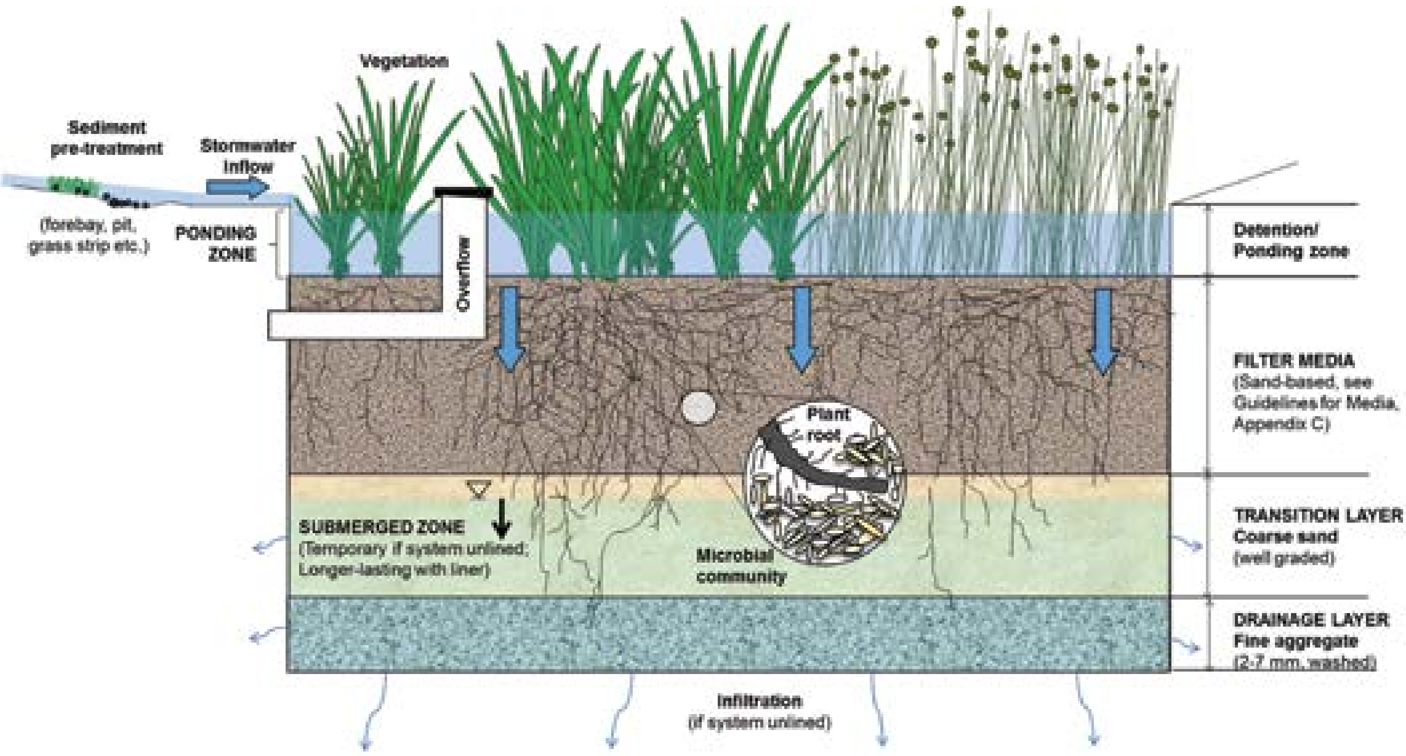


Figure 6. Essential components for stormwater biofilters (although note that configurations can vary widely from the general illustration shown above)

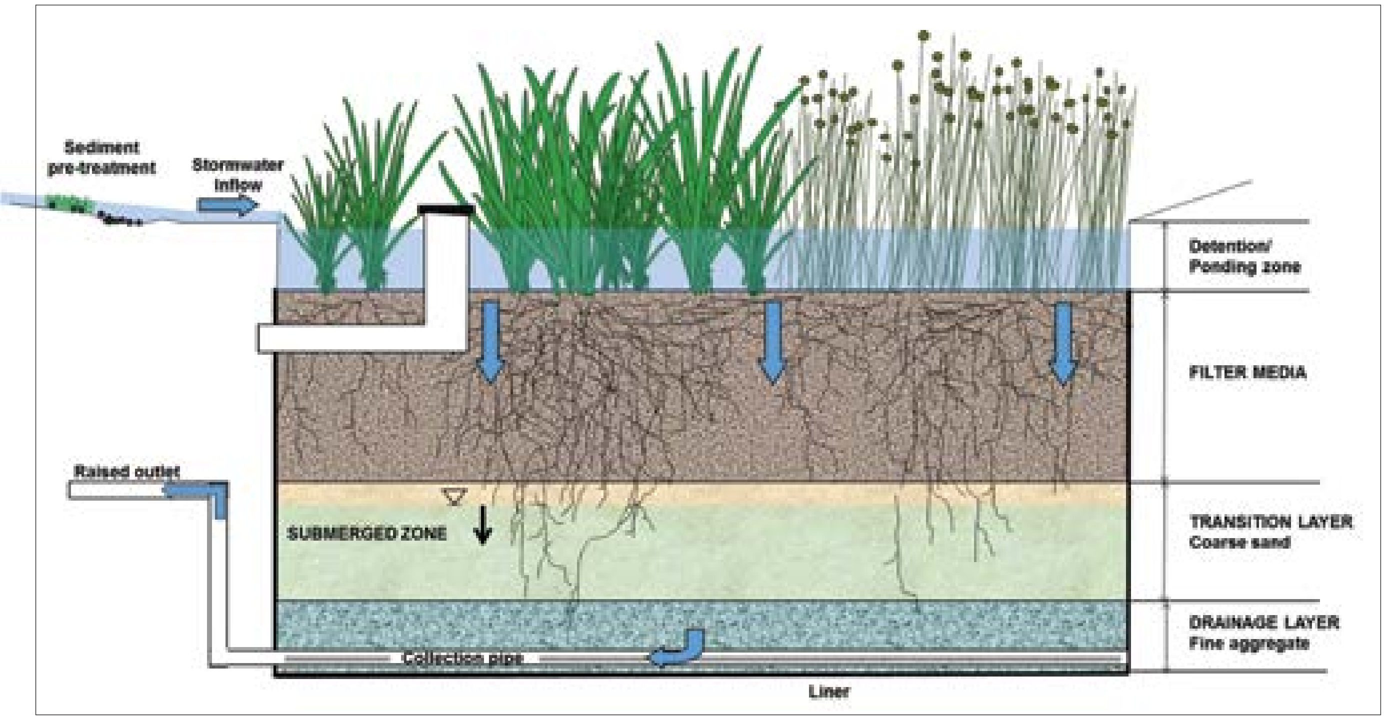


Figure 7. Typical biofilter configuration recommended for dense urban areas and/or where prolonged dry spells are experienced

3.3.2 Biofilter functioning and processes

A wide range of processes act to retain or transform incoming stormwater pollutants. These include physical, biological and chemical processes (Table 10 and Figure 8). The plants, filter media and microbial community all play important roles in pollutant processing as stormwater enters the biofilter, infiltrates through the filter media and comes into contact with plant roots and microbes.

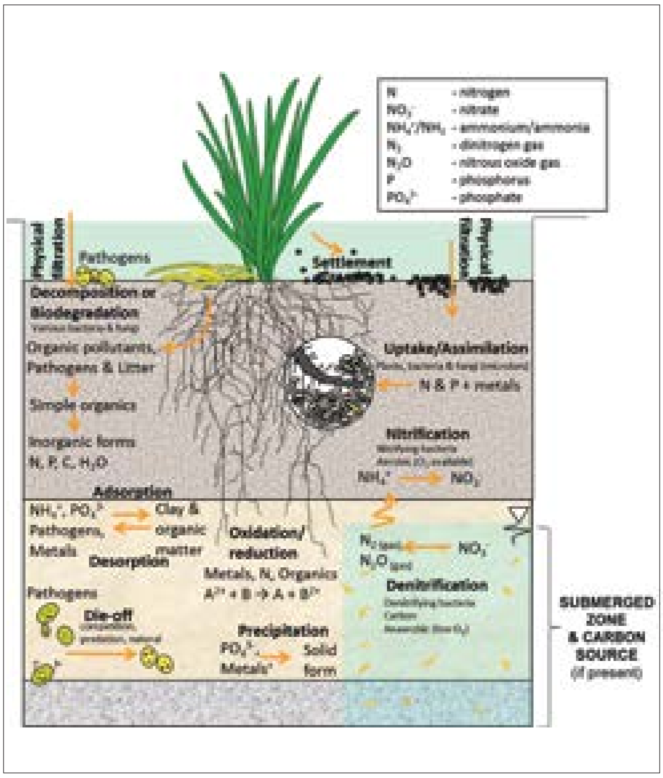


Figure 8. Key processes involved in pollutant attenuation, removal or transformation in stormwater biofilters

Table 10. Key processes involved in the removal or transformation of stormwater pollutants

Stormwater pollutant	Key processes
Sediment	• Settlement during ponding • Physical filtration by media
Nitrogen	• Nitrification • Denitrification • Biotic assimilation by plants and microbes • Decomposition • Physical filtration of sediment-bound fraction • Adsorption
Phosphorus	• Physical filtration of sediment-bound fraction • Adsorption • Biotic assimilation by plants and microbes • Decomposition
Heavy metals	• Biotic assimilation by plants and microbes • Physical filtration of sediment-bound fraction • Oxidation/reduction reactions
Pathogens	• Adsorption-desorption • Physical filtration by media • Die-off (either natural or due to competition or predation)
Organic micropollutants*	• Adsorption • Biodegradation

**Hydrocarbons, pesticides/herbicides, polycyclic aromatic hydrocarbons (PAHs), phenols, phthalates*

3.4 Conceptual design

Despite the same underlying principles and basic elements, it is highly unlikely that any two biofilters will be exactly the same, therefore "big-picture" thinking and decisions are required before the detailed design can be specified. There are several existing useful conceptual design guidance documents to which we refer the reader, particularly the South East Queensland Healthy Waterways Partnership's Concept Design Guidelines for Water Sensitive Urban Design (Water by Design, 2009 b). Possible considerations at the conceptual design stage could include:

- How will the biofiltration system be integrated within the urban design?
  - Scale of approach: end-of-pipe (regional, precinct) versus distributed (at-source, streetscape)
  - Drainage function: biofiltration swales are "on-line" systems and provide both treatment and conveyance, whereas biofiltration basins are "off-line" and provide treatment only. However, basins are less likely to scour because they are non-conveyance and so generally do not have to withstand high flow velocities.
- What opportunities and constraints are associated with the site?
  - Is there a landscape/urban design theme?
  - What, if any, are the treatment targets? (Section 3.2.1)
  - What are the local water demands?
  - What are the catchment properties? E.g. size, flow rates, land use.
  - Are there any obvious sources of high pollutant loads? E.g. high numbers of deciduous trees or ongoing development in the catchment
  - Is the site sloped? Flat? Both very sloped and very flat slopes can be challenging.
  - What is the underlying geology of the site and the depth and condition of the groundwater?
  - Is there an existing drainage system?

- Are there existing stormwater treatment systems in the catchment? What condition are they in?
- What services are 'in the way' of the proposed construction area? Are there any potentially sensitive assets in close proximity?
- What is the space availability?
- What are the in situ soil properties? E.g. salinity, acidity, infiltration capacity
- How is the urban design arranged? E.g. solar orientation

Conceptual design tip

Variations in site conditions provide the opportunity for creative design. It is important to note that what might initially be perceived as a constraint can lead to innovative solutions. These broad conceptual design ideas can then start to be developed into more detailed functional design.

Important!

Like all other WSUD elements, incorporation of biofilters into the urban design is far more straightforward and successful if it is considered in the initial stages of development (i.e., when the "slate is clean"), rather than after the design of other elements of the urban environment (e.g. roads, lot configurations) has been completed.

It is important to design in consultation with those who will be responsible for maintaining the system to ensure practicality.

3.4.1 Linking design parameters to management objectives and site conditions

One of the greatest benefits of biofiltration is the adaptability and flexibility of the technology. As a result, the design process is essential for the successful implementation of stormwater biofiltration. **The design of a biofilter should be governed by the objectives for the particular catchment** and the opportunities and constraints presented by the specific site. Whilst this seems an obvious statement, there is often very little thought given to the management objectives and site conditions. As a result, systems are often designed in a way that is sub-optimal for the particular requirements of an individual project, even if the same design may perform well in another location or meet other (perhaps less important) objectives. A number of case studies illustrating various applications and design of biofiltration systems is provided in Appendix E.

Objectives, site opportunities and constraints should be identified in an initial site inspection, with **all stakeholders** in attendance. Stakeholders are discussed further in Section 2.3, but at a minimum a representative from each stage of the project lifecycle must be involved throughout design. This must include people experienced in design, construction, establishment, maintenance and reset or decommissioning.

Possible objectives are discussed in Section 3.2.1 and could include:

1. Water quality treatment (i.e., reduction in concentrations and/or loads of certain pollutants);
2. Flow management (i.e., reduction of runoff frequency and volumes or flow rates, etc.); and/or
3. Provision of pre-treated water for stormwater harvesting applications.
4. Addi tional objectives, such as enhancing biodiversity, cooling the urban environment and public amenity.

Site-specific conditions that must be considered in design include:

5. Local climate
6. Geology of surrounding soils
7. Groundwater characteristics
8. Catchment characteristics (relative size, land-use, level of development (imperviousness), hydraulic connectivity of impervious areas, degree of construction activities or other sediment sources, prevalence of deciduous trees etc.)

9. Nearby sensitive infrastructure
10. Surrounding landscape and vegetation
11. Safety considerations
12. Maintenance access and efficiency

Optimal design of a biofilter will differ, depending on which objective(s) are to be met, as well as on local environmental conditions. Tips to adapt biofilter design to these various considerations are provided in Table 11.

Table 11. Summary relating applications and performance objectives with design tips

Waterways Protection	
Nutrients	• Plants are essential – 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 N & P 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 N removal is a key objective • Minimise desiccation by watering across dry periods and using species that cover or shade the surface • To enhance P 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) • Incoming load may be higher in industrial catchments. Zinc accumulation can be problematic. • 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, 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 extended 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

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Table 11. Continued

Stormwater harvesting	
Pathogen, sediment, heavy metals and organic micro-pollutants may be key objectives (see above, and further below for more details) Nutrient removal may not be important if re-use for irrigation purposes	
Maximise pathogen removal & yield	• Use a fully lined system • Use good species for pathogen removal. • Use media that are good for the removal of pathogens (see Appendix D, but note that the use of this new and novel antimicrobial media requires care as field testing is still to be completed).
Additional	
Biodiversity	• Use a diverse mixture of local native species
Microclimate	• Include trees to provide shading and cooling via evapotranspiration • Local in urban zones lacking green spaces e.g. streets and car parks
Amenity, aesthetics & community engagement	• Use species and landscaping with compatibility with local surrounds (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 the design (e.g. signage), and encourage the public to view and walk alongside the biofilter • As far as practical keep biofilter looking neat, well-kept and green – design for low-level maintenance
Habitat	• Use flowering species to promote birds and insects, and native plants from nearby habitat patches

3.5 Key design configurations

While all biofilters share the same basic principles and fundamental components, the particulars and complexity of each system will differ. No one design will suit all possible performance objectives or the wide variation in possible site conditions. Hence, it is imperative that site-specific treatment objectives are defined and the opportunities and constraints of the site, its surrounding catchment and local climate, are identified (Section 3.4.1).

While there are many possible design variations for biofiltration systems, they may be broadly grouped into five main design configurations. The features of each of these configurations are described below, as well as suitable applications.

For all configurations it should be noted that designs may vary substantially from the illustrated examples below, particularly if an innovative approach is taken; these are only intended to highlight the key distinguishing features. Biofiltration systems can be shaped to fit into the available space and can therefore be built as simple trenches or basins. They can also be constructed as “on-line”, conveyance (commonly referred to as biofiltration swales) or “off-line”, non-conveyance (known generally as biofiltration basins) systems.

Biofiltration swales have an additional component that must be specified – a conveyance channel. As such, they also generally need to be able to withstand higher flow velocities, which need to be considered when designing the inflow and overflow zones. However, all other design elements are specified in the same way as for biofiltration basins.

Important!

Inclusion of a raised outlet is universally recommended, except in the case of simple exfiltration systems with no outlet. The former provides substantial benefits in designs both with and without a liner. The raised outlet allows a submerged zone in the lower biofilter layers, which increases moisture availability to plants, thereby increasing their drought resilience and better sustaining biofilter function in the long-term. The benefits of retention within a submerged zone for pollutant removal have been clearly demonstrated, particularly for nitrogen and pathogen removal. It also provides hydrological benefits

If the system is unlined with a raised outlet, the submerged zone will be temporary and exfiltration will be promoted. Exfiltration provides reduction in pollutant load and stormwater volume, providing substantial benefit to the health of downstream waterways.

If a liner is included, a longer-lasting submerged zone will be sustained. This is strongly recommended in dry climates (when > 3 weeks drying is common) to sustain plant and microbial communities, and biofilter function. Without adequate moisture, severe drying will lead to plant death, poor pollutant removal (including the possibility of re-release of previously captured pollutants) and eventual system failure.

3.5.1 Unlined biofiltration system with raised outlet (i.e. temporary submerged zone) or no outlet

This type of biofilter is the simplest form of system to design and build. The system is unlined and drains freely, allowing exfiltration into surrounding soils. In the most basic form, the biofilter may be disconnected from any downstream drainage and lack an outflow, with all treated stormwater exfiltrated into surrounding soils (Figure 9; bottom). A thicker layer of aggregate at the base provides greater storage capacity for stormwater prior to exfiltration.

However, if an outlet is present, a raised outlet pipe is strongly recommended to promote exfiltration, provide prolonged retention and create a temporary submerged zone to support vegetation (Figure 9; top). A collection pipe at the bottom of the drainage layer is shown in Figure 9 (top), however another variation is also possible, where the collection pipe is raised above the base of the drainage layer (this is discussed in further detail below). This type of system – unlined with a raised outlet - is highly recommended for:

- Climates that do not experience long dry spells – defined as no inflow into the system for three continuous weeks (Note: biofilters will receive inflows even during very small events due to their very small size relative to the catchment, therefore modelling is required to ensure that this criteria is met);
- Sites with high exfiltration potential, but also sites where the exfiltration potential is low due to low hydraulic conductivity of the surrounding soils (i.e. at least one order of magnitude lower than the filter media). In the latter case, a liner may not even be necessary to achieve similar hydraulics to a lined and drained system (Section 3.5.2);
- Systems that are NOT designed for stormwater harvesting;
- If the available head difference across the biofilter is restricted by the invert levels of the existing drainage network, existing services or shallow topography, the raised outlet allows a deeper biofilter than would otherwise be possible;
- Providing passive irrigation of the surrounding landscape; and,
- Recharging groundwater levels (similarly to natural pervious catchments).

It should be noted that, where there are assets that need to be protected, one or more sides of the system can be lined. Suitable areas for unlined biofiltration systems include those where soil salinity might initially be considered a risk (e.g. western Sydney, Wagga Wagga), as it has been demonstrated that the dominant flow path is from the biofilter to the surrounding soils, thereby preventing salt from entering the system (Deletic and Mudd, 2006).

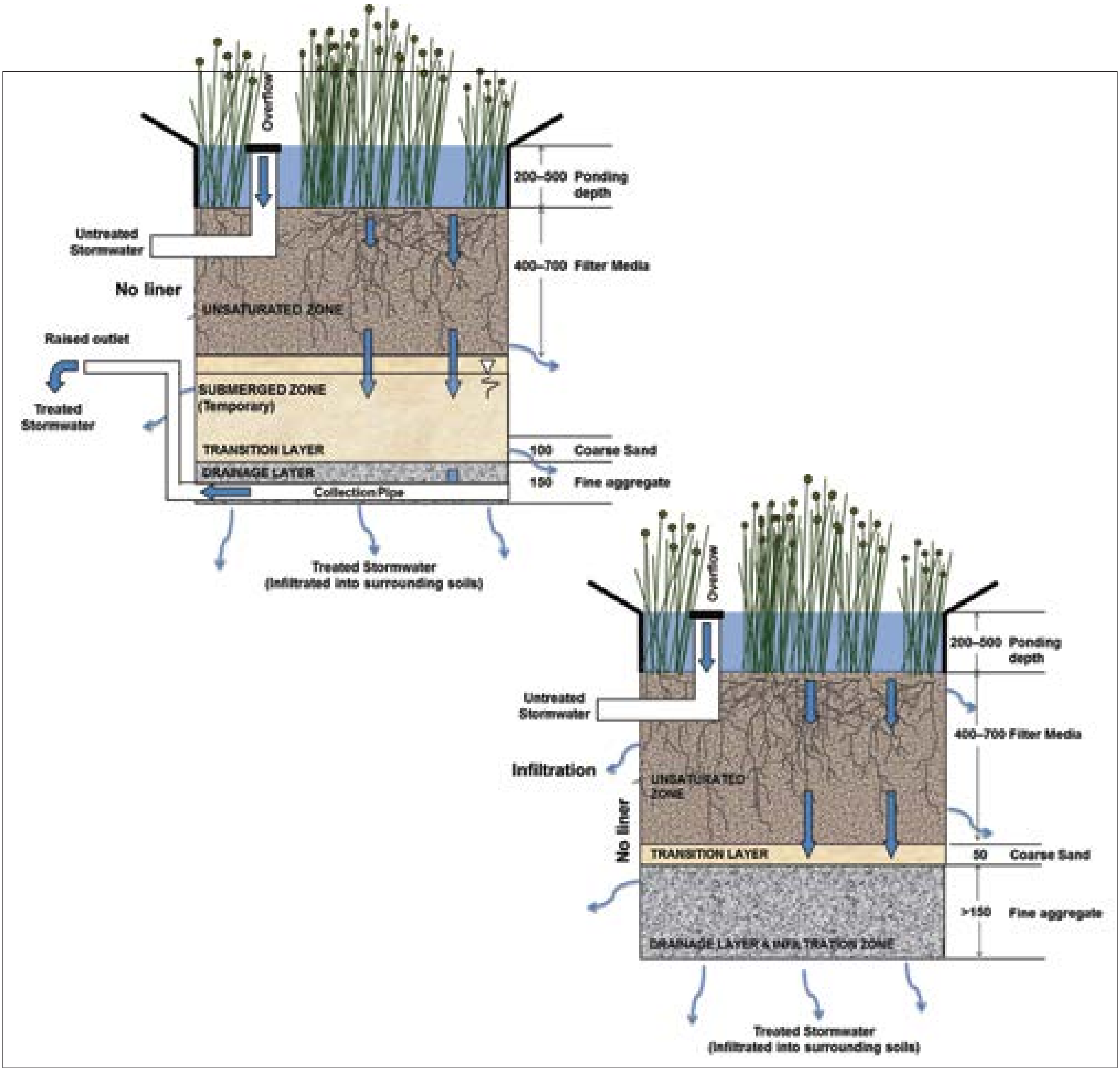


Figure 9. Unlined standard biofiltration system with raised outlet (top) and without formal outflow drainage (i.e. all exfiltration; bottom)

3.5.2 Lined biofiltration system with raised outlet (i.e. longer-lasting submerged zone)

Two possible configurations of this type of system are given in Figure 10. The systems are fully lined and incorporate an elevated outlet, which allows accumulation of a longer-lasting submerged zone, relative to unlined systems (Section 3.5.1). The top biofiltration system contains a submerged zone created in a sand layer, while the bottom system contains a submerged zone created in a layer of fine aggregate.

This type of biofilter is optimal for the following cases:

- Climates that have very long dry spells (because the longer-lasting submerged zone will act as a water source to support the plants and microbial community for several weeks without rainfall; Section 3.6.3);

- Sites where exfiltration is not possible. For example, where there is a need to protect built infrastructure, or interaction with a shallow groundwater table is undesirable. Refer to *Australian Runoff Quality* (Wong, 2006) for allowable offset distances from specific structures;

- Systems designed for stormwater harvesting;
- If systems are designed for NOx or pathogen removal, or if receiving waters are highly sensitive to Cu or Zn; or
- If a shallow system is unavoidable, either due to restrictive invert levels of the existing stormwater drainage system or underlying services (the raised outlet of a submerged zone allows a deeper system with less head required, and the submerged zone provides moisture retention in shallow systems that are otherwise more sensitive to drought stress).

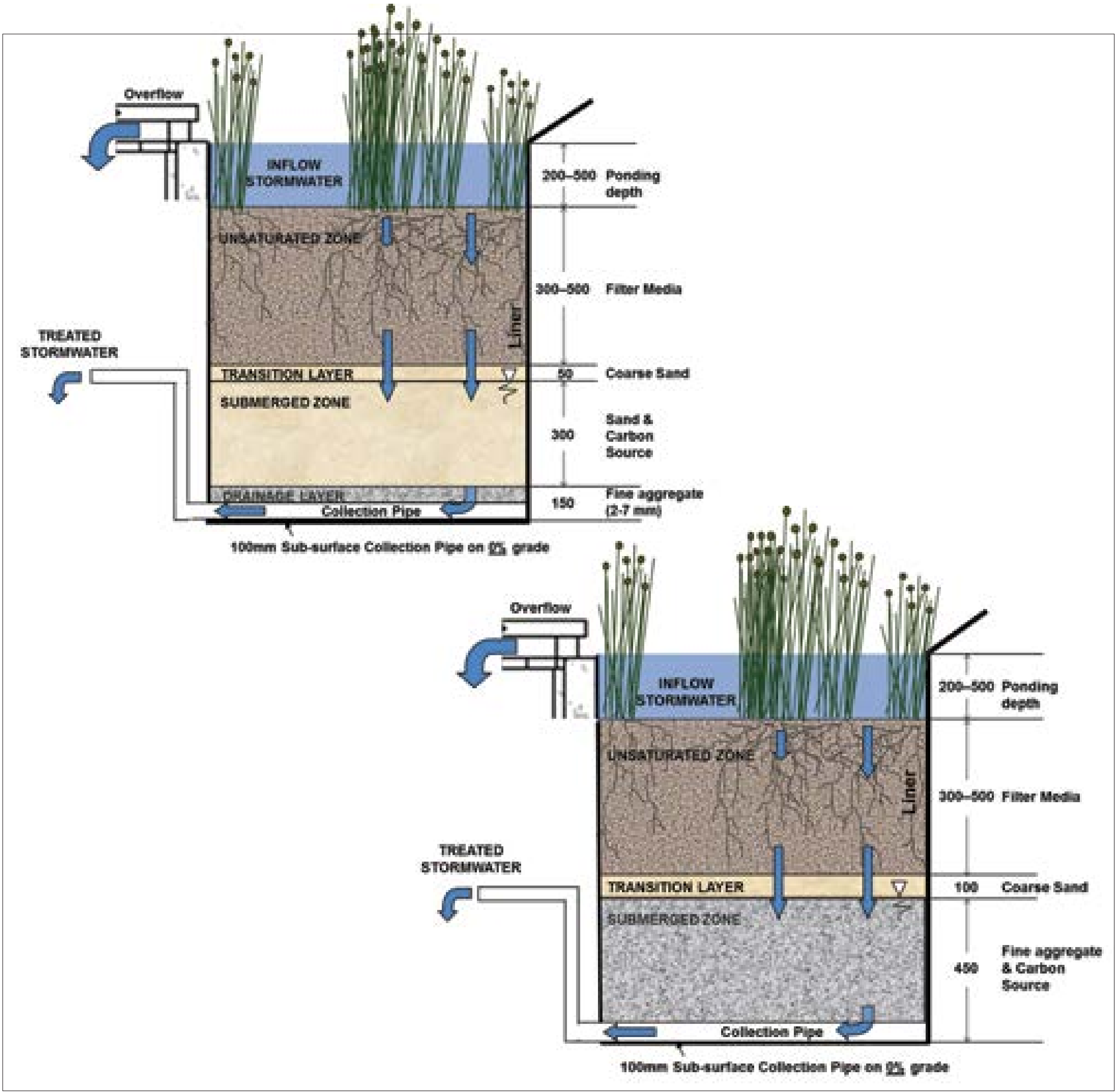


Figure 10. Lined biofiltration system with submerged zone comprised of sand (top) and fine aggregate (bottom)

3.5.3 Partially unlined biofiltration system with raised outlet and lined submerged zone

This configuration includes a raised outlet in combination with a liner in the lower portion of the biofilter to create a longer-lasting submerged zone (relative to unlined). The upper portion of the biofilter remains unlined to allow some exfiltration into surrounding soils. Such a design is suitable when:

- Exfiltration is allowed but the local climate is very dry (i.e., plant survival may be uncertain), with > 3 weeks dry common. However, the benefit of exfiltration will be very limited as it can only occur through the sides of the system, while the majority of flow will be vertical (Figure 11).
- These systems are not recommended for stormwater harvesting applications.

It is important to note that, even though this system is partially unlined, the bottom and sides of the submerged zone still need to be lined in order to maintain a longer-lasting pool of water. As discussed in previous sections, liners can be combined in different ways. For example, it may be desirable to line just one side of the system to protect a nearby asset (e.g. side butting up against road).

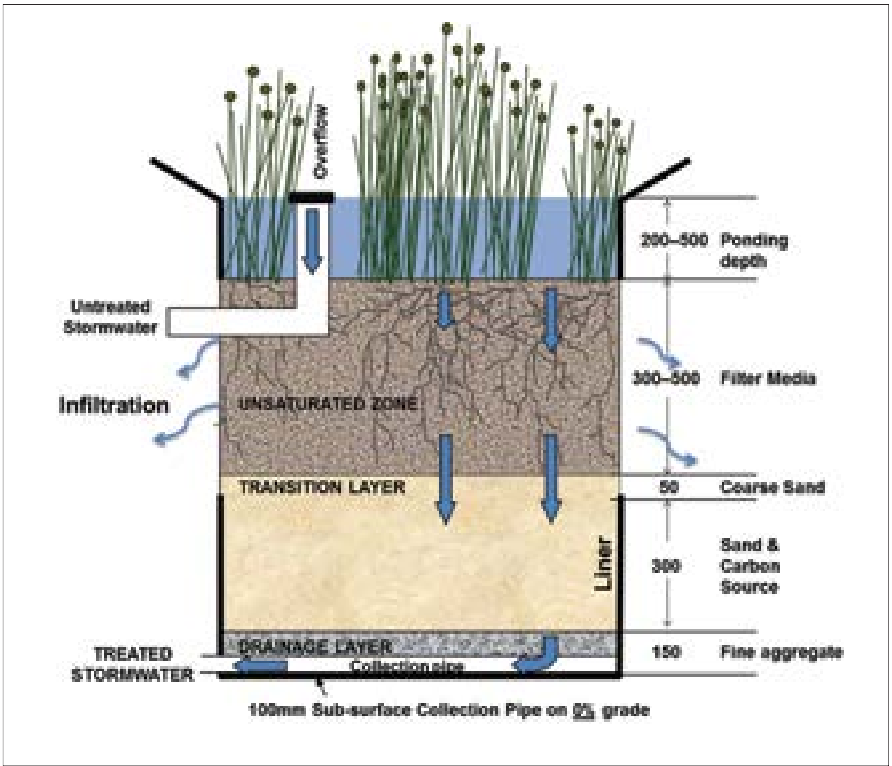


Figure 11. Partially unlined biofiltration basin with submerged zone

3.5.4 Bio-infiltration system with both lined and unlined cells

This type of biofilter is a hybrid of both lined and unlined systems, incorporating a lined cell with raised outlet (thereby creating a more durable submerged zone), which drains into an unlined cell that allows exfiltration. This configuration combines the treatment efficiency and moisture retention benefit of a longer-lasting submerged zone with the advantages of exfiltration. By infiltrating stormwater at or near the source, runoff frequency, peak flows and runoff volumes are significantly reduced. Overall, this provides substantial hydrological benefits for downstream waterways and flood mitigation.

It is important to note that the lined submerged zone can be created without installation liner material. In fact, in areas where the soils are clay, a submerged zone will automatically be created as the exfiltration rate is likely to be low so that the system rarely completely drains. However, in areas where the soils have a high drainage rate, a two-component configuration can be adopted, as shown in Figure 12.

Two-component bio-infiltration systems are highly recommended for:

- Climates that have very long dry spells, where plant survival is likely to be compromised without a longer-lasting submerged zone;
- Soils with a high drainage rate, where a liner is required to create a more durable submerged zone (in contrast to using the unlined design with raised outlet shown in Figure 9 in heavy clay soils where a liner may not be required).
- Sites where exfiltration is allowed. Refer to *Australian Runoff Quality* (Wong, 2006) for allowable offset distances from nearby structures that may be sensitive to infiltration;
- Providing both water quality improvement and reduction in runoff volumes, peak flows and runoff frequency – this benefits the health of downstream waterways but also provides flood mitigation benefits;
- Providing passive irrigation of the surrounding landscape;
- Recharging groundwater levels (similarly to natural pervious catchments); and
- Systems that are NOT designed for stormwater harvesting.

Bio-infiltration systems are preferable to standard, non-vegetated infiltration systems because they provide for superior treatment, particularly with respect to nutrient removal. They are therefore highly recommended, particularly if surrounding soils have a good infiltration capacity.

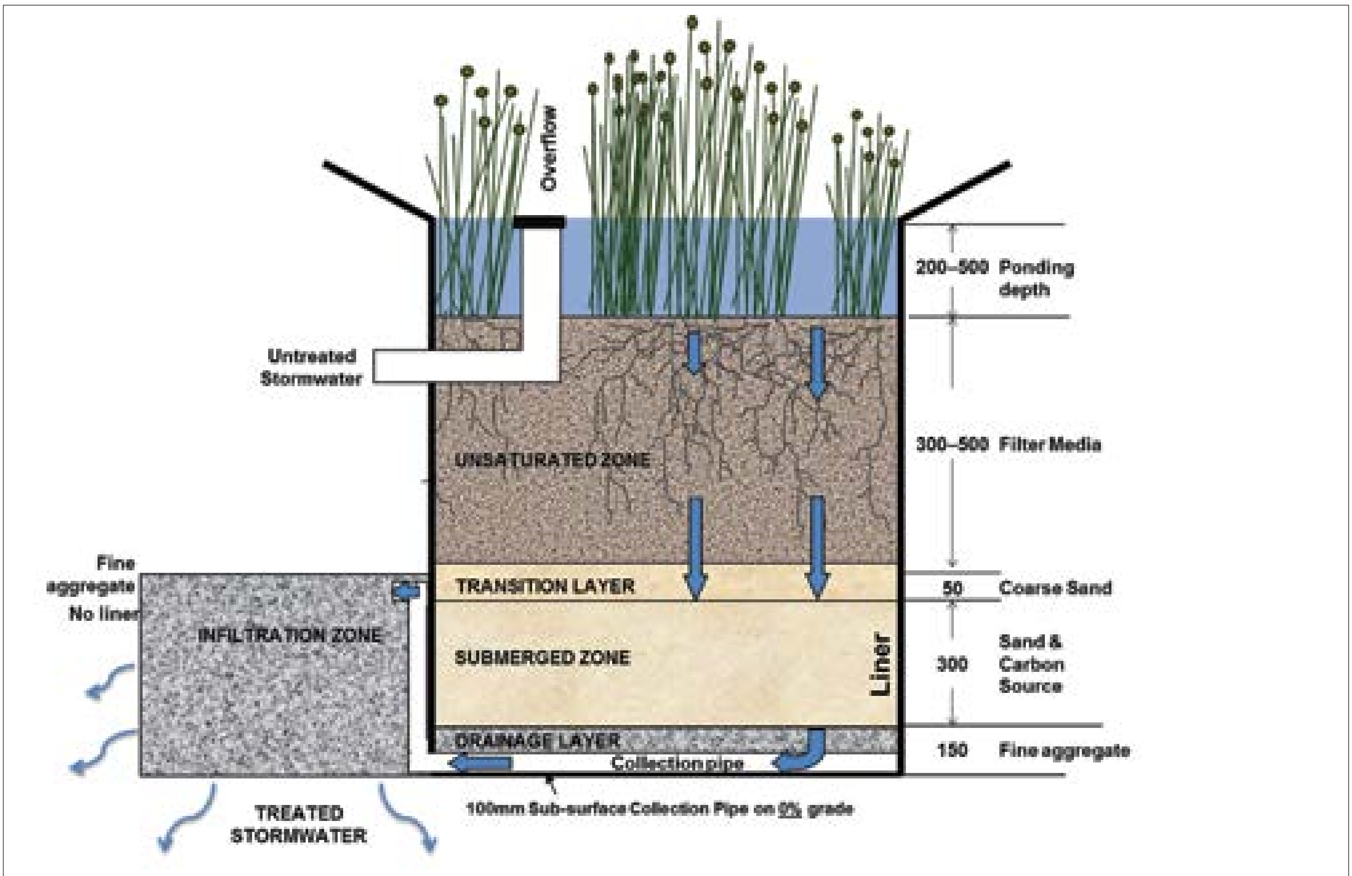


Figure 12. Schematic of a bio-infiltration system containing a submerged zone.

3.6 Design procedure

3.6.1 Introduction; Designing for successful long-term operation

The general procedure for the design of a stormwater biofilter is illustrated in Figure 13. Components controlling the volume of water that can be treated (filter surface area, ponding depth, filter media hydraulic conductivity) and the level of treatment (filter media characteristics, vegetation, raised outlet (creating a submerged zone, even if only temporary)), are specified first, after which the inflow and outflow controls are designed. Typical ways in which biofilter design is influenced by objectives and site conditions are illustrated using a decision flow chart in Figure 15.

The long-term success of biofilters is contingent on the implementation of good design principles. Careful planning from the early design stage will lead to more effective performance, prolonged lifespan and reduced costs for maintenance or extensive rectification works. **The importance of considering long-term operation at the outset cannot be overstated**, with field studies highlighting that most issues encountered can be linked back to the design, construction and establishment phases rather than inadequate maintenance (E2DesignLab, 2014a). Design issues that are particularly critical to system success or failure include:

- Ensure the system is **sized appropriately** – avoid excessive oversizing (the catchment may not provide sufficient inflows to sustain vegetation; more commonly a problem in retrofitted systems) and undersizing (treatment capacity will be reduced, maintenance demands higher and the lifespan shortened due to clogging). Similarly, pre-treatment devices should not be oversized as vegetation within the biofilter may be deprived of moisture.

- Carefully **select the filter media in accordance with the Guidelines** for Filter Media in Biofiltration Systems (Appendix C). It is particularly vital to ensure low clay content to ensure adequate infiltration rates and low organic matter content to minimise nutrient leaching (if nutrient removal is a treatment objective), while also balancing the need for adequate moisture retention.

- Ensuring there is **sufficient availability of soil moisture to support the vegetation**. This is critical for effective performance in the long-term. It can be **achieved by including a raised outlet to allow pooling in the lower portion of the biofilter** (strongly recommended for both lined and unlined systems), but also with adequate media depth and ensuring some degree of water holding capacity in the filter media (e.g. not too sandy, but within the media specifications given in Appendix C).

- **Design system hydraulics** to ensure an even distribution of flows across the entire surface, the desired ponding depth and safe bypass of high flow events. Critically, the designed hydraulics need to be **carefully checked during construction** (including landscaping works). Common problems include incorrect surface gradients for streetscape systems (sloping towards the kerb and inadequate (or no) ponding capacity (discussed further in Section 4.2).

- **Implement sediment pre-treatment and other controls**, most particularly in systems with construction activities in the catchment. Excessive sediment inputs will clog the biofilter, severely shortening its lifespan, crippling treatment capacity and requiring expensive rectification works.

- **Carefully tailor designs to local site** conditions, including **climate** (a key variable between sites with a strong influence on design success), **geology, topography and groundwater.**

- Select **appropriate plant species and planting layout** to meet treatment objectives, aesthetic, safety and microclimate considerations. Plants are a vital component for all aspects of biofilter function and species differ in their performance for pollutant removal (particularly nitrogen) and tolerance to wetting and drying.

- **Plant densely** to enhance pollutant removal (particularly for nitrogen) and evapotranspiration loss (if these meet the performance objectives). This will also aid maintenance by minimising weed intrusion and heling top maintain infiltration capacity.

- **Locate the system appropriately** – offline and outside retarding basins wherever possible. Equally, the system must suit its position in terms of aesthetics (Section 3.6.6) and safety considerations (Section 3.6.8).

- **Include a submerged zone via a raised outlet** – in systems without a liner this will be temporary (suitable in wet climates), but longer-lasting with a liner (recommended in dry climates). The submerged zone is essential to help plants and microbes survive prolonged dry periods (although some irrigation or topping up will be required for prolonged dry periods), benefits performance and can provide low-oxygen conditions for permanent nitrogen removal via denitrification.

The following sections briefly describe the design procedure for each functional component of a biofilter. Where further details or specific expertise is required, this is highlighted.

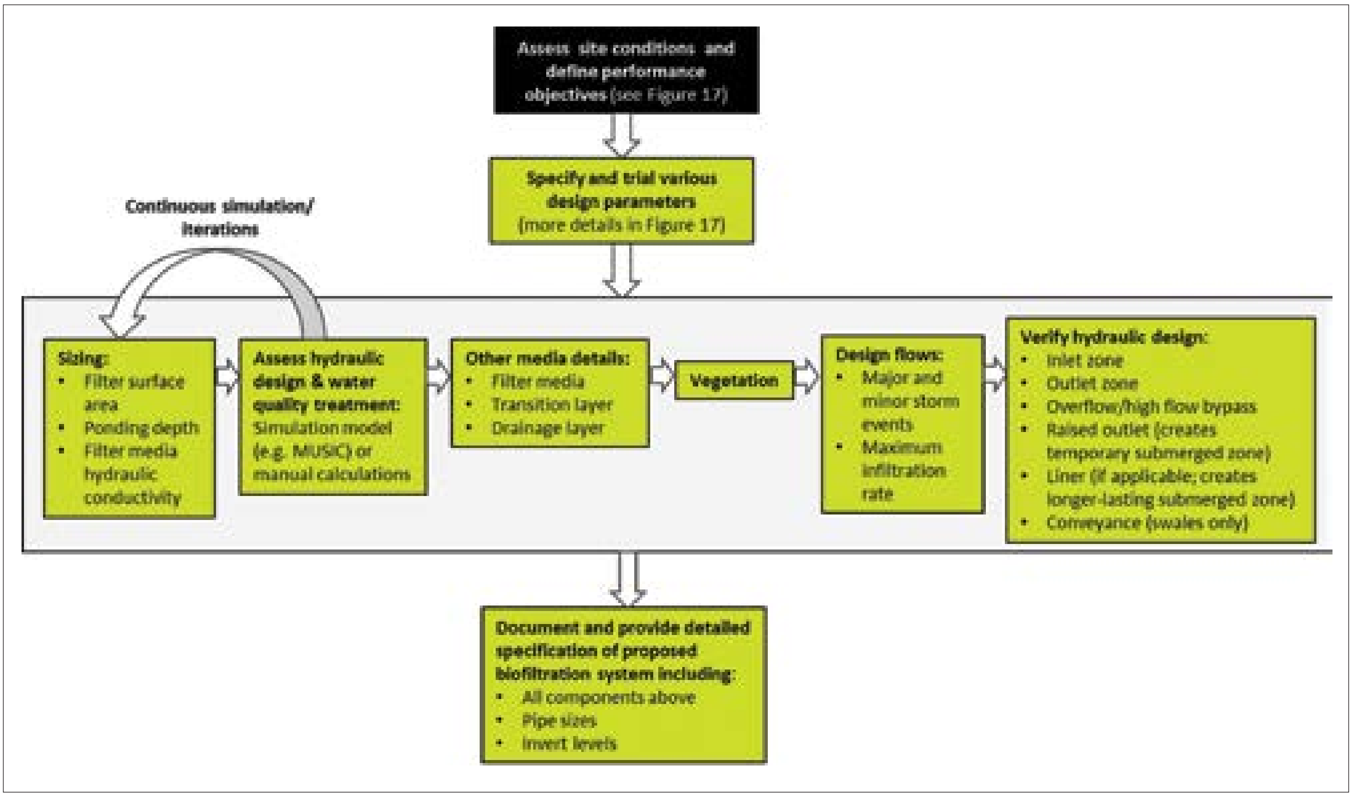


Figure 13. Overview of the design process for specifying the components of a biofiltration system (with detail provided in Figure 15).

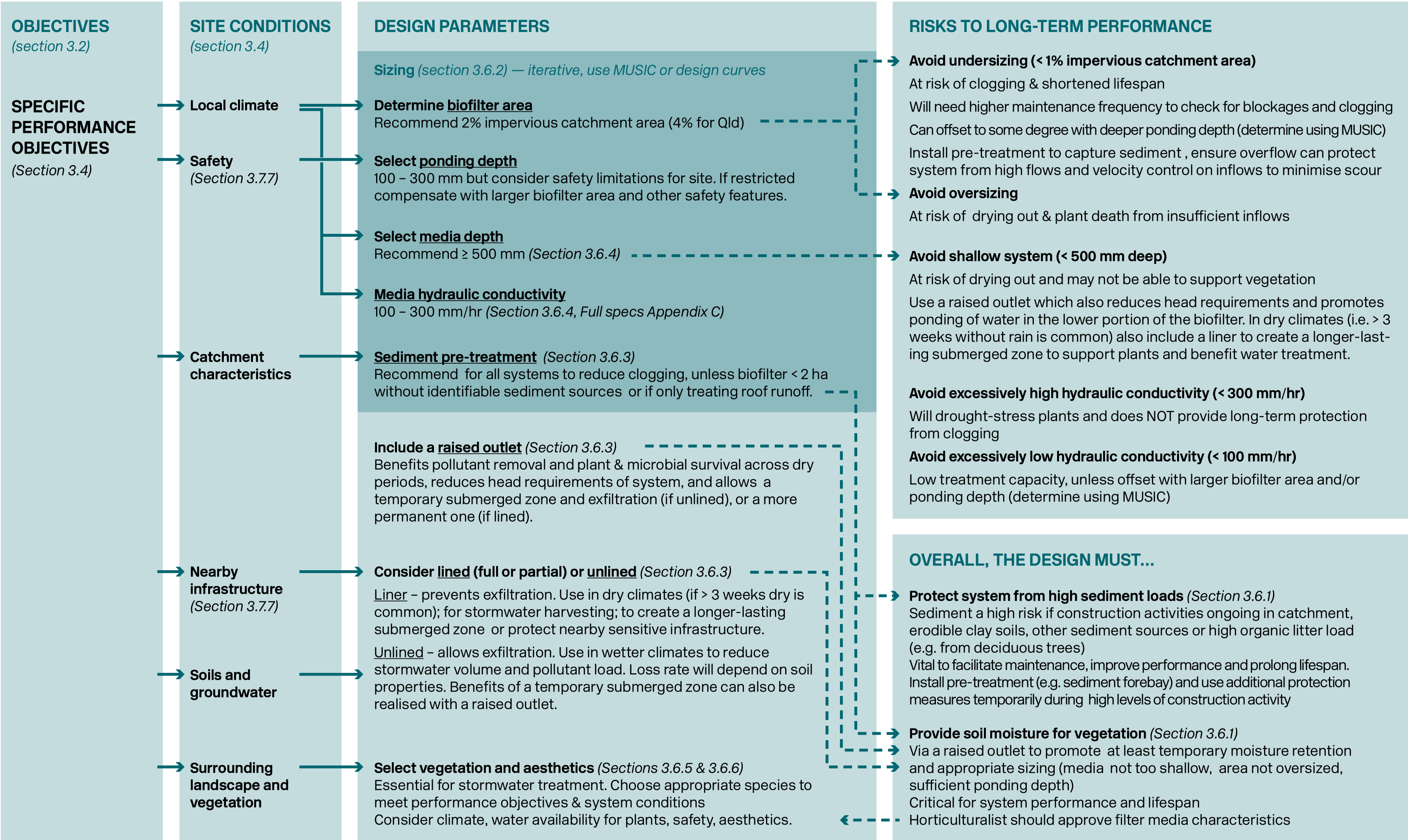


Figure 14. Key design decisions and tips to adapt to site conditions and performance requirements

3.6.2 Sizing

Sizing is vital for volumetric treatment capacity, the rate of sediment and pollutant accumulation (therefore lifespan) and the moisture regime to support plant and microbial communities. Sizing in design will take into consideration the biofilter area, ponding depth and hydraulic conductivity of the filter media. Each of these parameters influences the overall infiltration capacity of a biofilter (Figure 15).

Each design parameter may be adjusted to achieve the desired moisture availability, depending upon site constraints and objectives. Importantly, choice of media hydraulic conductivity requires an inevitable trade-off between volumetric treatment capacity and water holding capacity. Volumetric treatment capacity is usually maximised and other design features can be implemented to allow plants to access water. This may include use of a submerged zone, increased media depth or allowing root access to shallow groundwater or surrounding soils with higher moisture availability.

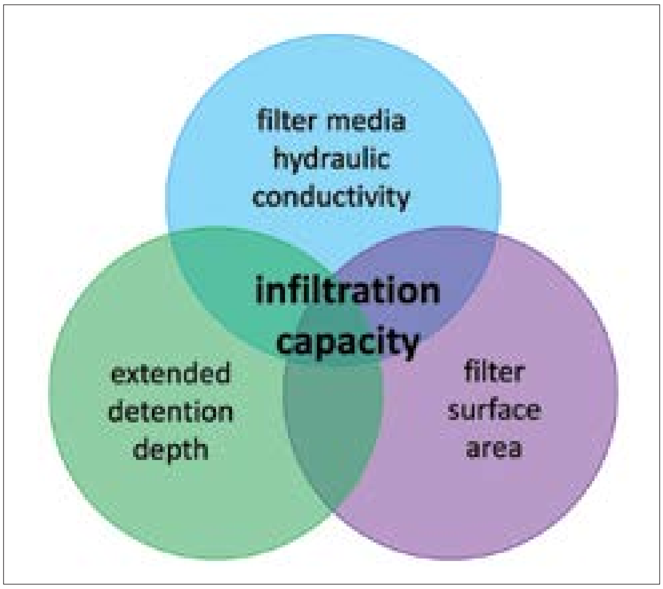


Figure 15. Relationships between design parameters for system sizing and infiltration capacity

The required size of a biofiltration system could be determined using the following principles:

- Design flows are used to estimate the biofilter size. The following design flows should be estimated:

    1. The minor storm event (5 year ARI for temperate climates, 2 year ARI for tropical climates, or according to local regulations), to size the inlet zone and overflow structure, and to check scouring velocities;

    2. The major storm event (100 year ARI for temperate climates, 50 year ARI for tropical climates, or according to local regulations), if larger storms will enter the biofilter (i.e., are not diverted upstream of the system), to check that erosion, scour or vegetation damage will not occur; and

    3. The maximum infiltration rate through the filter media, to size the underdrain. For small systems (contributing catchment area < 50 ha), use the Rational Method to estimate minor and major flows. For large systems (contributing catchment area > 50 ha), use runoff routing to estimate minor and major flows.

- Performance curves, such as those provided in the Water Sensitive Urban Design Technical Design Guidelines for South East Queensland (BCC and WBWCP, 2006), where the surface area can be selected according to the ponding depth and desired pollutant removal performance. The hydraulic conductivity of the filter media should also be considered.

- Note that sizing needs to be conducted with specific reference to the local climate - performance curves representative of the local climate should be used; similar curves exist for most States and Territories.

- As a starting point, a biofiltration system with a surface area that is 2% of the impervious area of the contributing impervious catchment, a ponding depth of 100 – 300 mm and a hydraulic conductivity of 100 – 300 mm/hr would be a fairly typical design in order to meet regulatory load reduction targets for a temperate climate.

- However, the hydraulic conductivity may need to be higher in tropical regions in order to achieve the required treatment efficiency using the same land space and ponding depth (i.e., ensuring that the proportion of water treated through the media meets requirements).

- Where one of these design elements falls outside the recommended range, the treatment capacity can still be met by offsetting another of the design elements. For example, if there is a desire to use a particular plant species (landscape consideration) but that plant requires wetter conditions than can be provided with a filter media that drains at 200 mm/hr, use of a slower draining filter media to support healthy plant growth may be feasible if the surface area of the system can be increased to compensate.

- However, problems can arise if properties deviate too far outside the recommended range – likelihood of drought conditions, clogging and sediment accumulation, or a risk to public safety may increase. Some of the various design possibilities have been summarised in Table 12 and, if considered, should be investigated using a model such as MUSIC.

Table 12. Biofilter design – benefits, offsets and risks if designs stray outside the range of recommended specifications

Design property	Benefits or offsets in design	Risks
Undersized biofilter area	Greater inflows, reduced drought potential. Can help offset a high hydraulic conductivity or minimal ponding depth.	Reduces treatment capacity. Clogging and sediment accumulation occurs more rapidly, shortening lifespan. Plant drowning likely if clogging or blockage of outlet or overflow occurs, unless rectified quickly. Erosion and scouring from high inflows.
Oversized biofilter area	Increases treatment capacity. Reduced rate of sediment accumulation, increasing lifespan and reducing clogging potential. Can help to offset a slow hydraulic conductivity.	Increased drought potential due to low inflows, particularly in zones far from inlet/s. Greater need for inclusion of a submerged zone.
High hydraulic conductivity	Increases treatment capacity. Reduced likelihood of clogging. Can offset a smaller biofilter area or reduced ponding depth.	Low water holding capacity in media, drought-stress on vegetation more likely and plant survival may not be possible without additional watering or inclusion of a submerged zone.
Low hydraulic conductivity	Greater water holding capacity to support vegetation. Can help to offset an oversized biofilter area.	Reduces treatment capacity. Clogging more likely.
Deep ponding zone	Increases treatment capacity. Can help to offset low hydraulic conductivity or small biofilter area.	Must consider public safety depending upon biofilter location – risk of drowning and tripping hazard from a drop down. Risks can be reduced with design of ledges, batter slopes or barriers/fencing, but otherwise may need to use reduced ponding depth. Risk of vegetation drowning if system clogs or outlet/overflow blocked.
Shallow ponding zone	Reduces safety risk to public.	Reduces treatment capacity.

This preliminary design should be refined and adjusted as necessary using a continuous simulation model, such as MUSIC (see Important Information box).

Design tips

- Design and model using a filter media hydraulic conductivity of half the desired value (to allow for gradual reduction in the hydraulic conductivity of the filter media over time).
- The bigger the system relative to its contributing catchment, the greater the volumetric losses will be, however this may require specification of different planting zones to accommodate different wetting and drying conditions (i.e., how often each zone receives stormwater, which will be influenced by the distance from the inlet and the height from the base of the system).
- Ideas to increase effective size:
  - Break up the catchment if space is limited.
  - Increase ponding depth (use novel design to ensure safety).
- Remember that undersizing systems might provide short-term cost savings but leaves a long-term cost legacy for the asset owner with a likelihood of higher maintenance and renewal costs due to clogging, accumulation of sediments and pollutants and potential plant death from flooding.
- Equally, avoid excessive oversizing as it can lead to more frequent drought conditions, plant death and system failure from drought. Also avoid oversizing pre-treatment devices for the same reason.
- Conversely, in the specific case of tree pits, the pit itself should be adequately sized to facilitate maintenance access for cleaning.
- Consider factoring in buffer space to the ponding zone to accommodate sediment and litter accumulation.

3.6.3 System Hydraulics

Pre-treatment (clogging prevention)

Pre-treatment facilitates removal of accumulated sediment or litter and protects against premature failure due to clogging of the filter media. As a result, **pre-treatment makes biofilter maintenance easier, improves system performance and prolongs biofilter lifespan**. Pre-treatment can be provided by a grassed buffer strip, sediment forebay, sedimentation pond or sedimentation pit/tank. **Inclusion of pre-treatment is highly recommended, as excessive sediment loading is a leading cause of failure in biofiltration systems**.

The size of the biofilter and expected sediment load will determine the need for pre-treatment. The latter is essential for biofilters with high levels of construction activity in their catchment, or other sources of high sediment or litter (e.g. unsealed road shoulders, unsecured batters, high numbers of deciduous trees), or systems that are small relative to the size of their catchment. Following the guidance from Water by Design's *Bioretention Technical Design Guidelines* (2014a), **it is recommended that pre-treatment is always included, except in the case of:**

- Biofilters that only receive roof runoff;
- Biofilters with catchments < 2 ha without identifiable sediment sources;
- In the case of biofiltration swales, the swale component is likely to provide sufficient pre-treatment to protect the biofiltration component.

Design of sediment forebays should facilitate cleaning and avoid oversizing, which can starve the biofilter of inflows, leading to stress or death of the vegetation. However, the size of the pre-treatment device will vary with the position of the system within the catchment – deeper pits or longer swales will be required closer to the catchment outlet. More detailed design procedures can be found in Water by Design's *Bioretention Technical Design Guidelines* (2014a).

Inlet Zone

Inflows to biofiltration systems may be concentrated (via a piped or kerb and channel system) or distributed (surface flow). It is important to deliver inflows so that they are uniformly distributed over the entire surface area and in a way that minimises flow velocity i.e., avoids scour and erosion, and maximises contact with the system for enhanced treatment. Therefore, distributed inflows are the preferred option, however this is not always possible. In the case of biofiltration basins, inflows are almost always concentrated. Regardless, multiple inlet points can, and should, be used wherever possible.

Critically, all inflow points should be located a maximum distance from the outflow point/s. This prevents short-circuiting of the system and ensures maximum treatment efficiency.

Comprehensive design procedures for inlet zones are given in Water by Design (2014a). However, also refer to local guidelines for design procedures and local council policies to ensure that their requirements for flow widths, etc. are met.

If inflows enter the biofilter over a flush kerb (distributed system), an area is needed for coarse sediments to accumulate. This can be achieved by having a step down, where the vegetation and filter surface are approximately 40 – 50 mm and 100 mm below the hard surface, respectively, to prevent sediment accumulation occurring upstream of the system (Figure 16). **Inclusion of a drop-down is critical to reduce the risk of blockages and allow water to enter the system.**

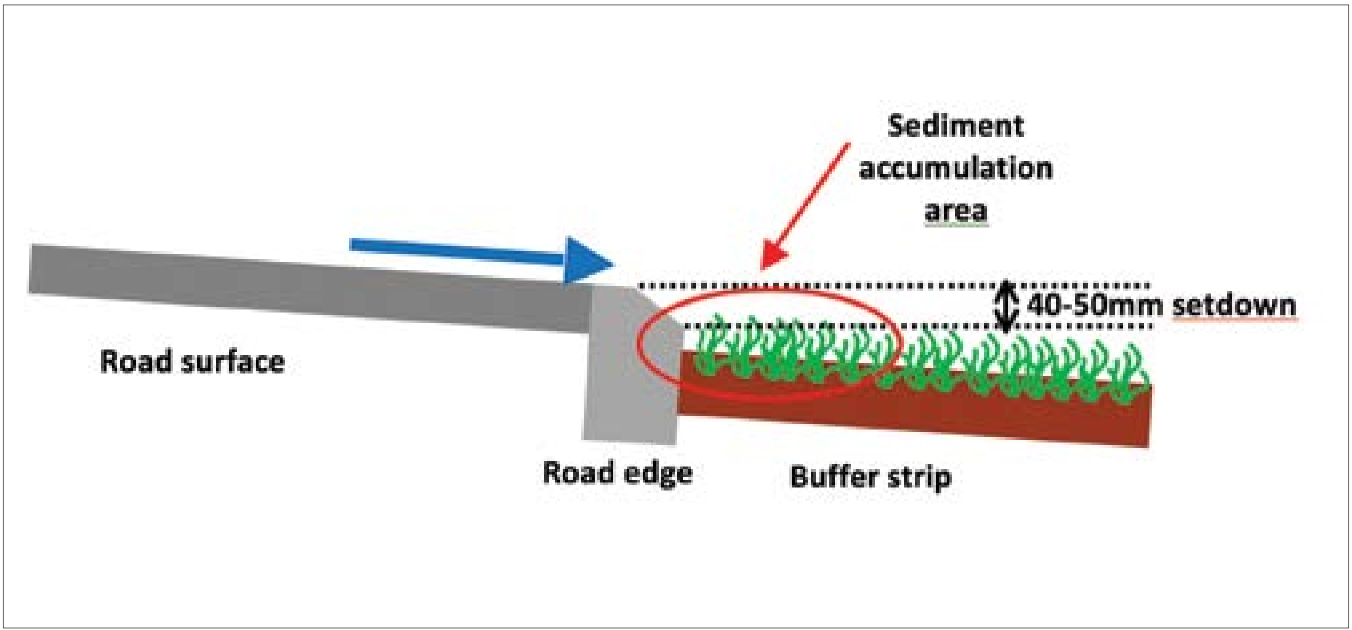


Figure 16. Edge detail of biofilter inlet zone showing setdown (source: Melbourne Water, 2005)

If the entry point(s) for flows are concentrated, the catchment is steep or incoming drains have a steep gradient, an energy dissipater and flow spreader to reduce flow velocities protect against erosion will generally be required. Options for energy dissipation include:

a. Rock beaching/impact type energy dissipation – where rocks (several of which are as large as the pipe diameter) are placed in the flow path to reduce velocities and spread flows (Figure 17 & Figure 18);

b. Dense vegetation – technical manuals suggest that planting can cope with <0.5 m/s for minor flows and < 1.0 m/s for 100 year ARI flows (Figure 18). Select robust species (e.g. sedges or rushes), able to withstand and slow incoming flows, and plant densely, leaving minimal bare ground;

c. Surcharge pit – where piped inflows can be brought to the surface. Surcharge pits need to have drainage holes in the case to avoid standing water (Figure 19) and must be accessible so that any accumulated sediment can be removed. A removable geotextile layer aids cleaning of accumulated sediment (Figure 19). It should be noted that, depending upon the catchment characteristics, surcharge pits can be prone to blockage and may require frequent cleaning; and,

d. Flow distribution channel - often perpendicular, but may be parallel traversing middle of the biofilter. In addition to protecting against scour, distribution channels also help to distribute low flows.

Design tips

- Consider the need for maintenance access when designing energy dissipation or pre-treatment structures.
- Size the inlet to reduce the risk of blockage, accounting for the size of litter washed in from the kerb. It can be removed from within the biofilter during the next maintenance check.

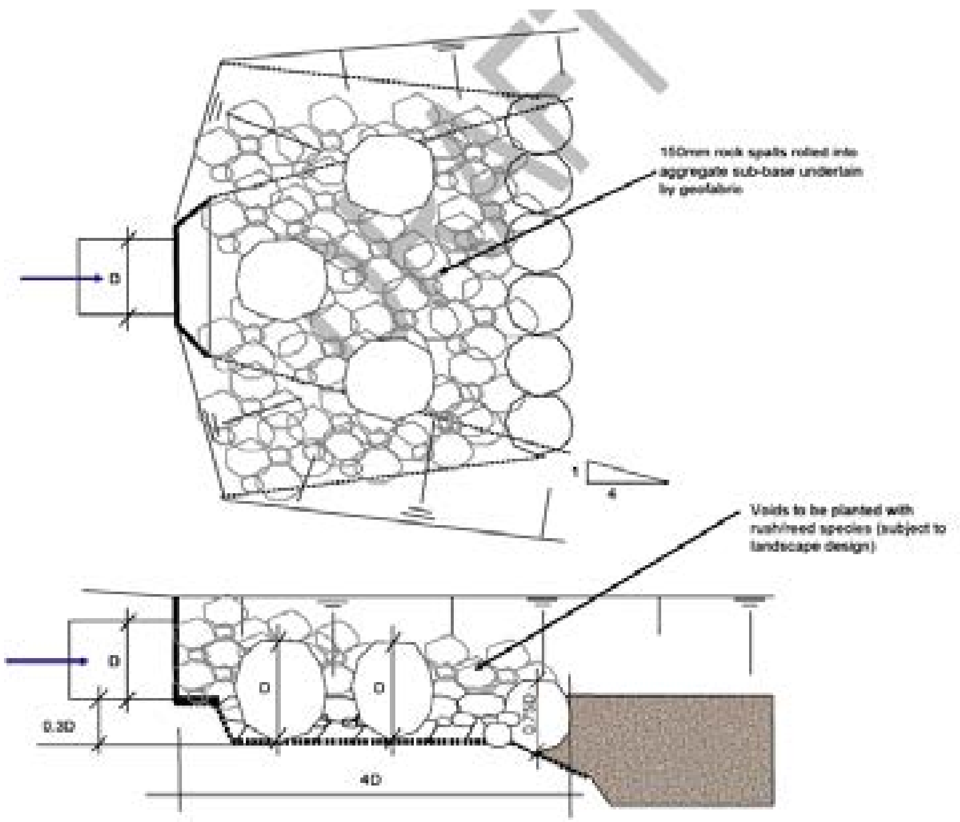


Figure 17. Rock beaching for scour protection in a biofilter receiving piped flows, where D represents the pipe diameter (source: BCC and WBWCP, 2006).

Figure 18. A rock apron (left) and dense vegetation (right) at the inlet to a biofilter can be used reduce flow velocities and prevent scour and erosion damage.

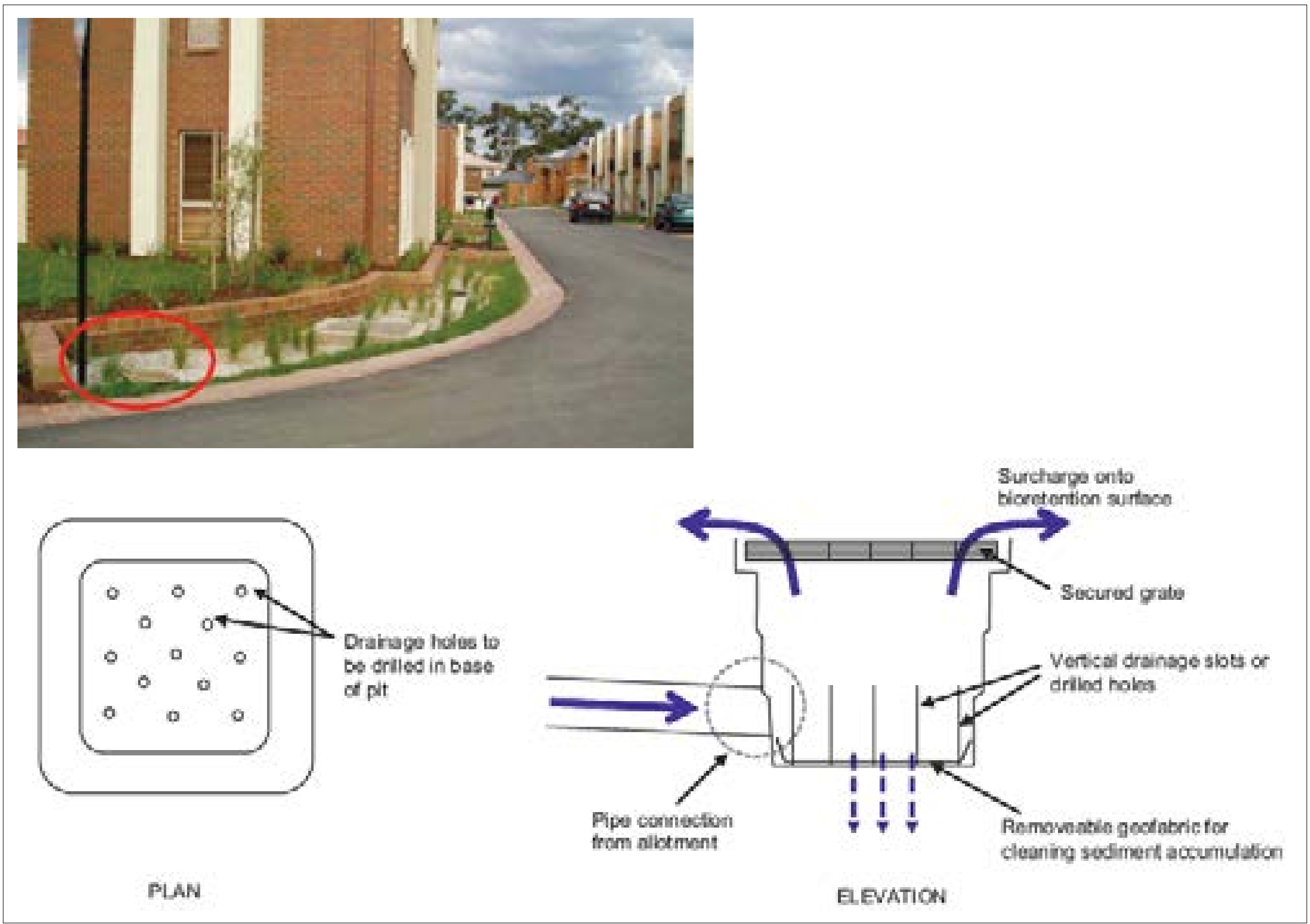


Figure 19. Surcharge inlet pit containing drainage holes at base of pit and removable geotextile layer for cleaning accumulated sediment (source: (Melbourne Water, 2005)).

Important!

The inlet zone needs to be designed by a hydraulic engineer.

Overflow or High Flow Bypass

The overflow or bypass mechanism is essential in all systems to prevent erosion and scour within the biofilter during high flow events. Even if the system is only designed for bypass during relatively rare events, blockage of outflows is a common problem and may engage the overflow mechanism. A high flow bypass is particularly vital for biofilters located within retarding basins or those receiving inflows from steep gradients.

Design of the overflow zone is different for biofiltration basins and biofiltration swales. Wherever possible, minor floods should be prevented from entering a biofiltration basin to prevent scour and erosion. Conversely, biofiltration swales are designed to convey at least the minor flood, therefore overflow provisions must be sized accordingly.

Basins. Where inflows enter the basin via a kerb and channel system, a normal side-entry pit may be located immediately downstream of the inlet to the basin (Figure 20), to act as a bypass. When the level of water in the basin reaches maximum ponding depth, flows in the kerb will simply bypass the basin and enter the downstream side entry pit. This pit should be sized to convey the minor flood to the conventional stormwater drainage network.

Where it is not possible to use a conventional side entry pit, a grated overflow pit should be located in the biofiltration basin and as close to the inlet as possible to minimise the flow path length for above-capacity flows (thus reducing the risk of scouring, Figure 20). Tapering the filter media up towards an outlet can help to prevent erosion, but this must be limited to the immediate surrounds of the outlet, not overfilling of the entire biofilter, which would compromise the ponding depth and treatment capacity.

Figure 20. A side entry pit downstream of a biofiltration tree pit accepts high flows that bypass the tree pit (left) while a grated inlet pit close to the inlet of a biofiltration basin conveys above-design flows to the conventional drainage network (right).

Design tips

- Where a grated overflow pit in the basin is used, flow velocities in the basin need to be checked to avoid scour of the filter media and vegetation. Technical manuals suggest planting can cope with < 0.5 m/s for minor flows and < 1.0 - 1.5 m/s for 100 year ARI flows.
- Ensure that the full ponding depth is provided by setting the level of the overflow at the same level as the maximum ponding depth.

Swales. Overflow pits are required where the flow capacity of the swale is exceeded; these are generally located at the downstream end of the swale, but may need to be staggered along the system (creating a series of segments along the swale), depending on the length of the swale. Refer to local engineering procedures for guidance on locating overflow pits.

Important!

The overflow zone needs to be designed by a hydraulic engineer.

Raised outlet to create a submerged zone

The submerged zone (also referred to as a submerged zone) serves multiple roles in biofilter function including:

- Supporting plant and microbial communities across extended dry periods
- Helping to maintain pollutant removal capacity across extended dry periods (nitrogen removal in particular)
- Enhancing removal of some pollutants, particularly nitrogen, relative to free draining designs
- Providing prolonged retention for a volume of water between inflow events, which allows ongoing processing and drawdown by evapotranspiration
- Reducing differences in nitrogen removal performance between different plant species, which can help buffer against poor plant choice
- Reducing the head requirement for a given biofilter depth
- Promotes exfiltration (if systems is unlined with a raised outlet)

Submerged zones are particularly essential for systems that are unavoidably shallow or over-sized, in low rainfall areas or when nitrogen or pathogen removal is a key objective.

The submerged zone is created using an upturned outlet and is strongly recommended for all designs, both lined and unlined, except simple unlined systems without an outlet. It allows ponding in the lower layers of the biofilter (within the transition and drainage layers) (Figure 25), which is temporary in unlined systems (appropriate in wet climates) and longer-lasting if a liner is installed (recommended in dry climates, which commonly experience > 3 weeks of dry).

In the case of unlined systems, longevity of the submerged zone following an inflow event will be influenced by the hydraulic conductivity of surrounding soils. Exfiltration will be rapid into sandy soils, yet considerably more permanent if heavy clay soils with very low hydraulic conductivity surround the base of the biofilter. In fact, some clay soils can effectively act as a liner.

Hybrid designs are also possible, such as the bioinfiltration shown in Section 3.5.4. Alternatively, an experimental biofilter constructed by Ku-ring-gai Council included both lined and unlined zones. This allowed pooling of water in some sections, while other zones permitted infiltration into surrounding soils (Jonasson and Findlay, 2012). The design harnessed the benefits of both exfiltration and water retention, and achieved good reductions for nitrogen and phosphorus.

1. Submerged zone material

The submerged zone should be located within the transition and drainage layers of the biofilter. Specifications for these media layers are given in Table 13. A carbon source if also often included mixed throughout lined submerged zones (see further below).

2. Submerged zone depth

The depth of the submerged zone must be deep enough to provide optimal water treatment and drought resilience. Increased depth will require less maintenance to top-up the submerged zone or irrigate the biofilter during prolonged dry periods. A submerged zone depth of 450-500 mm is recommended for optimal performance (Zinger et al., 2007).

At a bare minimum a depth of 300 mm is required.

For stormwater harvesting applications it is important to design a submerged zone that is deep enough to retain a large proportion, or the entire, inflow event. This provides ongoing treatment that is particularly beneficial for pathogen and nitrogen removal. This is discussed further in Section 3.6.7, which included an analysis using MUSIC to determine the minimum submerged zone depth to capture a median rainfall event for different capital cities. However, the depth must also be designed for drought resilience, and an estimate of the time required to draw down the submerged zone in periods of high evapotranspiration demand can be used (Equation 1). The submerged zone should be filled as required, either via surface irrigation or direct filling.

Design tips

Estimating the time required for submerged zone drawdown during peak summer months:

$$\text{Drawdown period for submerged zone} = \frac{\text{Porosity x Depth}}{\text{Daily Evapotranspiration}}$$

Equation 1. Calculation of estimated rate of submerged zone drawdown

where:

Submerged zone drawdown period – (days)

Porosity – estimated porosity of submerged zone material (combination of sand transition and fine aggregate drainage layers) A porosity of 0.4 is suggested.

Depth – depth of submerged zone (mm)

Daily Evapotranspiration – rate specific to local area (mm/day). Use local measurements of pan evapotranspiration (in mm/month – convert to daily), taking care to select a value for areal actual evapotranspiration for the month of interest, at http://www.bom.gov.au/jsp/ncc/climate_averages/evapotranspiration/index.jsp

In some systems the outlet from the submerged zone can be configured to allow variation in depth of the zone. This can be achieved using a series of outlet valves on a fixed pipe, or using flexible pipe which can be raised or lowered within the outlet pit. This flexibility can allow the submerged zone depth to be raised to closer to the surface to assist seedling establishment. It can then be lowered as plant root zones extend.

Design tips

- Inclusion of a raised outlet, to create either a temporary (if unlined) or longer-lasting (if lined) submerged zone, is strongly recommended in all biofilter designs with an outlet.
- The submerged zone is vital to help plant survival during dry seasons, improve stormwater quality treatment (particularly nitrogen and pathogen removal), provide hydrological due to its prolonged retention, help reduce performance differences between plant species and provide conditions for denitrification to occur. In unlined systems, the raised outlet helps to promote exfiltration into surrounding soils.
- Since the invert of the outlet pipe in a biofilter containing a submerged zone is raised above the bottom of the system, this can assist in achieving a suitable filter depth where the available depth to the underdrain invert is limited.

Underdrain

The use of an underdrain and outlet will depend upon treatment objectives and site conditions. It may not be required in all unlined systems where infiltration is a key objective, and in some cases the aggregate drainage layer itself may provide sufficient drainage to outlet piping (see below for further details). However, use of perforated underdrains will facilitate drainage of the system and will be a particularly important component in systems that are large, lined, harvest stormwater, or where surrounding soils are heavy clay with slow infiltration rates (for example, see CSIRO's SoilMapp for local soils information).

Slotted PVC pipes are preferable to flexible perforated ag-pipe, as they are easier to inspect and clean and ribbed pipes are likely to retain moisture which might attract plant roots into pipes. In addition, blockages within ag-pipes cannot be readily inspected for blockages using pipe snakes. Slots can be created manually on site.

The upstream end of the collection pipe should extend to the surface to allow inspection and maintenance; the vertical section of the pipe should be unperforated and capped (Figure 25). Where more than one collection pipe is required, these should be spaced no further than 1.5 m apart.

The following need to be checked:

a. Perforations in pipe are adequate to pass the maximum infiltration rate.

b. Pipe has sufficient capacity to convey the treated water; this component should be oversized to ensure that it does not become a choke in the system.

c. The pipe is suitably surrounded by, and covered by, drainage layer material to prevent intrusion of fine particles.

d. Material in the drainage layer will not wash into the perforated pipes.

e. Perforations should be horizontal (i.e., perpendicular to the pipe) and not vertical (or parallel) along the length of the pipe. This will facilitate entry of water into the pipe.

f. Design pipe bends to be 45o, rather than 90o, to facilitate inspection and clearance of blockages (Figure 21)

Positioning and slope of the underdrain will vary with treatment objectives and design configuration:

For unlined systems with raised outlet promoting exfiltration:

In order to promote exfiltration into the surrounding soils, the collection pipe can be raised from the bottom of the drainage layer. In this case, the depth of the drainage layer = 50 mm pipe cover + pipe diameter + depth from invert of pipe to bottom of drainage layer (Figure 21). However, the collection pipe must still be sized to convey the maximum infiltration rate, as described above, to ensure that the system will be operational even without exfiltration (i.e., in case the bottom of the system clogs).

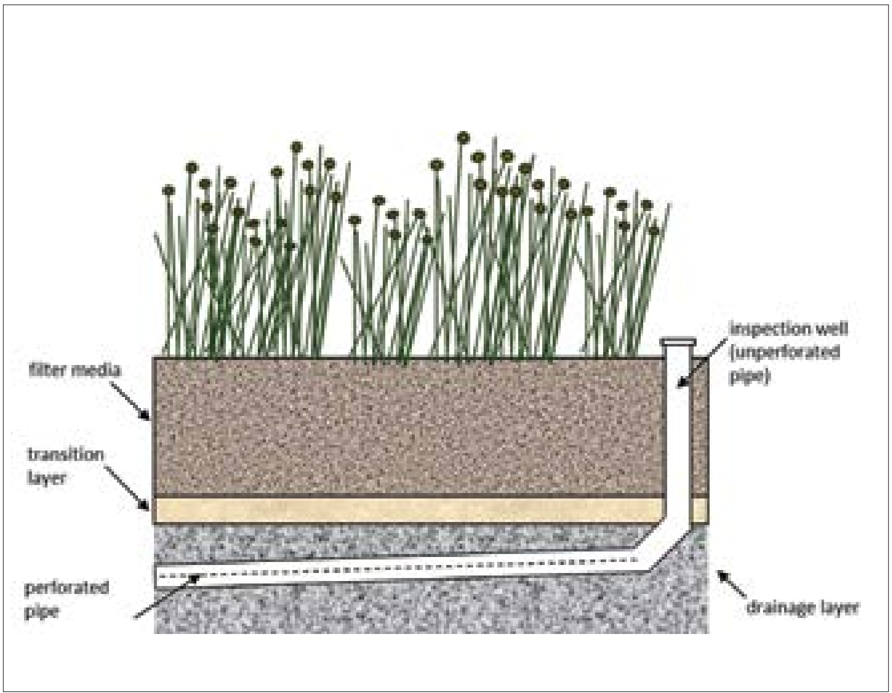


Figure 21. Long section of a biofilter showing collection pipe raise above bottom of drainage layer to promote exfiltration. Note series of 45° elbows rather than 90° elbows, to facilitate entry of maintenance equipment (e.g. pipe snake or water jet). Also note that perforated pipes do not necessarily need to be laid on a slope

For lined biofilters with longer-lasting submerged zone:

There are two possible configurations:

1. Perforated collection pipe with riser outlet

In this configuration, the collection pipe(s) is placed in the drainage layer with an elbow to create a riser outlet to raise the invert (Figure 22). The collection pipe(s) does not need to be sloped as the outlet is elevated.

2. Riser outlet only (no collection pipe)

A collection pipe is not strictly necessary in a biofilter with a submerged zone; inclusion of a riser outlet confines exit flow to a course via this path and the drainage layer can act as a surrogate collection pipe (Figure 23). The riser outlet should extend to the surface to allow inspection and maintenance.

The following need to be checked:

a. Pipe has sufficient capacity to convey the treated water; this component should be oversized to ensure it does not become a choke in the system.

b. Material in the drainage layer will not wash into the riser outlet.

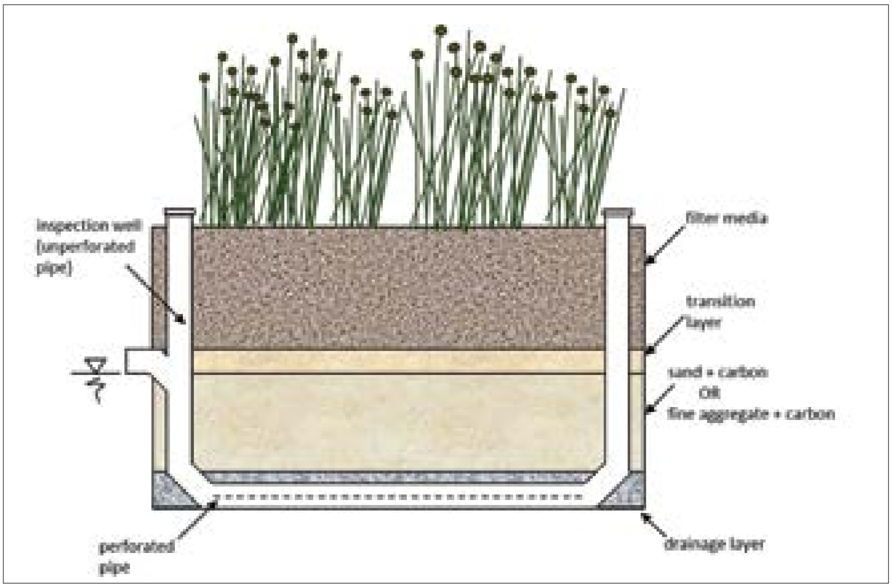


Figure 22. Long section of a biofilter with a submerged zone showing collection pipe and riser outlet (Note that, in this system, the transition layer is between the filter media and submerged zone). Note series of 45° elbows rather than 90° elbows, to facilitate entry of maintenance equipment (e.g. pipe snake or water jet)

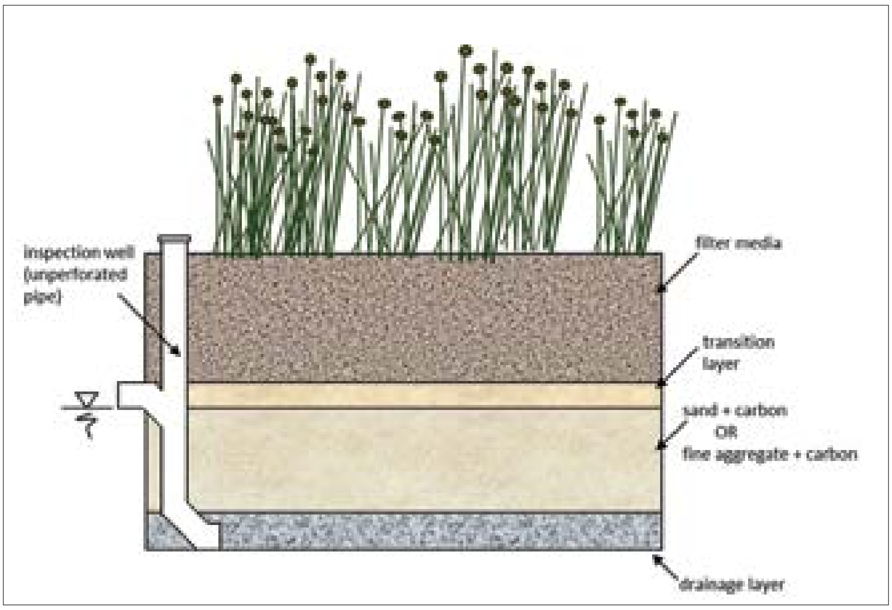


Figure 23. Long section of a biofilter with a submerged zone showing riser outlet (Note that, in this system, the transition layer is between the filter media and submerged zone). An appropriate screen should be placed over the outlet pipe entry in the drainage layer, to prevent ingress of the fine aggregate

Design tips

- Use slotted PVC pipe (can be manually slotted on-site) instead of ag-pipes, which are more difficult to inspect and maintain.
- The perforations in the collection pipes should be small enough that the drainage layer cannot fall into the pipes. A useful guide, or method, is to check to that the D_{85} (drainage layer) is greater than the pipe perforation diameter.
- Use 45° connectors to soften the bends in the collection pipe(s) for easier maintenance access.
- Place screen over entry into outlet pipe in fine aggregate drainage layer, to avoid ingress of aggregate into pipe.

Outlet

The underdrain will connect to an outlet, which may simply involve connection to a stormwater drainage pipe, or an outlet collection pit may be present at pipe junctions. If present, it is important to oversize outlet pits to allow easy access for maintenance. For detailed design procedures refer to Water by Design (2014a) or other local design guidelines.

Outlet pits may also serve as the overflow pit, but this is only desirable for biofilter basins that are offline and protected from damaging high flows. In contrast, biofilter swales should instead be designed to bypass high flows before they enter the system.

It is strongly recommended that all outlets are raised, primarily to provide sufficient moisture retention to support plant growth, but also for multiple additional benefits, irrespective of whether the system is unlined or lined (see Submerged Zone Section).

Liner

Biofilters may or may not be lined, depending upon treatment objectives and site conditions. A liner may not be incorporated into systems where exfiltration of treated water to the surrounding soils is a key objective. It also may not be necessary in areas of heavy clay soils with very hydraulic conductivity. **Impermeable liners, either on the full perimeter of the system or only one section, allow biofilters to be constructed in proximity to sensitive structures**, where infiltration near footings or foundations is a concern. To determine if this is necessary refer to the offset distances provided in *Australian Runoff Quality* (Wong, 2006). Liners are also necessary to incorporate a longer-lasting submerged zone is required (i.e. in dry climates), or if stormwater harvesting is an objective.

The following are feasible options for lining a biofilter, where an impermeable liner is necessary:

1. Compacted clay

Where the hydraulic conductivity of the surrounding soil is naturally very low (i.e., the saturated hydraulic conductivity of the native soil is 1 – 2 orders of magnitude less than that of the filter media) flow will preferentially be to the underdrain and little exfiltration will occur (see information sources such as CSIRO's Soil Mapp application for local soils data). Here, it may be deemed sufficient to compact the sides and bottoms of the system.

2. Flexible membrane

A heavy duty flexible membrane, such as high-density polyethylene (HDPE), can be used to line the base and sides of the drainage layer. It is unlikely that sides higher than this will need to be lined, as flow through the biofilter will preferentially be vertical and there is little opportunity for exfiltration through the sides of the system.

Important!

A raised outlet to create a submerged zone, even if only temporary, is recommended in all biofilter designs with an outlet, irrespective of the presence or absence of a liner.

Design tips

- Use unlined systems wherever possible in wetter climates as this will allow exfiltration to surrounding soils, increasing groundwater recharge and facilitating further water treatment, thus providing better outcomes in terms of reducing flows and improving water quality.
- Where an impermeable liner is not required, geotextile can be used to line the walls and delineate the system from the surrounding soils, however this is optional.
- In dry climates lining the submerged zone is strongly recommended to provide a longer-lasting moisture retention to support vegetation (alternatively, the system may be left unlined if surrounding soils are slow draining clays that can essentially act as a liner).
- Other approaches to lining biofilters that have been successfully used include:
  - spraycrete concrete coating (this is more expensive but useful in rocky areas where plastic liners may be punctured)
  - the use of modular biofilters

Biofilter Swales

Specific issues to consider in the design of biofilter swales include:

- Check dams (located at regular intervals along the swale) will be required in steeper areas to control flow velocities and to maximise the opportunity for infiltration to occur.
- In flat areas, it is important to ensure adequate drainage to avoid prolonged ponding.
- Where biofilter swales are installed in median strips, pedestrian crossings must be incorporated.
- Where biofilter swales are installed in nature strips/ verges, driveway crossings must be incorporated, and consideration for interaction with other services must be given, at the start of the design process.

Conveyance (Swales only)

The efficient passage of stormwater through a biofiltration system is core to its treatment function.

Design tips

- Design the swale component first when designing a biofiltration swale, as it will determine the available dimensions for the biofiltration component. Refer to local engineering procedures for the design procedure and guidance on suitable flow velocities.
- Consider site gradients and pipe invert levels early in design to guide decisions on system depth, drainage, inflow and outflow configurations.
- Provide flow arrows on system diagrams to illustrate the designed hydraulic function to the construction and landscaping teams. This should be in addition to checks throughout the construction process (Section 4.2)

Walls and bunds (if present)

The need for walls (earthen or rock) and bunds will depend upon site topography, geology and drainage (e.g. steep sites or systems that are online). When designing these features it is critical to ensure water-tight sealing to prevent preferential flow paths and erosion. This is particularly crucial at the interfaces of flow structures with the filter media, and points where pipes pass through walls (discussed further in Section 4.2). Rock walls and bunds will also add substantially to the project cost, and can dwarf the cost of the biofilter itself (which in some cases may only comprise 10-15% of the total budget).

3.6.4 Media

Filter 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.

Full specifications for biofilter media are described in the Guidelines for Filter Media in Biofiltration Systems (Appendix C, but noting that the **most recent version** of these guidelines should always be consulted). Each media layer within a biofilter serves an important role in the treatment of stormwater runoff (Figure 25). A summary of the key specifications for each layer of material is given in Table 13. Some requirements are essential specifications (highlighted in blue), while other characteristics are only recommended to provide guidance for the selection of appropriate materials (highlighted in grey). The rationale(s) for each requirement are also given in the table. Readers are referred to Appendix C for further discussion and clarification of the media requirements.

Media layers

The biofiltration filter media guidelines require three layers of media: the filter media itself (400 600 mm deep or as specified in the engineering design), a transition layer (≥ 100 mm deep), and a drainage layer (≥ 50 mm cover over underdrainage pipe). The biofilter will operate so that water will infiltrate into the filter media and move vertically down through the profile. The material used for each of these layers must to meet essential specifications to ensure they serve their intended purpose (outlined in Table 1).
For the system to drain appropriately, it is also important that the underlying transition layer has a higher hydraulic conductivity than the filter media, and in turn the drainage layer at the base should have the highest hydraulic conductivity. Importantly, the use of geotextile fabrics between layer interfaces is not recommended, due to risk of clogging. Provision of mulch across the biofilter surface is also not recommended as it hinders maintenance for sediment removal, can restrict plant growth and spread, and clog the overflow.

Application of a thin additional layer of sand of higher porosity overlying the filter media, known as a 'protective layer', can delay the onset of clogging and enhance performance. The concept has been trialled successfully in lab studies and is currently undergoing field testing before it is recommended more generally in biofilter designs. Further details can be found in a separate section below.

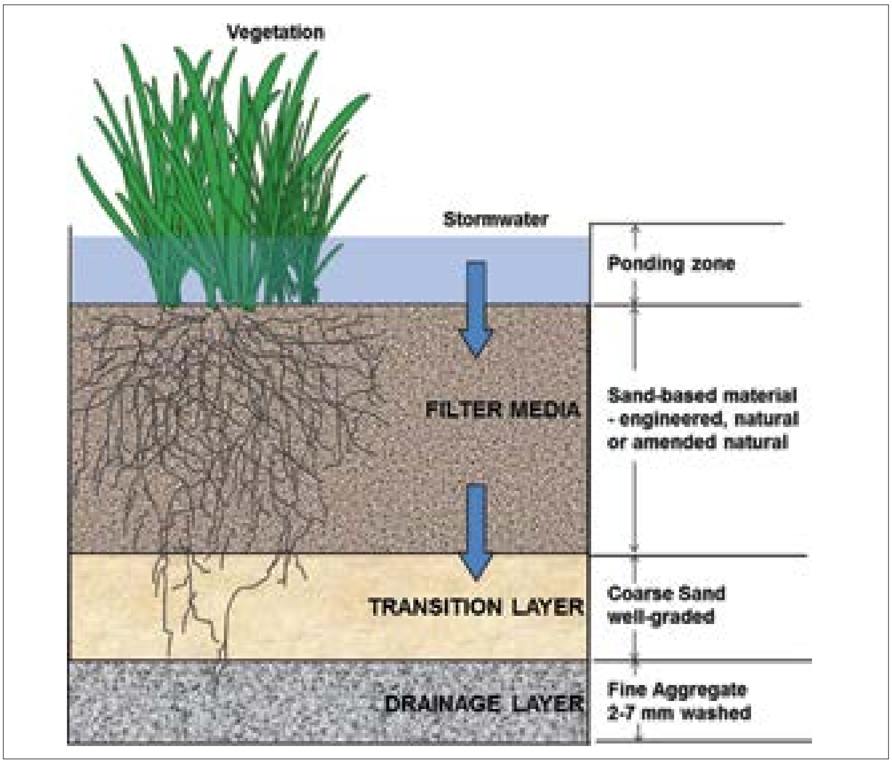


Figure 24. Layers within a biofilter and their function in the treatment of stormwater

Stormwater

Enters the biofilter, can pond temporarily and infiltrate downwards through the media layers. The hydraulic conductivity should increase with each underlying layer of media, allowing the system to drain. Physical, chemical and biological processes act to remove pollutants before the treated water is either collected, discharged or exfiltrated into surrounding soils.

Vegetation

Without plants, the biofilter won't function effectively for pollutant removal

Ponding zone

Increases the treatment capacity by allowing stormwater to temporarily pond before it infiltrates downwards.

Filter media

- Allows infiltration of stormwater at a suitable rate
- Provides a growing medium for vegetation
- Designed to help remove pollutants from the stormwater, so must not leach nutrients itself (i.e. low nutrient content)
- Must be structurally stable

Transition layer

Prevents filter media washing down into the drainage layer – reduces the vertical migration of fine particles

Drainage layer

Allows the system to drain, either into an underdrain or outflow point, or provides storage before exfiltration into surrounding soils (if the biofilter is unlined)

Submerged zone

The submerged zone is created by an upturned outlet pipe, allowing saturation of the lower filter layers (within the transition and drainage layers) and storing some stormwater in the pore water between inflow events. It supports plants and microbes across dry periods and helps to improve pollutant removal, particularly for nitrogen. It will be temporary in unlined systems but longer lasting if combined with a liner.

Carbon source (if present with submerged zone)

The carbon source is mixed throughout the media within the submerged zone if a liner is present and can help to further improve nitrogen removal

Table 13. Essential and recommended media requirements

<table>
<tr><th></th><th>Property</th><th>Specification to be met</th><th>Why is this important to biofilter function?</th></tr>
<tr><td colspan="4">Filter media (top layer/growing media)</td></tr>
<tr><td rowspan="9">ESSENTIAL SPECIFICATIONS</td><td>Material</td><td>Either an engineered material - a washed, well-graded sand - or naturally occurring sand, possibly a mixture</td><td>Media must be sand-based (and not a loam) to ensure adequate hydraulic conductivity, low nutrient content and structural stability.</td></tr>
<tr><td>Hydraulic conductivity</td><td>100 – 300 mm/hr (higher in tropical regions but must be capable of supporting plant growth).
Refer to Appendix C for more details.
Determine using ASTM F1815-11 method</td><td>Provides adequate capacity to treat a higher proportion of incoming stormwater.
Testing method best represents field conditions.</td></tr>
<tr><td>Clay & silt content</td><td>< 3% (w/w)</td><td>Above this threshold hydraulic conductivity is substantially reduced. Too many very fine particles also reduce structural stability leading to migration and leaching.</td></tr>
<tr><td>Grading of particles</td><td>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)</td><td>Provides a stable media, avoiding structural collapse from downwards migration of fine particles.</td></tr>
<tr><td>Nutrient content</td><td>Low nutrient content
Total Nitrogen (TN) < 1000 mg/kg
Available phosphate (Colwell) < 80 mg/kg</td><td>Prevents leaching of nutrients from the media.</td></tr>
<tr><td>Organic matter content</td><td>Minimum content ≤ 5% to support vegetation.</td><td>Although some organic matter helps to retain moisture for vegetation and can benefit pollutant removal, higher levels will lead to nutrient leaching.</td></tr>
<tr><td>pH</td><td>5.5 – 7.5 – as specified for ‘natural soils and soil blends’ in AS4419 – 2003 (pH 1:5 in water)</td><td rowspan="3">To support healthy vegetation over the long-term – without which the biofilter cannot function effectively.</td></tr>
<tr><td>Electrical conductivity</td><td>< 1.2 dS/m - as specified for ‘natural soils and soil blends’ in AS4419 – 2003</td></tr>
<tr><td>Horticultural suitability</td><td>Assessment by horticulturalist – media must be capable of supporting healthy vegetation.
Note that additional nutrients are delivered with incoming stormwater.</td></tr>
</table>

Cont.

Table 13. Continued

	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 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 to 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 PSD 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.
	Protective surface layer	Include a surface layer 100-150 mm deep overlying the biofilter media. Use a coarser particle size of higher infiltration rate than the filter media, generally commercially available sands.	Lab studies have demonstrated the potential for this layer to delay clogging and improve treatment performance. Currently being tested in the field.
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): D15 (transition layer) ≤ 5 x D85 (filter media) where: D15 (transition layer) is the 15th percentile particle size in the transition layer material (i.e.,15% of the sand is smaller than D15 mm), and D85 (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

Cont.

Table 13. Continued

	Property	Specification to be met	Why is this important to biofilter function?
		Bridging criteria only in designs where transition layer is omitted ((Water by Design, 2009); ((VicRoads, 2004): D15 (drainage layer) ≤ 5 x D85 (filter media) D15 (drainage layer) = 5 to 20 x D15 (filter media) D50 (drainage layer < 25 x D50 (filter media) D60 (drainage layer) < 20 x D10 (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)
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 D15 (drainage layer) ≤ 5 x D85 (transition media) where: D15 (drainage layer) - 15th percentile particle size in the drainage layer material (i.e., 15% of the aggregate is smaller than D15 mm), and D85 (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: D85 (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

Sustainability tip

In some areas, it may be feasible to construct a filter medium from the in situ soil, although some amendments are likely to be required, to ensure that the resulting medium complies with the Guidelines for Filter Media in Biofiltration Systems (see Appendix C).

Design tips

- Typical filter media hydraulic conductivity: 100 – 300 mm/hr
- Must demonstrate prescribed hydraulic conductivity
- Test to ensure the filter media will remain permeable under compaction
- < 3% silt and clay
- Does not leach nutrients
- Ensure EC and pH is in the range for healthy plant growth
- Do not use geotextile fabrics within media layers as these have a tendency to cause clogging
- If media with a particularly high infiltration rate (e.g. washed sand or coarse river sand) is used, other mechanisms must be incorporated into the design, or site conditions must be sufficiently favourable, to ensure adequate soil moisture retention to support plants. Alternative design options include:
  - the use of deeper media
  - soil additives (see above)
  - selection of particularly drought-tolerant plant species
  - inclusion of a raised outlet to create a submerged zone (in both unlined and lined systems, but in dry climates (> 3 week dry periods are common) the liner is recommended to provide a longer-lasting submerged zone)

1. **Drainage layer depth**

For biofilters with an underdrain:

Where there is no underdrain, the aggregate layer acts to drain the system. Where there is an underdrain present, depth of the drainage layer will be determined by the underdrainage pipe diameter, minimum pipe cover, the slope of the underdrain (if sloped; perforated pipes can be laid flat) and the length of system being drained. In general, the minimum pipe cover of the fine aggregate drainage layer should be 50 mm, to avoid ingress of the sand transition layer into the pipe. For example, for a biofiltration system with a collection pipe diameter of 100 mm that is 10 m long and on a slope of 1%, the drainage layer would be 150 mm deep at the upstream end and 300 mm deep at the downstream end (Figure 25).

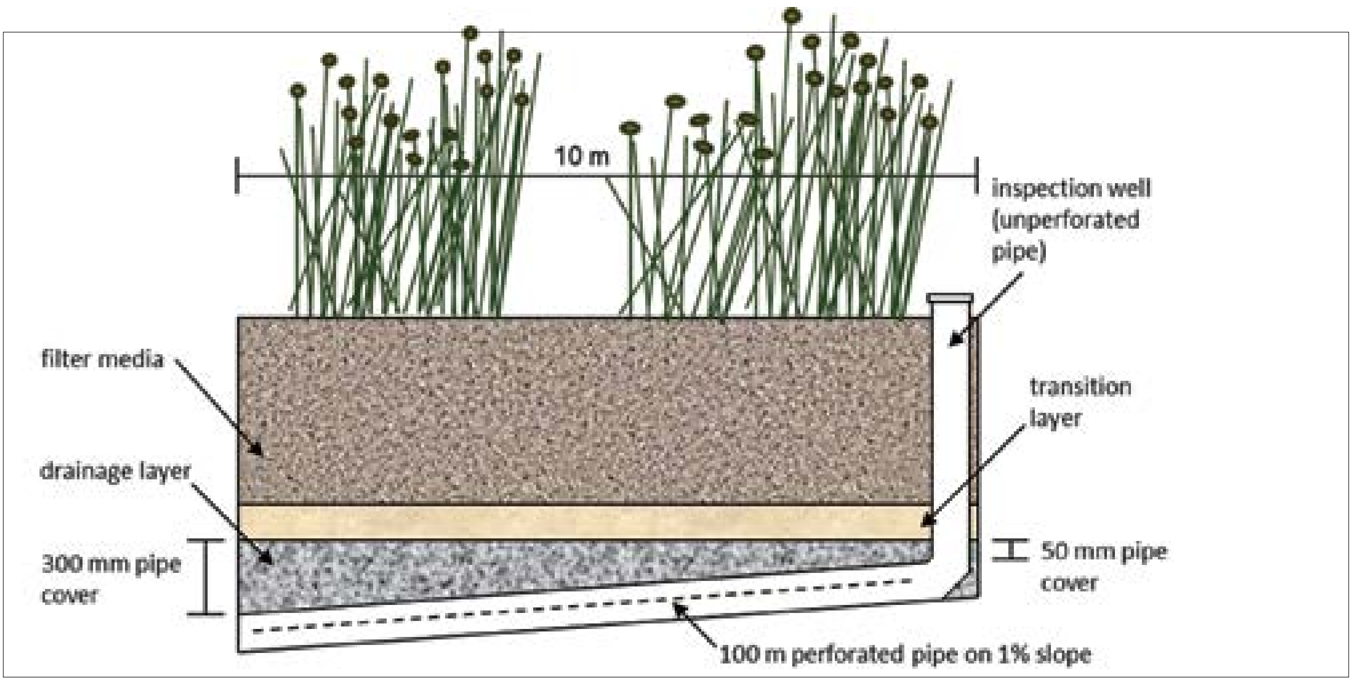


Figure 25. Long-section of a biofilter showing variable drainage layer depth. Also note that perforated pipes can be laid flat.

For biofilters that allow exfiltration (without liner):

In the absence of a liner, the drainage layer acts also as a storage zone, in that treated water is temporarily retained in this zone and then released into underlying soils via exfiltration (Figure 26). In this case, depth of the fine aggregate layer should be determined using modelling to determine the required depth to ensure performance targets (e.g. reductions in pollutant load, runoff volume and/or frequency) are met (Figure 26). As a general guide, the storage zone needs to be at least as large as the ponding volume, and preferably larger, to ensure that the filter media does not become saturated after consecutive rainfall events (i.e., where the storage zone has not emptied between rainfall events).

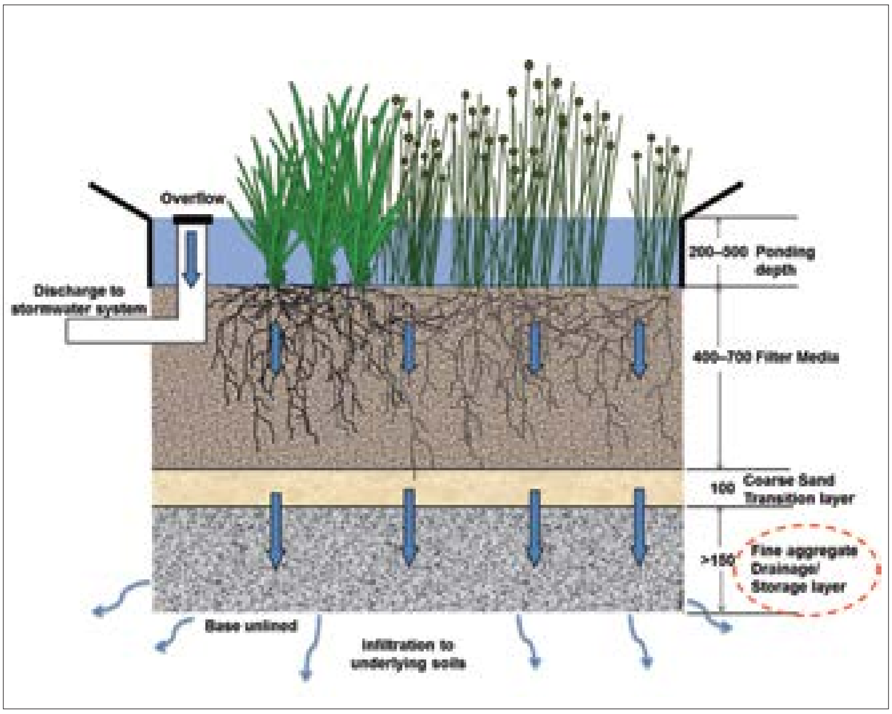
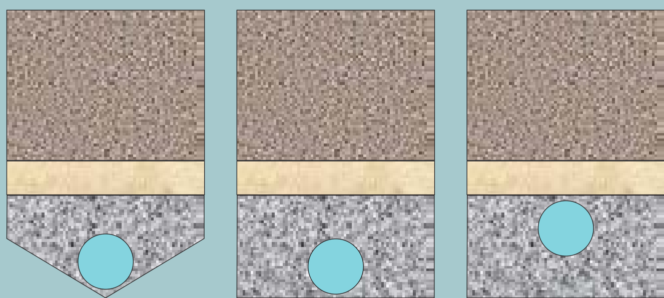


Figure 26. Use of the aggregate drainage layer as a storage zone in a biofiltration system without underdrain.

Design tip

Shaping of the bottom of system: if a design objective is to collect as much water as possible, the bottom of the system should be shaped to define a flow path towards the underdrain (left). However, if the goal is to exfiltrate water to the surrounding soil, then the bottom of system should be flat (centre), particularly if the pipe is raised above the bottom of the system.



Important!

Geotextile fabrics are a clogging risk and are **not** recommended anywhere within the filter profile (i.e., to separate layers) or around drainage pipes due to the risk of clogging.

Carbon Source

If a more enduring submerged zone is created using a liner, a carbon source is also recommended. This is mixed throughout the submerged layers and provides electrons to drive denitrification (a key nitrogen removal process). The carbon source should decompose in the first or second year of operation, while plant roots develop (which provide carbon over the longer term).

The carbon source should comprise approximately 5% (v/v) and include a mixture of mulch and hardwood chips (approximately 6 mm grading), by volume. The carbon source material needs to be low in nutrients; appropriate materials include sugar cane mulch, pine chips (without bark), 6-10 mm hardwood chips, and pine flour ('sawdust'). High nutrient sources such as pea straw (derived from nitrogen-fixing plants) should be avoided, as these are likely to leach nitrogen and phosphorus, negating the benefits of including a submerged zone. In addition, straw should not be used as a carbon source, due to reports of odours emanating from some systems using straw.

The carbon source is commonly provided separately to the media in bags, and it can be mixed in on site (e.g. using a rotary hoe).

Design tip

Typical recipe for submerged zone filter media (per 100 L):

- 98 L sand or fine aggregate (by volume)
- 500 g readily biodegradeable material such as sugar-cane mulch (i.e., low in nitrogen and phosphorus)
- 1.5 kg wood chips

Sustainability tip

Recycled timber (must not be chemically treated) or hardwood chips from sustainable sources (e.g. certified plantations) should be specified for the carbon source.

Designing to prevent clogging

As biofilters work to filter sediment and pollutants from stormwater, they will inevitably accumulate fine particles over time. This gradually reduces the infiltration rate over time, eventually leading to clogging and greatly reduced treatment capacity. Most clogging happens in the surface layer and can be removed by scraping off and replacing the surface layer of media as required (discussed further in monitoring and maintenance, Section 4.3).

However, good design can also help to delay the onset of clogging, prolonging biofilter lifespan and improving stormwater treatment performance. Clogging is closely related to particle sizes within the biofilter media. Laboratory studies have found that clogging can be significantly reduced by having two distinctly different layers of particle sizes, with a coarse upper layer overlying the biofilter media (Kandra et al., 2014). Including this overlying layer of higher porosity protects the finer media below from sediment, leading to better performance - in terms of both volume of stormwater treated and sediment removed - than in the case of a single layer of media.

Recently, more laboratory trials have been carried out to assess the benefits of including a protective layer of distinct particle size distribution and 100 mm thickness above the biofilter media. This protective layer comprises a commercially-available sand-based product (including engineered sands). Using accelerated dosing, these types of designs maintained significantly higher outflow rates in the longer-term relative to designs without a protective surface layer (Hatt, 2014). These designs are undergoing testing in the field, but the laboratory trials demonstrate the potential for a potential surface layer to prolong biofilter lifespan and reduce clogging.

3.6.5 Vegetation

Role of plants

Plants are an essential component of biofilters. Numerous studies have demonstrated the superior performance of planted biofilters compared with that of non-vegetated filters. Plants are particularly critical for nitrogen removal and maintaining the infiltration capacity of biofilters (Figure 27). Plants also provide additional benefits within the urban environment, including improving amenity, creating green spaces, enhancing biodiversity and habitat, and providing microclimate benefits, which are associated with considerable human health and economic benefits (see Chapter 2 for further discussion).

Why is plant species selection important? Not all plant species will perform identically, and nitrogen removal is particularly sensitive to plant species selection. Other common stormwater contaminants benefit from the presence of plants, yet are less sensitive to the selection of plant species. In addition, biofilter performance and plant survival are dictated by climatic variation and shifts between wet and dry conditions. The system aesthetics are also governed by the chosen vegetation and its layout, and attractiveness of the biofilter is critical for community engagement and support. As a result, designing biofilter vegetation requires careful consideration of species selection, diversity, planting density and layout; all in light of the treatment objectives, the local climate and surrounding landscape. At the construction stage, timing of planting is vital, as well as management of plant establishment. These early stages in biofilter life will be vital to its long-term performance and maintenance or renewal requirements. These key issues have been outlined in the sub-sections below, and construction and establishment are additionally discussed in Section 4.2.

Much of the relevant research summarised below was originally collated in the *'Vegetation guidelines for stormwater biofilters in the South West of Western Australia'* (Monash Water for Liveability Centre et al., 2014b, a). These guidelines form a comprehensive guide for biofilter plant selection, incorporating practical considerations, extensive planting lists and explanation of the background science. Readers are referred to these guidelines for more extensive guidance on plant selection for stormwater biofilters.

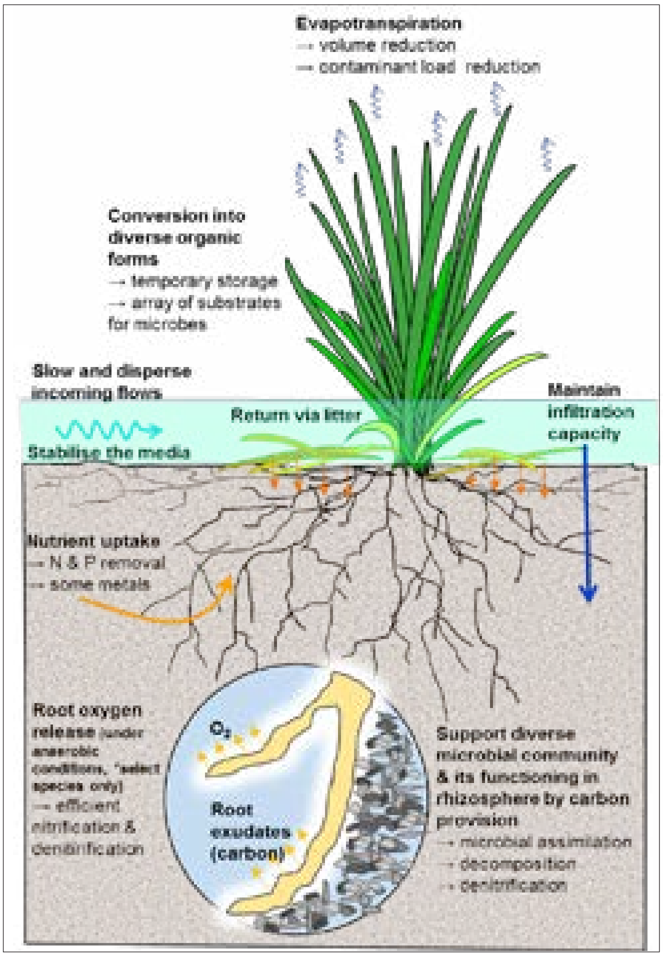


Figure 27. Multiple roles served by plants in water treatment processes within biofilters

Plant species selection

Plant species should be selected to meet the specific objectives defined for each individual system. The guiding principles for plant selection are to:

i. Use species capable of survival in sandy and low nutrient media, intermittent inundation and prolonged dry periods;

ii. Use species that are compatible with the local climate and surrounding vegetation;

iii. Include a mixture of species to provide resilience;

iv. Incorporate at least 50% of species with effective characteristics (Table 14 and Table 15) to meet treatment objectives; and,

v. Select the remaining species to meet additional objectives such as enhanced aesthetics, biodiversity, habitat or shading.

Key plant species characteristics to meet various treatment objectives are summarised in Table 14, while the list of known effective (or conversely, poorer performing) species is given in Table 15. Plant species selection should be guided by these principles, and species should not be limited to those outlined in Table 15, which is not intended to be an exhaustive or exclusive list. The key characteristics (Table 14) can be used to select suitable plant species beyond those listed in Table 15; this may also be facilitated by discussions with local plant experts, local council, nurseries, and reference books. Potentially suitable species may be native or exotic; this will determined by the local climate, surrounding vegetation and performance objectives.

General considerations for plant selection (summarised here and discussed in further detail in the following sections):

- **Refer to Table 14 for a detailed list of considerations to tailor plant selection** to meet performance objectives and to **Table 15 for examples** of plant species known to be either effective or poorly performing. Figure 28 illustrates a number of species known to be effective in stormwater biofilters for nitrogen removal.

- **Primarily consider plant root characteristics** as the basis for plant selection, and do not choose plants based on similarity in above-ground appearance or similarity in plant type. Plants of similar above-ground appearance and plant type can exhibit significantly different performance for nitrogen removal in particular.

- Plant species must be **capable of survival in biofilter conditions**, including growth in a sandy medium with low organic matter, drought-tolerance and tolerance of variable periods of inundation.

- **Species must be appropriate for the specific site conditions and hydrological requirements should be assessed** – these will vary with the local climate, the hydraulic conductivity and water holding capacity of the media, accessibility of moisture in surrounding soils (if unlined), sizing, and design features (such as inclusion of a submerged zone). If systems are located in dry climates, or have shallow or rapidly draining media (see below) without a submerged zone, plant species with a particularly high drought tolerance will be required. Other possible issues that might need to be considered include frost tolerance, shade tolerance and landscape requirements (e.g. height restrictions).

- In both small and large systems, **wetter and drier zones may occur** (e.g. wetter nearer inlets, drier further from inlets and on batter slopes, if present). This has been observed in systems as small as 2 m^2. **Appropriate species should be selected for each zone** and, since it is difficult to precisely delineate these zones, a number of plant species should be used in each zone to allow 'self-selection' and resilience.

- Importantly, **a mixture of plant species will develop a resilient system** in the face of climatic variation. A mixture is also important given that different treatment objectives often call for multiple or opposing plant traits.

- It is recommended that biofilters are **planted with at least 50% effective species** to address the treatment objectives, while the remaining species can meet additional requirements, such as biodiversity or aesthetic considerations. The effective species should be distributed across the biofilter surface, to ensure optimum performance.

- Plant species should be **compatible with the surrounding vegetation**, in terms of aesthetics and biodiversity. For example, exotic species should not be used in settings near remnant bushland or within native parks. Community acceptance is also more likely if biofilter vegetation complements the local neighbourhood and gardens (discussed further in Section 3.6.6).

- **Non-invasive species should always be specified**.

- **Deciduous trees should be avoided if possible**, either within or in close proximity to biofilters. Their high leaf litter load which will contribute to clogging of flow structures and across the media surface. Similarly, be aware of placing biofilters in catchments with an abundance of deciduous trees: a different location might be more suitable, or a higher maintenance frequency may be required to manage the leaf litter (E2DesignLab, 2014a).

- **Plant morphological characteristics and growth form** are important considerations. Optimal performance for pollutant removal results from extensive root systems (see Table 14 for details). Suitable species should have extensive root structures which ideally penetrate across much of the filter depth. Dense linear foliage with a spreading growth form is desirable, while clumping structures, such as bulbs or large corms, should generally be avoided, because they can promote preferential flows around the clumps, leading to erosion.

Plant selection to meet performance objectives

Table 14. Differing roles of plants and desirable plant traits for biofilters to meet a range of performance objectives (Read et al., 2010, Bratières et al., 2010, Virahsawmy et al., 2014, Payne, 2013, Hatt et al., 2009, Ellerton et al., 2012, Le Coustumer et al., 2007, Russ, 2009, Farrell et al., 2013, Feng et al., 2012, Chandrasena et al., 2014, Monash Water for Liveability Centre et al., 2014b)

Objectives	Role of plants	Desirable species traits and plant selection tips
FUNCTIONAL OBJECTIVES (i.e. directly relate to stormwater treatment)		• Include <u>at least 50% plant species with effective traits</u> that meet water treatment objectives • Distribute these across the biofilter area as much as possible
Nitrogen (N) removal	• Plants are essential for effective removal. • Choice of plant species is especially important for N. • N processes are highly dependent upon plant and microbial functions. • Plants directly uptake N, support microbial functions in their root zone, convert N into various organic forms, return N via plant litter, reduce N loads via evapotranspiration. • Plant species differ widely in morphological and physiological characteristics, leading to different interactions with N processes. • N processes are also highly sensitive to wetting and drying, and different evapotranspiration fluxes will influence this. • Note that media composition is also vital for effective and consistent removal, as is inclusion of a submerged zone (see Sections 3.6.3 and 3.6.4).	• Effective species have <u>extensive and fine root systems</u> which maximise uptake capacity, contact with the stormwater and supports a vast microbial community alongside the root: ¬ High total root length ¬ High root surface area ¬ High root mass ¬ High root:shoot ratio ¬ High proportion fine roots • Relatively rapid growth but ability to survive and conserve (or 'down regulate') water across dry periods • High total plant biomass often accompanies an extensive root system • <u>Do not select species based on similarity in above-ground appearance or plant type</u> – this is a poor indicator of performance for N • <u>Exclude species with limited root systems</u> (i.e. minimal total root length and mass) or dominated by thick roots which are less effective • In particular, avoid trees or shrubs with limited root systems as these tend to be poor performers under both wet and dry conditions • Use a <u>diversity of plant species and types</u>, as species can vary in their relative performance between wet and dry conditions • Avoid nitrogen-fixing species which can input additional N to the system .These include wattles (Acacia species), clover and peas; all legumes from the Fabaceae family, and members of the Casuarinaceae family, which includes common Australian trees or shrubs such as Allocasurina. • Use a <u>high planting density</u> to maximise root and microbial contact with the media and stormwater • If feasible, consider harvesting the plant biomass to permanently remove N and possibly stimulate new growth and uptake

Cont.

Table 14. Continued

Objectives	Role of plants	Desirable species traits and plant selection tips
Phosphorus (P) removal	• Media composition is more important to P removal than plant species selection. See Section 3.6.4 for details. • P removal can occur via plant uptake, but other mechanisms are dominated by physical and chemical processes – filtration of particulates, adsorption and fixation	• Although plant selection is less critical, select species with extensive root systems, similar to characteristics effective for N removal – these will also effectively take up P.
Heavy metal removal	• Some metal removal occurs via plant uptake • Media composition is again critical as key processes include filtration of particulate-associated metals, adsorption and complexation	• Sevvvlect effective species with <u>extensive root systems</u> (e.g. *Carex appressa*)
Pathogen removal	• Plants can directly and indirectly influence pathogen removal • Plant species do differ in pathogen removal performance within biofilters • Plant species will differ in root uptake, microbial dynamics in the rhizosphere, exudation of antimicrobial compounds from roots, influence on infiltration rate and wetting and drying flux (via evapotranspiration) – each of these can influence pathogen retention and die-off • Plant roots may also release exudates which can facilitate die-off	• Select effective species with <u>extensive root systems</u> (e.g. *Leptospermum continentale, Melaleuca incana, Carex appressa*) • Select species associated with lower infiltration rates
Hydrological treatment - Volume reduction	• Plants influence the evapotranspiration loss, which helps reduce the volume of stormwater and pollutant loads	• Select species with high transpiration (such as trees) but also able to conserve water in dry periods • Use multiple layers of vegetation and various plant types to increase transpiration (i.e. trees and shrubs with understorey of sedges, rushes and grasses)
Infiltration capacity	• Plants help to maintain long-term porosity with significantly higher infiltration rates compared with non-vegetated areas – possibly 150 mm/hr higher (Virahsawmy et al., 2014) • Mechanisms can include stem movement and growth disturbing the clogging layer and preferential pathways created by root growth and senescence (particularly thick roots) • Plant species do differ in their interaction with infiltration rate • At times in early biofilter life, plants can adversely affect the infiltration rate, possibly due to root expansion and soil compaction, but this is expected to be a short-term effect	• It is recommended to - ¬ Include species with a proportion of thick roots (e.g. *Melaleuca ericifolia*), ¬ Include species with robust stems able to disturb the surface layer ¬ Avoid species with predominantly fine roots (i.e. no thick roots) ¬ Avoid species with shallow or minimal root systems (e.g. Microleana stipoides) ¬ Plant relatively densely • Some studies have shown contradictory results – when species with large and extensive root systems generally impede conductivity (Pham, 2015), but this may in part be due to restricted column size in laboratory tests and relatively young systems. In mature field systems the opposite relationship may be observed.

Cont.

Table 14. Continued

Objectives	Role of plants	Desirable species traits and plant selection tips
Effective	• Plants are critical to the long-term success of biofilters - From a maintenance perspective, healthy and dense vegetation cover will prevent scouring and erosion of the media, shade the media surface, and help to reduce the effects of clogging.	• Plant densely across the entire biofilter • Select robust species for edges and plant densely to deter pedestrian access • Similarly, near inflow points carefully select robust species and offset planting rows to help widely distribute inflows • Include a diversity of species to provide resilience and allow plants to 'self-select' and expand if other species die out. • Do not select short-lived or annual species • Avoid species that require regular pruning or those that produce large volumes of litter at senescence • Avoid the use of deciduous trees in or near biofilters • If possible, include trees to shade understorey layers and the media surface. Many successful mature biofilters incorporate trees • Plant sedges or grasses along biofilter edges adjacent to lawn – these species may shade the edge, prevent lawn expansion and facilitate lawn mowing without the need for time-consuming edge trimming
ADDITIONAL OBJECTIVES		• Plants with attributes that only suit these objectives (i.e. do not overlap with effective traits for functional objectives) should comprise < 50% of biofilter vegetation
Biodiversity	• Plant species provide floral diversity • Plants will also provide habitat to promote faunal diversity, particularly for insects and birds	• Select local indigenous native species, compatible with nearby remnant vegetation • Include a diversity of species and plant types to provide structural diversity • Include flowering plant species, including those used by local birds and insects • Never use invasive species in biofilters – not only known invasive species, but beware of species that can rapidly and easily spread by rhizomes or seeds
Aesthetics and Amenity	• The selection and layout of plant species is a key factor in system aesthetics • Plant community acceptance and amenity value is also dictated by the plant selection • Plants can also be selected to provide shelter from wind or provide a screening effect to block out views, or reduce sounds or dust	• Understand the site context - match species, layout and materials to surrounding landscape and neighbourhood character (conduct a site visit) • Consider land use, architecture, other landscaping and plantings in the area • Balance unity and variety in design • Include some complexity but the design should be orderly (i.e. avoid 'messy' and 'unkempt' appearance) • Consider long-term appearance and form as plants grow • Consider use of colours, textures, patterns, and use of light and shade • Include trees as features (if possible), consider use of colours and textures • Include seasonal variety with various flowering plants • For wind shelter, or screening out unsightly features, sounds or dust, use rows of shrubs or trees with dense above-ground growth
Habitat	• Plants provide shelter and food resources for various insects and birds	• Use a diversity of plant species and plant types • Incorporate woody plants and some woody debris if possible

Cont.

Table 14. Continued

Objectives	Role of plants	Desirable species traits and plant selection tips
Microclimate	• Plant transpiration and shading can significantly cool the urban environment, reducing energy demand and providing human health and amenity benefits	• Include trees with a sizeable canopy and depth of shade (broad-leaved)
Safety	• Plant species mature size and growth form can influence visibility • Plant growth can also potentially intrude on adjacent public pathways or spaces	• Always consider plant species size at maturity and any tendency to collapse during senescence, drop limbs, fruit or significant volumes of leaf litter • Consider line-of-sight requirements for vehicles and pedestrians • Avoid planting species in border plantings that may protrude or collapse onto adjacent pathways

Table 15. List of known plant species tested for their performance in stormwater biofilters (Read et al., 2008, Le Coustumer et al., 2012, Feng et al., 2012, Chandrasena et al., 2014, Monash Water for Liveability Centre et al., 2014b)

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 28. Examples of effective plant species for nitrogen removal in stormwater biofilters

Design tip

- Use a diversity of plant species and types to provide resilience against variable climatic conditions
- Species with extensive and relatively fine root systems are most effective for nitrogen removal, and have also shown efficiency for pathogen and iron removal
- Include a minimum of 50% species with effective characteristics, particularly for nitrogen removal

Diversity promotes resilience

Vegetating a biofilter with a range of species increases the robustness of the system, because it allows species to "self-select" i.e., drought tolerant plants will dominate in areas furthest from the inlet, while plants that prefer wetter conditions are likely to thrive nearer the inlet. A minimum of four species are recommended within each hydrological zone of the biofilter (E2DesignLab, 2014a).

Planting density

Overall planting density should be high to increase contact between plant roots and their associated microbial community with the passing stormwater. Dense vegetation will also protect surface porosity, promote even distribution of flows, increase evapotranspiration losses (which helps to reduce runoff volume and frequency), and reduce the potential for weed invasion.

The biofilter should be planted extensively; at a density of 8 – 12 plants/m^2, depending on the growth form. Shrubs and trees should be planted at density of < 1 plant/m^2 and according to landscape requirements. Batters should be planted with species that are tolerant of drier conditions.

Design tip

- Plant biofilters with 8 – 12 plants/m^2 for groundcovers, grasses, sedges and rushes. This investment in dense vegetation will be rewarded with more effective water treatment and reduced maintenance requirements.

Figure 29. Dense planting is strongly recommended in biofilters to enhance water treatment and reduce the occurrence of weeds and erosion

Zoning of planting

In large biofilters, areas furthest from the inlet may not be inundated during small rain events. Plants in these areas may therefore need to be particularly hardy and tolerant of drying conditions. Similarly, if the biofilter has an uneven surface or batter slopes, species with higher drought tolerance should be used on the higher elevations (E2DesignLab, 2014a).

Plants near the inlet may be frequently inundated, and potentially impacted by higher flow velocities and sediment load, and so robust species with relatively rapid growth should be selected for this zone. In addition, staggered planting layout (relative to aligned rows) should be used to help disperse and slow flows (Monash Water for Liveability Centre et al., 2014b).

Planting

In temperate climates, planting should generally be undertaken late in winter or early in spring, to allow sufficient time for the plants to get established before the hot summer period. In tropical or sub-tropical climates, appropriate planting times will vary, and generally be at the beginning of the wet season. Be sure to consult local botanists or nurseries.

It is also crucial to carefully co-ordinate planting with building activity in the catchment. Planting should be delayed until the majority of building activity has ceased and in the meantime sediment controls **must be implemented** to protect the biofilter (see Section 4.2 for more details).

Mulch

The use of mulch is **not recommended** in stormwater biofilters. Organic mulches are at risk of floating and clogging outlets. Gravel mulch can be useful to decrease the ponding depth for safety reasons, but it restricts plant spread, increases stress on plants due to heat retention, and severely impedes removal of accumulated sediment (Figure 30).

Instead, using a high planting density and care during seedling establishment is recommended to quickly develop high plant cover. If possible, the use of trees to shade the surface can also reduce drying.

Figure 30. Downsides of rock mulch i. and ii. limiting the spread of vegetation and iii. complicating the removal of accumulated sediment

Harvesting

The harvesting of vegetation (or pruning/cutting back with litter removal) can permanently remove accumulated pollutants from the system (nutrients and heavy metals), stimulate new plant growth and uptake, and potentially improve aesthetics. Research is ongoing to determine if this can help to maintain long-term removal performance. Trimming of certain species might also be necessary for safety reasons, such as species that could obstruct or drop litter onto adjacent pathways.

Use of trees

Trees are a popular landscaping feature, also commonly identified as a key component of successful mature biofilters (Mullaly, 2012). The benefits of trees for aesthetics are discussed in Section 3.6.6. Wetlands research shows that the general community values and prefers the presence of trees within a landscape (Dobbie, 2013). Critically, trees provide shading of understorey species and the media surface, and leaf litter, which can help to reduce drying out and to suppress weeds. As a result, **trees can reduce**

maintenance requirements (e.g. bioretention basins on a neighbourhood scale with only an understorey cost 80% more to maintain than those with a canopy and understorey; Water by Design (2015)) and contribute to the long-term success of a system (Mullaly, 2012).

Trees may be present as single features in small biofilters, including tree pits, or planted in clusters or rows in larger biofilters. Trees also provide significant microclimate and amenity benefits to urban environments (Section 2.5).

The following includes design tips and issues to consider when incorporating trees into biofilters:

- Ensure sufficient depth of media for root growth – a minimum of 800 mm is recommended. If it is difficult to achieve this depth across the entire biofilter, trees can be planted on elevated mounds (Figure 31), or the system can be left unlined (if this suits performance objectives and site conditions) to enable root penetration into surrounding soils. Tree pits should be unlined or incorporate sufficient volume to support a healthy and mature-sized tree.
- Avoid the use of deciduous tree species, which would deposit a high leaf litter load within the biofilter.
- Trees with an open canopy support a greater range of species in the understorey than trees with a closed canopy (which require more shade-tolerant species).
- Avoid the use of species with notoriously aggressive water-seeking roots, such as willows or poplars.
- Do not plant trees immediately adjacent to flow control structures or drainage pipes. Underdrains are not recommended in treed systems.
- If conditions within the biofilter are not suitable for trees, they can be planted outside but adjacent to the biofilter.
- Select appropriate species for the understorey. This will depend upon the extent of shading from the tree canopy. A good starting point is considering species naturally found in forests or woodlands alongside the tree species. Dense shade will require shade-tolerant understorey species.

Figure 31. Trees planted on elevated mounds within biofilters (City of Port Phillip)

Lawn grasses

The use of lawn grasses is common in swales and filter strips. When planted within biofilters, laboratory studies have shown that lawn grasses demonstrate promising performance for nutrient removal in particular. The root depth of lawn grasses can be deeper than expected (Figure 32). However, it must be noted that research on field-scale biofilters planted with lawn grass is currently limited. Further testing is required to investigate the potential for clogging, performance across dry periods and the impact of mowing on performance. Mowing (with the collection of clippings) has the potential to permanently remove nutrients from the system, thereby promoting further plant uptake and preventing return via litter and decomposition. However, the mowing equipment must not significantly compact the filter media, nor must any pedestrians be tacitly encouraged to access the biofilter, for example by appealing features of a lawn area.

Figure 32. Buffalo, a common lawn grass, grown in a column-scale laboratory experiment

3.6.6 Aesthetics – Biofilters that look good

Introduction

Biofilters form part of local streetscapes and neighbourhoods, and successful integration into the urban landscape requires community support. In residential streets, the design must consider the landscape preferences of residents so that the biofilter visually complements their street. Studies show that most people prefer urban landscapes with trees, curving lines, the presence of water, and a hint of mystery. Landscapes that appear healthy, with lush green vegetation and manicured foliage, are also preferred over those that are dry or messy (Dobbie and Green, 2013, Dobbie, 2013, Cottet et al., 2013, Kaplan and Kaplan, 1989). A detailed discussion of landscape design and aesthetic principles for biofilters is provided in Appendix F, but in summary, designers should consider the following design principles, even for the simplest of biofilters:

Context: Context is critical and informs many design decisions. A biofilter is not an isolated landscape element but is 'read' with all the other elements within a landscape or streetscape. Designs must be site-specific; an appealing landscape design for one environment might not be suitable for another. To understand context, a site visit is required to provide insight into the neighbourhood character and the community for which you are designing the biofilter, along with its landscape preferences. Things to look out for on a site visit are:

- Land use and appearance of surroundings, e.g. dense urban environments, leafy suburban streets or parks, semi-urban areas fringing natural bushland.
- Predominant period of architecture, e.g. Edwardian, post-World War 2, contemporary.
- Predominant hard landscaping materials.
- Predominant planting style, i.e., formal or informal.
- Predominant plant selection, i.e., native, exotic, or mixed.

Figure 33. Design of a raingarden should reflect its context, including land use, predominant architectural style and plant selection in the surrounding gardens and streetscape. Photos supplied by M. Dobbie, Monash University

Unity and variety: There should be a balance of unity (a sense of order and cohesion) and variety (creating interest) within the design. Include some complexity so that the landscape is interesting, but there should also be order. Much research has shown that orderly urban landscapes are generally preferred to disorderly or untidy landscapes (Kaplan and Kaplan, 1989, Nassauer, 1995). If the design of the biofilter must appear messy because of the choice of plant, e.g. sedges, grasses, reeds, consider including 'cues to care' (Nassauer, 1995), such as such as regular maintenance, mown edges, street furniture, signage and flowering plants.

Form: All landscapes, including biofilters, are dynamic, changing in form with time. Consider how the various landscape elements relate to each other and how this might change over time as plants grow. The challenge is to design a biofilter that not only looks good when first constructed but that continues to look attractive as it matures. This requires appropriate plant selection.

Scale: Scale relates to proportions of the various elements within the biofilter and of the biofilter in relation to the broader landscape. Elements within the biofilter should be in proportion to each other. In turn, the biofilter should be in proportion to its setting.

Seasonal variation: A biofilter can be designed to provide seasonal variation through the thoughtful choice of appropriate vegetation, particularly throughchoice of appropriate vegetation, and incorporation of flowering plants.

Figure 34. Inclusion of flowering plants adds interest through seasonal variation throughout the year. Choice of species or flower colour can be guided by existing vegetation in private gardens nearby. Photos supplied by M. Dobbie, Monash University; photo manipulation by Hamish Smillie, Seddon.

Patterns and Plant layout: Landscape patterns are what people notice in the landscape (Gobster et al. (2007)). Patterns can be created through the placement of plants with contrasting form, foliage and flowers. Plant layout will be influenced by site context and may be random, geometric (e.g. bands, zig zags/ chevron) or curvilinear (e.g. waves or concentric).

Patterns can be formal or informal, using native plants only or a mix of native and exotic plants. Formal patterns tend to be geometric, whereas informal patterns tend to be random or curvilinear. When creating formal patterns, consider plant growth over time and implement a suitable maintenance regime (e.g. pruning).

Figure 35. Different plant layouts for a specific site create quite different aesthetic effects. Left: random; centre, geometric; right, curvilinear. Photos supplied by M. Dobbie, Monash University; photo manipulation by H. Smillie, Seddon.

Light and shade: In a biofilter, choice of plants and placement of those plants can create a play of light and shade, to stimulate visual interest. This might be achieved through use of plants of different height, so that shadows are cast through the day, or by the use of contrasting vegetation colour, e.g. golden-brown grasses contrasting with dark green shrubs.

Texture: Texture can be both physical and visual. It is especially important when the choice of colour within a biofilter is limited. Texture can be provided by any of the materials used to construct the biofilter, including plant material and hard landscaping materials. Small-leaved plants provide fine texture; large-leaved plants provide coarse texture.

Colour and tone: Green will usually be present in the vegetation. Additional or different colours can also be provided by the flowers or foliage (e.g. light grey foliage of Leucophyta), or by paving or edging materials. Visual interest can also be created through selection of a mix of vegetation with different tones of the same colour.

Figure 36. Selection of vegetation with contrasting colours can simulate light and shade for visual interest. Photo supplied by M. Dobbie, Monash University.

Figure 37. Green comes in many tones, which can add interest, even without the addition of another colour. Paving can also contribute visual interest. Photo supplied by M. Dobbie, Monash University.

Plant selection for visual appearance: Careful plant selection for biofilters is critical to ensure their technical function (discussed in Section 3.6.5) and visual appreciation. Context is again all-important. Plant selection in residential locations is more constrained than in commercial, industrial, and public open space, where the designer generally has more freedom. Within an existing residential streetscape, designs should reflect the predominant garden preferences of the residents. For example, in a street with predominantly informal gardens with native vegetation, or in bushland or semi-urban areas, consider an informal design and native plants. Conversely, in a street with predominantly formal gardens with exotic vegetation, or in heritage or older suburbs, consider biofilters with a formal design with exotic plants. Critically, however, at least 50% of all vegetation should be selected for effective stormwater treatment (see Section 3.6.5).

Figure 38. 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. Photos supplied by M. Dobbie, Monash University; photo manipulation by H. Smillie, Seddon.

Trees as landscape features: Trees are a popular feature in urban landscapes (Kaplan and Kaplan, 1989, Dobbie and Green, 2013), adding visual amenity and structural complexity to a design. A single tree can be used as a feature in a small biofilter. Clumps or groups of trees are suitable in larger systems; use odd-numbered groups, arranged either formally or informally, but spaced with the size of the mature tree in mind.

Keeping it green: Green, lush vegetation is preferred by most people to brown, dry vegetation, so design and maintenance must aim for moisture retention:

- Include a raised outlet to promote ponding in the lower portion of the biofilter. Add a liner in dry climates (if > 3 weeks dry is common) to provide a longer-lasting submerged zone;
- Top up the submerged zone or irrigate across very prolonged dry periods.
- Include a canopy layer of trees or shrubs to shade understorey species and the surface.
- Use appropriate plant species for the local climate and conditions within the biofilter.

Community engagement and landscape design: To further foster community understanding and engagement with the system, designers should consider the accessibility and visibility of the biofilter to the public. Where safety permits, allow members of the community to move close up to view the system through the appropriate design of edges, seating, system shape, crossings or pathways. Using labels or signage, and showing the visual movement of water into, through or out of the system, also help to illustrate the purpose and function of the biofilter.

3.6.7 Stormwater harvesting

In addition to waterway protection, stormwater biofilters are also commonly applied for the purpose of stormwater treatment and harvesting for re-use. This application takes advantage of the valuable resource provided by stormwater runoff and further satisfies the multiple benefit nature of biofiltration (Chapter 2). Research and case studies have demonstrated the effectiveness of biofiltration for this purpose. Moreover, the economic benefits can be considerable. Examples of stormwater harvesting case studies include:

- Clearwater website - www.clearwater.asn.au/resource-library/case-studies/
- Orange City Council website - www.orange.nsw.gov.au/site/index.cfm?display=147115
- City West Water website - www.citywestwater.com.au/business/rainwater_and_stormwater_harvesting.aspx

However, biofilters should be designed to suit the objectives of stormwater harvesting, which must be clearly defined from the outset. Applications include irrigation of open spaces, toilet flushing, washing machine, car washing, dust control, road construction, street cleaning, firefighting, water features, garden irrigation (including home-grown and commercial food crops), dual reticulation, industrial and agricultural uses (*Australian Guidelines for Water Recycling: Stormwater Harvesting and Reuse*, 2009). It is also vital to understand characteristics of the water demand and its method of reuse (e.g. timing of water demand, volume requirements such as peak demand and total demand, purpose and method of application (e.g. sub-surface, drip, spray), expected reliability of supply).

Regulatory requirements, yield and the removal of pathogens, heavy metals and organic micropollutants, are particularly relevant to the design of stormwater harvesting systems. In particular, designers should consider:

Relevant policies and legislative requirements – various policy documents and legislative acts may be applicable and require consultation when designing a stormwater harvesting scheme. This document is not intended to provide a summary, but designers must be aware of the relevant requirements. In particular, the relevant water quality targets must be satisfied but will differ depending upon application and likelihood of exposure. Some key national guidelines and policies include (N.B. each state and territory either rely directly on these, or have developed their own set of guidelines and policies):

- National Water Quality Management Strategy: Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2)
  - Augmentation of drinking water supplies (2008)
  - Stormwater harvesting and reuse (2009)
  - Managed aquifer recharge (2009) National Water Quality Management Strategy: Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1)
- Australian Drinking Water Guidelines
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality
- Guidelines for Groundwater Protection in Australia
- Australian Guidelines for Water quality Monitoring and Reporting
- National Water Quality Management Strategy: Policies and Principles

Yield and co-design for **ecosystem protection** – Stormwater harvesting systems can achieve a reduction in demand for potable water, whilst also benefitting ecosystem protection objectives with restored flow hydrology and water quality (towards pre-development conditions) (Fletcher et al. 2006). Harvesting reduces the volume, frequency, flow peaks and pollutant loads of discharged stormwater. However, the design and operation of each stormwater harvesting project should be optimised to meet specific flow objectives and achieve the greatest benefit to the local stream hydrology (while avoiding 'over-harvesting') (Fletcher et al. 2006). Designers also need to consider the available storage volume for treated stormwater, relative to the demand pattern and level of reliability required. However a balance between storage and demand is easiest to achieve if patterns of rainfall and end-use demand are compatible with each other and relatively consistent in time (Mitchell et al., 2006). In addition, while significant losses of stormwater volume can occur across biofilters (via exfiltration), and this is desirable for meeting waterway protection objectives alone, these losses reduce the available yield of treated stormwater. Hence, systems designed for harvesting purposes should generally be lined (but while balancing flow reduction objectives via re-use).

Pathogen removal – In both laboratory and field studies, well-designed biofilters have demonstrated effective removal of pathogens from stormwater, with at least a 1 log (i.e. 90% concentration) reduction for bacterial indicators and effective removal for reference pathogens, particularly protozoa (Chandrasena et al., 2012, Chandrasena et al., 2014, Li et al. 2012, Zinger and Deletic, 2012, Deletic et al., 2014). Designing for optimal pathogen removal should include consideration of –

- **Plant species selection** – The effectiveness of pathogen removal within biofilters does vary between plant species. Include species that are known to be effective with extensive root systems, such as *Carex appressa*, Leptospermum continentale and *Melaleuca incana*. Current research is investigating whether plants, which have known antimicrobial properties, can be used to further improve faecal microorganism removal.

- **Antimicrobial filter media** – Laboratory studies have demonstrated significantly higher removal and inactivation of E. coli using a layer of Copper-coated Zeolite ('ZCu') within the biofilter media without compromising removal of other pollutants (Li et al., 2014a, b). Inclusion of the novel antimicrobial layer also benefits consistency of performance between wet and dry conditions and between different sized storm events. However, further testing is required before use of such a layer is recommended for biofilter design. In particular, the design requires testing under variable field conditions, including cold temperatures and clogged conditions. Additional details are in Appendix D.

- **Post-disinfection** - Depending upon the re-use application, post-disinfection (e.g. UV disinfection) may also be required to comply with any relevant guidelines, with the biofilter providing effective pre-treatment to remove, for example, the high and variable suspended sediment concentrations found in raw stormwater. However, this step may not be required for all re-use purposes, particularly irrigation.

- **Wetting and drying** – pathogen removal benefits from some degree of drying, with reduced performance for extremely short dry weather periods (e.g. back-to-back events). However, longer dry periods, exceeding two weeks, also significantly reduce pathogen removal performance (Chandrasena et al. 2014). Inclusion of a submerged zone (see below) and features to reduce surface drying (e.g. shading and plant cover across the filter surface), are important to minimise the performance decline from drying (Zinger et al., 2013, Payne et al. 2013, 2014).

- **Submerged zone** (i.e. using a raised outlet and liner) – including a submerged zone provides prolonged retention of stormwater between inflow events, which allows a longer period for more effective pollutant removal. This is particularly beneficial for pathogen removal (Chandrasena et al., 2014). It is important to design a submerged zone that is deep enough to store a large proportion of, if not all, the inflow event. However, the necessary depth will depend upon local climate. An analysis was conducted using MUSIC and simplified assumptions[2] to estimate the minimum submerged zone depth required to capture a median rainfall event for different capital cities (excluding specific considerations for pollutant removal performance or the influence of antecedent dry weather periods):

  - Brisbane – 550 mm
  - Sydney – 500 mm
  - Canberra – 600 mm
  - Melbourne – 350 mm
  - Adelaide – 350 mm
  - Perth – 450 mm

  These depths provide a minimum guide for stormwater harvesting purposes, and as outlined in the Submerged Zone sub-section within Section 3.6.3, depths of at least 450-500 mm are recommended to provide

[2]Based upon rainfall data from 2000 – 2009 for each capital city. It should note that there were some significant droughts occurred during the selected period, which might be reflected in the high variability of future rainfall patterns. Analysis assumes i.) constant evapotranspiration rate of 1 mm/day from the impervious catchment's surface, ii.) runoff cut-off threshold of 1mm in a six minute interval , iii.) time of concentration of 120 min, iv.) biofilter sized to 2% of its impervious contributing catchment, and v.) porosity of submerged zone material is 0.35.

greater drought resistance and reduce maintenance requirements during prolonged dry periods.

- **Maintenance of the submerged zone volume** – keeping levels in the submerged zone relatively constant and full over dry periods will benefit faecal microorganism removal. This maximizes the benefit of the buffering capacity provided by the submerged zone. Equation 1 in Section 3.6.3 provides guidance to estimate a rate of drawdown of the submerged zone.

Heavy metals removal – Biofilters effectively reduce the concentrations of most metals in both laboratory and field studies (Zinger and Deletic, 2012, Hatt et al., 2009, 2008). Most metals are removed effectively in the top 30 cm of the media (Hatt et al., 2008). However, as metal reactivity varies, removal performance and optimal conditions can vary between different metals (Feng et al., 2012). Biofilter performance has been shown to meet irrigation water quality standards for a wide range of metals (Iron, Aluminium, Chromium, Zinc and Lead). Drinking water standards are met for many metals (Zinger and Deletic, 2012), but iron and aluminium removal is more challenging (Feng et al., 2012). In addition, metal accumulation, particularly of Zinc, can limit the lifespan of biofilters in catchments that contain current or past industrial activity.

- **Iron** – depending upon the re-use application, iron removal is important for water colour and taste, and its potential to clog groundwater bores. Removal of iron benefits from prolonged retention between events, so a larger biofilter area is recommended (sized to 4% of the catchment). In addition, *Carex appressa* is significantly more effective for the removal of iron (relative to other species tested in laboratory studies). Removal will also benefit from increased organic content within the media (Feng et al., 2012), but for the sake of nutrient removal, it is vital that the organic matter has a low nutrient content.

- **Aluminium** – although removal meets irrigation water quality standards and frequently exceeds 70%, it might not be possible to meet drinking water standards using current biofilter configurations (Feng et al., 2012). Additional treatment may therefore be required.

- **Zinc** – a survey of field systems indicated potential for Zinc in particular to accumulate beyond the Australian and European (Dutch) soil quality guidelines (NEPC, 1999a, Rijkswaterstaat, 2014). More rapid accumulation is expected in catchments with current or past industrial activity. These systems should be identified and monitored more frequently. Early detection of high metal accumulation and removal of the surface layer (top 2-5 cm) can generate substantial cost savings if disposal occurs before thresholds for the higher prescribed waste categories are reached (Hatt et al., 2008).

Removal of organic toxicants/micro-pollutants – studies have shown effective performance by biofilters for removal of hydrocarbons and oils, and phthalates. However, by current design, biofilters are less effective for removal of common herbicides (atrazine, simazine and prometryn), chloroform and the pesticide pentachlorophenol (PCP) (Zhang et al., 2014b).

Validation monitoring – as stormwater harvesting is increasingly adopted, validation monitoring may be required to demonstrate biofilter pollutant removal performance. Water quality monitoring may be required to ensure that i.) relevant water quality standards are met, ii.) performance is reliable and consistent, and iii.) performance is robust across a wide range of designs and variable system sizes. Further information on monitoring appears in Section 4.3, with discussion of detailed monitoring and validation through challenge tests in Appendix G.

For detailed information on designing for stormwater harvesting, readers are referred to the 'Stormwater Harvesting Guidelines' produced by Water by Design (2010b). Water quality specifications are given in the 'Australian Guidelines for Water Recycling: Stormwater Harvesting and Reuse' (Natural Resource Management Ministerial Council et al., 2009).

Design tip

- For optimal pathogen removal, select plant species with extensive root systems (e.g. *Leptospermum continentale* or *Melaleuca incana*) and include a deep submerged zone. Removal benefits from some drying between events, yet more than two weeks' drying is detrimental to performance.

- Systems should be designed to co-optimise to achieve the desired stormwater yield and meet objectives for ecosystem protection. This requires setting objectives relevant to local stream hydrology (under pre-development conditions) (e.g. in terms of flow volume, frequency and peaks), and balancing demand for the harvested stormwater with the volume stored. In addition, biofilters treating stormwater in harvesting projects will generally be fully lined to maximise the yield.

- Post-disinfection such as UV treatment can also be implemented alongside biofiltration when additional pathogen removal is required for higher-risk end-uses (such as for toilet flushing).

3.6.8 Other considerations

It is clear, from the preceding discussion, that each aspect of biofilter design must be tailored to suit performance objectives and site conditions. Each locality and site will have different requirements, and conditions (e.g. soils, groundwater, rainfall) may differ substantially over relatively short distances, even between suburbs of the same city. The sections below outline differing conditions or situations that may need to be considered in design. Relevance to each system will vary between locations, but some issues, such as safety and underground services, need to be addressed for every biofilter design. For an overview of design recommendations to meet different objectives and suit variable site conditions, see Section 3.2.2, while the sections below provide more specific and detailed discussion.

Designing for effective maintenance

The cost of maintenance and rectification works across the life of the biofilter can be significantly reduced if systems are designed for low-level maintenance from the outset. Effective construction and establishment procedures are also critical, as discussed in Section 4.2 and 4.3. It is in the early project stages that the maintenance legacy is established (E2DesignLab, 2014a). Planning for effective maintenance at an organisational and project level is also important, and this issue is further discussed in Section 2.7.3.

It is vital that designers consult with maintenance practitioners and consider access, safety, ease of checking pits and pipes, features that reduce maintenance requirements and prolong lifespan, and ease of sediment removal. Designs that embrace effective maintenance principles may include:

- **Use of a protective layer** – laboratory studies have demonstrated the potential for a shallow layer of coarse sand (a ‘protective’ layer) above the surface of the filter media to delay the onset of clogging. These findings are promising, but it is important to note that such systems are yet to be tested in field-scale applications. If successful, this design feature can potentially prolong the media lifespan and reduce maintenance costs. Once further testing is complete, and if the protective layer proves reliable in its performance for clogging, an online fact sheet will be released with further information.

- **Establish a dense and healthy cover of vegetation** – early investment in dense planting and careful seedling establishment will develop a system that is more resilient to erosion and more effectively serves its functional purpose. This reduces the need for long-term maintenance and rectification works (such as replanting, repair of the media surface).

- **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. .

- **Avoid the use of gravel mulch** – this limits the spread of plants and, as incoming sediment mixes amongst the gravel, greatly complicates and adds cost to the removal of accumulated sediment.

- **Design pits, pipes and culverts to facilitate inspection** – pit lids should not be difficult to manoeuvre, nor require heavy lifting by maintenance personnel, but should instead be designed with safety and ease of removal in mind. Grated covers for pits and culverts can help visual inspection without the need to lift the cover. For inspection purposes, underdrain pipes should extend to the surface (with a covering lid), incorporate 450 bends and comprise slotted PVC (not ag-pipe) (Section 3.6.3).

- **Provide safe and easy maintenance access with minimum need for traffic managemen**t – when locating and designing the system consider access requirements for maintenance crews. Maintenance vehicles must be able to access the area alongside the system. A safe environment must be provided for maintenance tasks. Streetscape systems, particularly those in busy areas, may require traffic management procedures to safely conduct maintenance. This will add to the costs of maintenance and if possible, systems should be located and designed to minimise the need for traffic management during maintenance.

- **A sketch or drawing of the system <u>as constructed</u>** – this should be provided to help maintenance personnel and asset managers understand the function and features of each system. The drawing should illustrate the system functions, including flow paths, to engender appropriate management and maintenance decisions.

Important!

For larger biofilters, an access track for maintenance vehicles (e.g. 4WD ute) should be provided to the full perimeter of the system for maintenance efficiency and ease.

Drought resilience

Further to the discussion of designing for different climates above, with the variable Australian climate and climate change all biofilters, should be designed with a degree of drought resilience. The following tips will help develop robust biofilters:

- Inclusion of a raised outlet to create submerged zone (temporary in unlined systems and longer-lasting in lined systems) – this is an essential feature to retain sufficient moisture for plants, and reduce the dependence of the system on watering, to withstand prolonged dry periods. In dry climates (> 3 weeks drying common), a liner is recommended to retain moisture for longer. Note that the rate of drawdown from the submerged zone will depend upon its depth, the evapotranspiration demand and length of the dry period. Topping up of the submerged zone or irrigation will be required across extended dry periods.

  Both a longer-lasting submerged zone and infiltration can be implemented together if a 'bio-infiltration' design is adopted (Section 3.5.4), or other hybrid design (Jonasson and Findlay, 2012), or for unlined systems with low conductivity clay soils which discharge water only slowly between events.

- Incorporate a mixture of plant species – species will vary in their tolerance to different conditions, so a mixture of species provides resilience against climatic variability. Species known to be drought-tolerant should be included.

- Ensure sufficient moisture retention capacity – various design features contribute to the moisture availability within a biofilter, including biofilter area, hydraulic conductivity of the media, ponding depth, depth of the media, accessible moisture in surrounding soils and inclusion of a submerged zone. If treatment objectives or site conditions restrain some of these parameters, one or more of the others should be adjusted accordingly, to ensure that sufficient moisture is available to support vegetation in the given climate.

Edge treatments

These are required to keep vehicular and pedestrian traffic away from the filter surface to avoid reduced infiltration capacity, due to compaction as well as damage to the structural components (inlet, outlet, etc.); reduced infiltration capacity results in more frequent overflows of untreated water. This will also serve to ensure public safety as well as to define clear lines for maintenance boundaries.

- For pedestrian traffic: dense planting, fencing, seating, etc. may be used.

- For vehicular traffic: where there is a likelihood of vehicles mounting the kerb (e.g. on a bend), concrete edge restraints should be used, although these may not be required on traffic buildouts where landscaping is behind the kerb. It is also important to allow sufficient turning space for vehicles, including turning trucks, and if this is not possible the location within the streetscape should be re-assessed (E2DesignLab, 2014a).

Figure 39. Vehicle damage to a biofilter – frequent parking on top of the system has compacted the media and left it devoid of vegetation. Photo courtesy of Mohammed Al-Ameri, Monash University.

Interaction with services

Potential conflicts with other services (e.g. gas, sewer, electricity, telecommunications) can be problematic, particularly in retrofit situations. However, creative design can overcome many of these options. For example, there are numerous cases of biofilters that have been successfully built surrounding services. Regardless, the relevant service authorities should be consulted.

Use of a bio-infiltration system can provide additional flexibility in dealing with intersecting services, because they do not require an underdrain. For example, where a sewer line intersects the proposed site, a bio-infiltration system could be constructed in two parts – one each side of the sewer line, with a connecting pipe in between them (Figure 40).

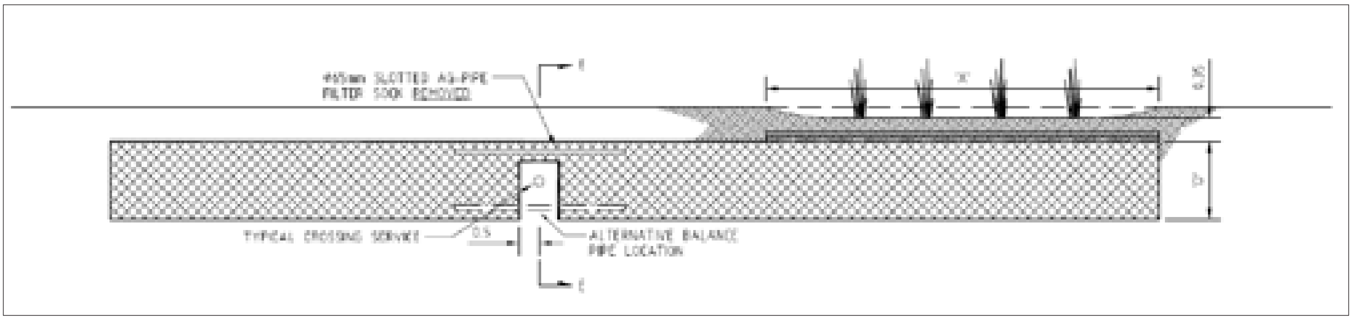


Figure 40. Example of innovative design to overcome interaction with services. In this example, the bio infiltration system is constructed either side of a sewer line, with a connecting pipe in between, avoiding excavation underneath and surrounding the sewer.

Asset protection

The owners of infrastructure assets in close proximity to biofilters need to be considered during design. For example, will maintenance of these assets impact the biofilter? Will installation of a biofilter adjacent to other infrastructure impact access to these assets?

Nearby structures, such as roads or buildings, may need to be protected from infiltration. However, this does not preclude the use of stormwater biofilters. Protection can be effectively achieved through the use of an impermeable liner on the adjacent side of the biofilter, or across the entire system (Section 3.6.3). Designers should refer to *Australian Runoff Quality* (Wong, 2006) for guidance on the allowable offset distances for infiltration in proximity to certain structures, in consideration the soil type present.

Issues of system size

The design, construction and maintenance of biofilters will differ with their overall size. Larger systems have the benefit of cost efficiencies during their construction (discussed in Section 2.7.2). However, the construction of very large systems requires care to avoid compaction of the media with heavy equipment (discussed in Section 4.2 and in detail in Water by Design 2009). In addition, management of runoff and sediment from the catchment will be even more challenging and require careful planning for large systems. Consideration of even flow distribution, wet and dry zones, and maintenance access are also critical in the design of large biofilters. Use of multiple inlet points, careful grading of the filter surface level, selection of appropriate species for each hydrological zone (Section 4.4.14 and WA Plant Selection Guidelines) and incorporating appropriate maintenance access tracks around the perimeter, can help to address these issues.

Safety

Public safety must be a critical consideration and priority during design. This includes maintenance crews, pedestrians and vehicles in the vicinity of the biofilter. Safety considerations should include:

- **Clear sightlines for traffic and pedestrians** – particularly for systems located in median strips or on street corners. Choice of plant species and layout, including considering the height and density of vegetation at maturity, is particularly important. In some situations, trees may be inappropriate; low-lying vegetation should suffice instead.

- **Reduced ponding depths near areas frequented by children** – such as public parks, particularly in the vicinity of play grounds. The performance implications of a reduced ponding depth can be offset by increasing the biofilter area or using a media with higher hydraulic conductivity. Gravel mulch may also be used to reduce the depth of standing water, but it is important to recognise that this will limit the spread of vegetation and increase the difficulty of sediment removal (see the Design Tip box in the next page).

- **Barriers, edge design or crossings in pedestrian areas** – these can be important design features to direct or deter public access (and damage) to the biofilter, but also prevent accidental falls, particularly if the system has a steep drop down immediately adjacent to a path. Careful selection of plant species and dense planting around the edges can also be used as a barrier. Consider the flow of pedestrians in busy areas when positioning biofilters (E2DesignLab, 2014a).

- **Use of batter slopes or a stepped design** – can further improve safety by avoiding a sharp drop down into the biofilter. However, these features will increase the footprint of the system and should be planted with drought-tolerant plant species (see Design Tip box in the next page).

- **Safe access for people alighting from parked vehicles** – it is dangerous for those entering and exiting parked cars to encounter a steep drop on the other side of the kerb. Flat extensions of the kerb can be used to safely accommodate people accessing kerbside parking (see Design Tip box below). E2DesignLab (2014a) recommend a minimum bench width of 400-500 mm.

- **Pedestrian refuges** – for systems located in the median strip, alongside parking spaces, busy roads or areas with frequent pedestrian crossings. In these situations it may be dangerous to barricade the biofilter off from pedestrians entirely, if there is a risk they may be caught between the traffic and the safety of the footpath. Refuges can be provided, such as breaks in barriers with stepping stones. Moreland City Council & GHD (2013) address this issue in detail with reference to Victorian road safety legislation.

- **Trip hazards** – may arise from various aspects of a design for systems alongside areas of public use:

  - Some plant species may require regular cutting back, particularly if their foliage protrudes onto pathways when mature. Alternatively, species planted along edges should be carefully selected to avoid this (E2DesignLab, 2014a).

  - Grated culverts crossing pedestrian paths must have sufficiently small grates to prevent heels being caught (E2DesignLab, 2014a).

Design tip

Ideas for ensuring both filter integrity and public safety

A wide bench area at kerb height provides a safe zone for vehicle drivers and passengers to access kerbside parking

A stepped design, edge planting or batter slopes help protect pedestrians from the drop down into the biofilter for systems alongside pathways

Design tip


Provide various crossings to safely direct pedestrians across or around biofilters


Seating also serves to keep pedestrian traffic away from the filter surface

Design tip

A broken kerb distributes inflow and keeps vehicles away from the filter surface

A deep gravel layer on the filter surface provides extra ponding whilst still ensuring pedestrian safety by avoiding large drops, although this design solution is not generally recommended, as it is likely to restrict the spread of vegetation and make removal of accumulated sediment more challenging.

Geology

Characteristics of the soils underlying and surrounding biofilters will dictate the potential for stormwater infiltration. If other factors (such as groundwater, performance objectives and nearby structures) permit, infiltration may be promoted using an unlined system, irrespective of the soil type. However:

- Sandy soils provide considerably greater potential to infiltrate a high volume of stormwater, in comparison to heavy clays with low hydraulic conductivity.
- Despite this, infiltration into clay soils can still provide useful dissipation of stormwater, while at the same time helping to retain moisture within the biofilter for longer periods between inflow events. As a result, clay soils can provide the benefits of both exfiltration and a longer-lasting submerged zone, if a raised outlet is utilised.

Other aspects of design and construction can be influenced by the local geology:

- Rocky areas can make it difficult to lay down a liner without punctures. A layer of compacted clay can be applied as a barrier, or it may be appropriate to leave the system unlined.
- Geology will also influence the ease and cost of excavation (Knights et al., 2010) (Section 2.7.2).

Climate

It is imperative that biofilter design accounts for the local climate, particularly in sizing (Section 3.6.2), but also for features that influence functioning between inflow events. Key considerations for challenging climates are outlined below:

- **Dry climate** – careful design is particularly crucial in dry climates. However, with sound design principles, biofilters are viable for use in drier climates. Care should be taken not to oversize the biofilter, nor any pre-treatment devices (e.g. sediment basins). In addition, deeper filter media should be considered and inclusion of a submerged zone is strongly recommended.
- **Tropical or wet climate** – a larger treatment capacity (increased ponding depth, biofilter area or hydraulic conductivity) is required for climates with high rainfall totals or intensity (Water by Design, 2010a). In these climates it is particularly important not to undersize the system as this will lead to poor treatment of runoff (much will bypass the system). Moreover, the damp conditions may also lead to clogging from sediment, moss or algal biofilms, and plant death from prolonged flooding.

Groundwater

The depth to groundwater, its water quality and any dependent uses (e.g. stock watering, drinking water, groundwater-dependent ecosystems), are important considerations when designing the depth of a biofilter and potential to infiltrate stormwater. It is important to also consider seasonal variation in groundwater levels. Biofilters can be constructed in areas with very shallow groundwater and, if desirable, interaction between treated stormwater and groundwater can be prevented through the use of an impermeable liner (Figure 40). However, the design solution will vary with site conditions and groundwater characteristics.

Shallow groundwater may:

- Restrict the depth of the biofilter and require use of an impermeable liner, particularly if interaction between stormwater and groundwater is not desirable.
- Restrict the potential for infiltration of stormwater and require use of an underdrain to ensure adequate drainage of the biofilter. E2DesignLab recommend a minimum of 0.5 m between the bottom of the biofilter and peak seasonal groundwater level if infiltration is to be successfully achieved.
- Conversely, provide potential to support the health of vegetation and microbial communities within the biofilter, particularly across prolonged dry periods. If roots can access groundwater and there is no risk from cross-contamination, leaving systems unlined may benefit biofilter performance, reducing the need for watering or inclusion of a submerged zone.

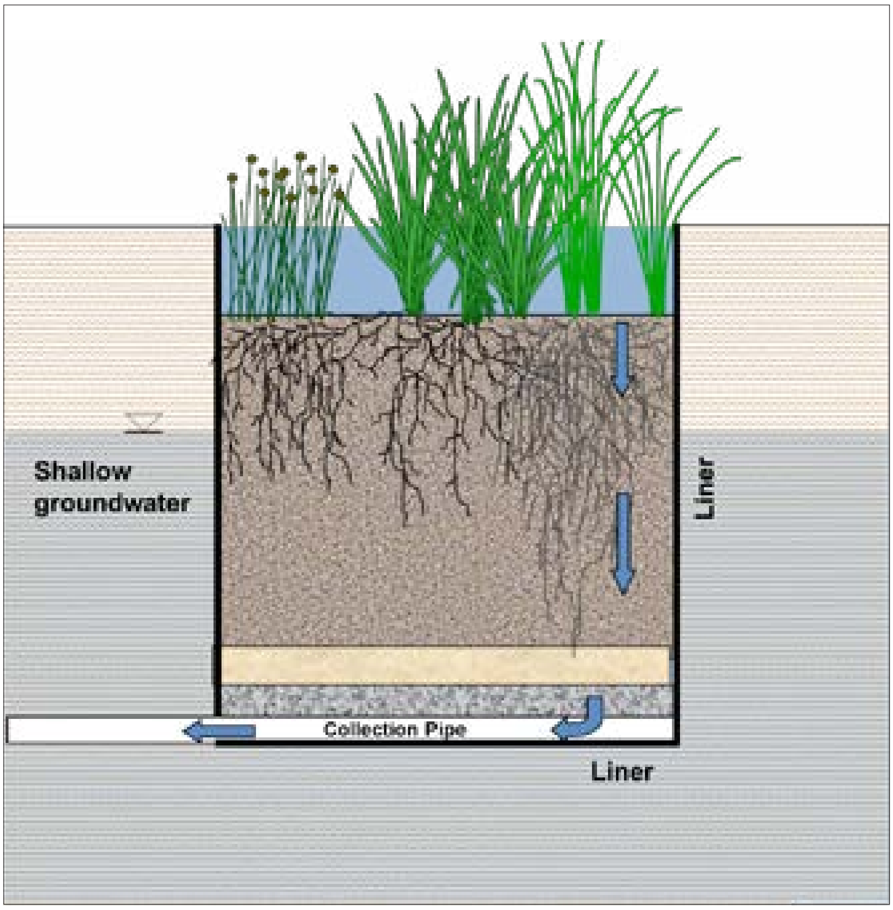


Figure 41. Biofilters can be used successfully in areas of shallow groundwater, with use of a liner if interaction with the groundwater is not desirable

Site gradient and available pipe inverts

The gradient of the site and drainage pipe invert levels are critical to the hydraulic function of the system. These characteristics influence the delivery of flow to the biofilter, its depth and conveyance of treated stormwater outflows.

In the case of flat topography, or sites with limited head differential between the pipe network immediately upstream and downstream of the biofilter, the following factors are likely:

- The depth of the biofilter is likely constrained. A minimum height difference of 900 mm is recommended between the inlet and outlets of a biofilter.

- However, inclusion of a submerged zone allows a deeper system to be used with a reduced head requirement (as a result of the elevated outlet required to create the submerged zone). This option is preferable to shallow systems, which are particularly susceptible to drying.

- Use of above-ground planter boxes (e.g. located below downpipes) is compatible with shallow gradients.

- Consider the use of biofilters alongside other WSUD design elements, such as rain water tanks and harvesting (Burns et al., 2010).

In steep topography, different issues dominate design:

- Inflow velocities will be higher, leading to greater risk of erosion and scour. Energy dissipation is an important consideration and can be achieved using rocks at the inlet, or distribution channels to dissipate low flows and reduce inflow velocities before contact with the filter media.

- The driving head increases the risk of preferential flow pathways or short-circuiting down through the media at the interface with flow control structures, or points where outlet pipes traverse walls or bunds. As a result, sealing the structural components of the biofilter to ensure they are water tight, is vital to avoid failure and wash-out of the media (discussed in the Construction section within Chapter 4).

- There is sufficient head to drive the hydraulic function of the system.

- The use of rock or earthen walls check dams or a terraced system may be necessary for design.

- Biofiltration swales, which also act to convey stormwater, are unlikely to be feasible for stormwater management where slopes exceed 5%.

Small space

In many urban areas, both established and new, density of housing is increasing. Reduced lot sizes and road frontages pose a challenge for the incorporation of biofilters into the streetscape and private gardens. This often constrains the biofilter size. Potential solutions to effectively save space include:

- Breaking up the catchment by using multiple smaller systems closer to source, including biofilters on private residential blocks (e.g. planter boxes).

- Implementing creative designs that may save space by incorporating systems into novel spaces – for example terraced systems can be incorporated into steeper components of the landscape (refer to Water by Design (2014b) for illustrations of this and other creative ideas).

High sediment loads

This is a critical risk for systems in new developments and can lead to system failure and costly rectification works early in the biofilter life. However, sediment poses a risk to all biofilter systems, either from building works within an established catchment, individual sediment sources (e.g. un-made road shoulders), or even the excavation and earthworks activities involved in construction of the biofilter itself. Temporary protection measures and plans for flow and sediment management are essential. These are outlined in Section 4.2. Pre-treatment measures and frequent maintenance are also important in systems that are at risk of ongoing sediment loads.

Coastal / Estuary environments

Biofilters have been applied in saline environments near the coast or adjacent to estuaries, but high salinity places plants under stress. Under these conditions:

- Salt tolerant plant species (halophytes) should be used

- Estuary environments are particularly sensitive, so it is imperative to ensure filter media with low nutrient content is used to reduce the potential for nutrient leaching.

Current research is investigating biofilter performance and plant species selection under saline conditions. More future information can be found at:

http://thegirg.org/optimising-saline-biofilter-performance-through-plant-selection/

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